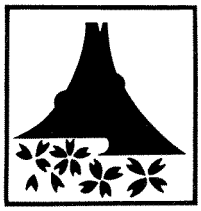
Ninth International Technical Conference on Experimental Safety Vehicles

HARDSON

U.S. Department of Transportation
National Highway Traffic Safety Administration



Ninth International Technical Conference on Experimental Safety Vehicles

Sponsored by:

The United States Government

Hosted by:

The Government of Japan

Co-Hosted by:

Japan Automobile Manufacturers Association

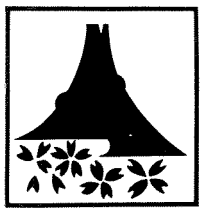
Japan Automobile Research Institute

Held at:

Kyoto, Japan, November 1 - 4, 1982

U.S. Department of Transportation

National Highway Traffic Safety Administration



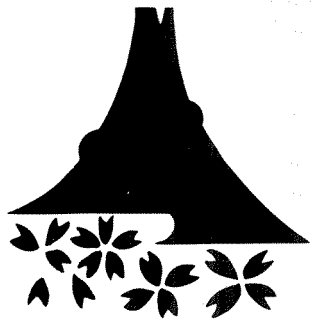
Foreword

This report of the proceedings of the Ninth International Technical Conference on Experimental Safety Vehicles was prepared by the National Highway Traffic Safety Administration, U.S. Department of Transportation.

We wish to thank the authors and all those responsible for the excellence of the material submitted, which aided materially in the preparation of this report.

For clarity and because of some translation difficulties, a certain amount of editing was necessary. Apologies are, therefore, offered where the transcription is not exact.

Participants



BELGIUM

Henssler, Herbert
Commission of the European Communities

FEDERAL REPUBLIC OF GERMANY

Albrecht, Jürgen Horst
Volkswagenwerk AG

Appel, Hermann
Technische Universität Berlin

Bez, Ulrich
Bayerische Motoren Werke AG

Brenner, Roland
Repa Feinstanzwerk GmbH

Burchard, Klaus-Dieter
Bundesministerium für Wirtschaft

Burow, Klaus
TÜV Rheinland

Danner, Maximilian
HUK-Verband

Föhl, Artur
Repa Feinstanzwerk GmbH

Friedel, Bernd
Federal Highway Research Institute (BASt)

Fritz, Gerhard
Daimler-Benz AG

Hoefs, Rainer
Dr. Ing. h.c.F. Porsche AG

Hornig, Karl-Günther
Volkswagenwerk AG

Huber, Guntram
Daimler-Benz AG

Klaus, Guenter
Volkswagenwerk AG

Kraft, Hans-J.
Bayerische Motoren Werke AG

Kunert, Heinz
Sekurit-Glas Union GmbH

Langwieder, Klaus
HUK-Verband

Lehmann-Horn, Peter
BMW Japan Corp.

Manteuffel, Peter
Verband der Automobilindustrie e.V.

Nilsson, K. E.
Bayerm-Chenie G.

Panik, Ferdinand
Daimler-Benz AG

Peters, Bernhard
Repa Feinstanzwerk GmbH

Praxenthaler, Heinrich
Federal Highway Research Institute (BASt)

Richter, Bernd
Volkswagenwerk AG

Rompe, Klaus
TÜV Rheinland E.V.

Rosenau, Wolfgang
Volkswagenwerk AG

Schmid, Walter
Daimler-Benz AG

Schwant, W.
Volkswagenwerk AG

Seiffert, Ulrich
Volkswagenwerk AG

Sorsche, Joachim-H.
Daimler-Benz AG

Zech, Günter
Adam Opel AG

Zomotor, Adam
Daimler-Benz AG

FRANCE

Cesari, Dominique
Organisme National de Sécurité Routière (ONSER)

Chapoux, Edouard
UTAC

Cheynet, J. P.
UTAC

Claire, Olivier B.
Association Française de Normalisation (AFNOR)

De Saint-Martin, Jean Moreau
Institut de Recherche des Transports

Gauvin, B.
Ministry of Transportation

Leroy, Jean
Organisme National de Sécurité Routière (ONSER)

Provensal, Jacques
Régie Nationale des Usines Renault

GREAT BRITAIN

Cart, John
Lucas Girling Limited

Fitchie, John
Transport and Road Research Laboratory

Fowler, John E.
Austin Rover, BL Cars Ltd.

Furness, John W.
U.K. Department of Transport

Grime, Geoffrey
University College London

Jacobson, Marcus
Automobile Association

Manton, S. M.
Lucas Girling Limited

Matthews, C.
Lucas Girling Limited

Neilson, Ian
Transport and Road Research Laboratory

Oppenheimer, Paul
Lucas Girling Limited

Penoyre, Slade
Transport and Road Research Laboratory

Rothman, George
K. L. Automotive Products Ltd.

Tidbury, Guy
Cranfield Institute of Technology

ITALY

Abbo, M.
Kawasaki Motor, Italia

Barile, Mario
FIAT Safety Center

Chidini, Luciano
Alfa Romeo Auto S.p.A.

Chirico, Domenico
Alfa Romeo Auto S.p.A.

Franchini, Enzo
FIAT Safety Center

Jcaffa, L.
Kawasaki Motor, Italia

Landsberg, Erwin
Alfa Romeo Auto S.p.A.

Maestripieri, Lamberto
Alfa Romeo Auto S.p.A.

Magnoli
Alfa Romeo Auto S.p.A.

Rossi, Franco Roberto
Ministero Transporti-Motorizzazione Civile

Schinaia, Claudio
Ministero Transporti-Motorizzazione Civile

Surace, Filippo
Alfa Romeo Auto S.p.A.

JAPAN

MITI

Arita, T.
Nakabayashi, K.
Shiga, M.
Takase, K.

MOT

Matsunami, M.
Miyazaki, T.
Tozawa, H.
Uno, N.

DAIHATSU

Asano, T.
Furusho, H.
Maeda, H.
Nagai, M.
Nishida, H.
Ohara, S.
Okuyama, Y.
Ono, J.
Osuga, J.
Tanigawa, T.
Watanabe, Y.

FUJI

Arai, H.
Desaki, Y.
Fukushima, T.
Hataya, G.
Itoh, E.
Matsumoto, R.
Morinaga, M.
Nagaoka, A.
Nagashima, S.
Saeki, N.
Sasaki, S.
Yamagishi, G.

HINO

Iwasaki, S.
Kato, T.
Nakano, M.
Ohtsuki, K.
Sudo, T.
Takahashi, T.

HONDA

Baba, T.
Hale, C.
Harrington, T.
Itabashi, M.
Kawamoto, N.
Kizawa, H.
Kobayashi, S.
Komatsu, S.
Meganck, A.
Mori, K.
Nakamura, Y.
Sano, S.
Satoh, M.
Shiraishi, S.
Sugiura, H.
Takamatsu, H.
Takeda, H.

ISUZU

Kaneshige, I.
Oho, K.
Shimizu, Y.

KAWASAKI

Ando, K.
Uemura, O.

MITSUBISHI

Hayashi, Y.
Iida, K.
Iwata, A.
Kataoka, K.
Katayama, N.
Kato, H.
Kato, M.
Kitaori, K.
Kobayashi, S.
Miyabe, M.
Nagaike, N.
Nakahama, R.
Shibata, K.
Shibata, T.
Shimizu, T.
Yoneda, S.
Yoshikawa, N.

NISSAN DIESEL

Achiba, J.

NISSAN

Aibe, T.
Ishihara, T.
Iwata, T.
Kawata, T.
Kiyoto, M.
Maeda, T.
Morita, S.
Murakami, J.
Nakamura, H.
Oguri, T.
Shimatani, Y.
Tachibana, A.
Takahashi, H.
Tanaka, M.

Tsujimura, H.
Yamamoto, A.

SUZUKI

Masuyama, T.
Okano, T.

TOYO KOGYO

Abe, T.
Ichinose, O.
Kurimoto, K.
Mitoya, Y.
Mitsunari, T.
Muramoto, H.
Nakai, T.
Okuno, A.
Sasaki, M.
Sugawara, T.
Yamashita, H.
Yorizane, M.

TOYOTA

Agetsuma, F.
Arai, H.
Baba, T.
Iba, Y.
Jinbo, S.
Kondo, Y.
Koujiya, M.
Morita, M.
Moriya, S.
Nogami, T.
Nomura, K.
Numazawa, A.
Sakakibara, J.
Sekiya, S.
Shimada, H.
Shindo, K.
Shinkai, H.
Suzuki, I.
Takahashi, T.
Toyoda, E.
Toyoda, S.
Tsuchiya, S.

YAMAHA

Arata, T.
Yamashina, K.

JAMA

Aoki, D.
Ishihara, T.
Nakamura, T.
Tanimoto, S.

JARI

Aoki, A.
Daigo, H.
Fukuda, S.
Goto, K.
Kikuchi, A.
Ohmae, H.
Ono, K.
Watari, A.

KOREA

Ha, Young Man
Hyundai Motor Company Ltd.

Hong, Tae Woong
Hyundai Motor Company Ltd.

Lee, Jaewan
Hyundai Motor Company Ltd.

THE NETHERLANDS

Bussemaker, H. O.
Dept. of Road Transport (RDW)

Hoekstra, Pieter, W.
Dept. of Road Transport (RDW)

Wegman, Fred. C. M.
Institute for Road Safety Research
SWOV

SWEDEN

Aldman, Bertil
Chalmers University of Technology

Almqvist, Rune
Volvo Car Corporation

Anderlind, Torsten
Saab-Scania

Bohlin, Nils
Volvo Car Corporation

Franson, Lennart
Volvo Car Corporation

Gustafsson, Hans
The Folksam Group

Jaksch, Friedrich
Volvo Car Corporation

Kling, M.
Volvo Car Corporation

Nilsson, Ulf
Volvo Car Corporation

Nilsson-Ehle, Anna
Volvo Car Corporation

Nordgren, Curt
Sveriges Bilindustri-och
Bilgrossistforening, AB
Bilstatistik

Nordstrom, Olle
National Swedish Road and Traffic
Research Institute

Norin, Hans
Volvo Car Corporation

Nygren, Aake, M.D.
The Folksam Group

Solberg-Larsen, Lauritz
Volvo Car Corporation

UNITED STATES

Beck, J. N.
Society of Automotive Engineers

Busby, David
Automobile Importers of America, Inc.

Chen, S.
Power & Energy International

Curran, Kristin
The Prism Corporation

Davis, Philip
U.S. Department of Transportation

Eppinger, Rolf
U.S. Department of Transportation

Faber, Karl-Heinz
Mercedes-Benz of North America, Inc.

Finkelstein, Michael
U.S. Department of Transportation

Finnegan, D.
Congressional Staff

Foust, D.
Nissan Motor Corporation in U.S.A.

Gilbert, J.
Society of Automotive Engineers

Griswold, Charles J.
General Motors Corporation

Hackney, James
U.S. Department of Transportation

Harvey, Thomas
U.S. Department of Transportation

Henson, Sherman
Ford Motor Company

Hess, Robert L.
University of Michigan

Junkin, T.
The Prism Corporation

Kahn, H.
Automobile News

Lenox, J. B.
Southwest Research Institute

MacLaughlin, Thomas F.
U.S. Department of Transportation

Maugh, Roger
Ford Motor Company

McAuliffe, M.
Senate Commerce Committee

Nield, George
Automobile Importers of America, Inc.

Peck, Ray A.
U.S. Department of Transportation

Quinn, B.
President of "Road Test"

Reilly, Jack
American Isuzu Motors Inc.

Romeo, David
Romeo Kojyo Co., Inc.

Schooler, D.
Congressional Staff

Schrandt, Robert W.
Toyota Motor Sales, U.S.A., Inc.

Scott, William E.
U.S. Department of Transportation

Seal, M. R.
Western Washington University

Shapiro, William
Volvo of America Corporation

Shively, James C.
U.S. Department of Transportation

Shwayder, P.
U.S. House of Representatives

Sprodes, C.
U.S. House of Representatives

Stockton, P.
Congressional Staff

Trent, D. M.
U.S. Department of Transportation

Trilling, D. R.
U.S. Department of Transportation

Williams, James
National Academy of Sciences

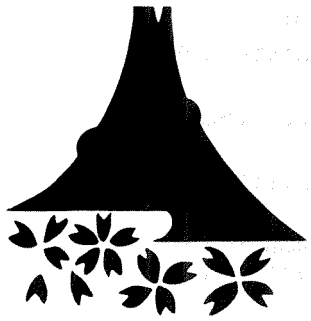
Wilson, Richard
GM Technical Center

Wismans, Jac
Ohio State University

Yamada, A.
Mike Masaoka Associations

Ziwica, Karl-Heinz
BMW of North America, Inc.

CONTENTS



FOREWORD iii
PARTICIPANTS v

SECTION 1: OPENING CEREMONIES
Welcoming Address
Mr. Manabu Shiga
Director General of the Machinery
and Information Industries Bureau,
Ministry of International Trade
and Industry 1

Welcoming Address
Mr. Taskashi Ishihara
President,
Japan Automobile Manufacturers Association

Keynote Address
The Honorable Darrell M. Trent
Deputy Secretary
United States Department of Transportation 2

SPECIAL SESSION: AWARDS PRESENTATIONS
Presentations by Mr. Raymond A. Peck, Jr.
United States 5

SECTION 2: GOVERNMENT STATUS REPORTS
Mr. Manabu Shiga, Chairman, Japan

United States Government Status Report
Mr. Michael M. Finkelstein
Associate Administrator for
Research and Development,
National Highway Traffic Safety Administration 15

European Experimental Vehicles
Committee (EEVC) Status Report
Prof. Dr. Bernd Friedel
Chairman of EEVC 25

Federal Republic of Germany
Status Report
Prof. Dr. Heinrich Praxenthaler
President,
Federal Highway Research Institute 26

United Kingdom Status Report
J.W. Furness
Chief Mechanical Engineer
Department of Transport 30

Italian Government Status Report
Dr. Franco R. Rossi
Civil Motorization
Ministry of Transportation 32

French Government Status Report
Jean Moreau de Saint-Martin
Director, O.N.S.E.R. 34

Swedish Government Status Report
Prof. Dr. Bertil Aldman
Professor, Swedish Transport Research Delegation
Chalmers University of Technology 36

Japanese Government Status Report
Kazuo Takase
Director, Automobile Division
Ministry of International Trade and Industry 39

SECTION 3: RESULTS OF ESV/RSV DEVELOPMENT
Mr. Michael M. Finkelstein, Chairman, United States

Results of the United States Research Safety
Vehicle Program

Mr. Frank G. Richardson
National Highway Traffic Safety Administration 41

Minicars RSV: Results of Angled Barrier and
Headform Impact Tests and a Comparison
with Those of the Calspan RSV and Chrysler Alpine
S.P.F. Petty
Transport and Road Research Laboratory 48

Design and Development of Modified Integrated
Vehicle for Enhanced Crashworthiness
G. Klaus, R. Sinnhuber, G. Hoffmann
Volkswagenwerk AG
Wolfsburg, W. Germany 60

SVAR Alfa Romeo Synthesis Vehicle
Alfa Romeo 69

The German Research Car Project
Klaus H. Burow

TÜV Rheinland, Köln
Jürgon Bandel
Federal Ministry for Research and Technology,
Bonn 82

Exterior Safety and Side Protection with
the Uni-Car
Hermann Appel,
Joachim Blödorn,
Arne Kühnel,
Reinhard Pasch,
Horst Rattaj, and
Wolfgang Wollert
Institute of Automotive Engineering at the
Technical University of Berlin, West Germany 88

The Safety Aspects of the VW Auto 2000
Ulrich W. Seiffert, and
Hans-Wilhelm Grove
Research Division
Wolkswagenwerk AG
Wolfsburg, Germany 95

Aspects of Passive Safety in the Mercedes-Benz
Research Car
Guntram Huber
Daimler-Benz AG,
Passenger Car Development 104

Study of Devices Designed to Improve
Safety Blet Performance
M. Petiot and J. Provensal
Renault State Owned Works
Research and Development Department 109

A Lightweight Two-Passenger Automobile Combining
Improved Crashworthiness, Good Performance, and
Excellent Fuel Economy
Michael R. Seal
Western Washington University
Michael Fitzpatrick
Fitzpatrick Engineering 118

SECTION 4: PANEL DISCUSSION ON ESV/RSV DEVELOPMENT
Mr. John Furness, Chairman, United Kingdom

Panel Member Statements
Michael M. Finkelstein
United States 131

Panel Discussion on ESV/RSV Development:
Panel member statement for EEVC
Prof. Dr. Bertil Aldman
Sweden 132

Panel Statement ESV/RSV Development
P. Von Manteuffel
Federal Republic of Germany 133

Panel Statement on ESV/RSV Development
I.D. Neilson
United Kingdom 134

Panel Statement on ESV/RSV Development
Enzo Franchini
Italy 135

Panel Statement on ESV/RSV Development
Dominique Cesari
France 135

Panel Statement: A Future Plan for the ESV/RSV Program
Kenichi Goto
Japan 136

SECTION 5: TECHNICAL SESSIONS

Session One: Frontal Crash Protection and Pedestrian Protection
Mr. Phillip W. Davis, Chairman, United States

Compatibility and Passive Safety Terminology and Problematics
Dr. Ulrich Bez, and
Dr. Walter Schmid
Bayerisch Motorean Werke AG
Germany 139

NHTSA Frontal Structures Research
Carl L. Ragland
National Highway Traffic Safety Administration 146

Frontal Crash Protection in a Modern Car Concept
Rune Almgrist,
Hugo Mellander, and
Magnus Koch
Volvo Automotive Safety Centre
Volvo Car Corporation 154

Computer Modeling of Occupant Dynamics in Very Severe Frontal Crashes
Sherman E. Henson
Ford Motor Company 164

Possible Future Trends Towards Increasing Occupant Protection In Frontal Impacts
G. Jones
Austin Rover Group Ltd. 170

Occupant Protection from Impact with the Steering Assembly

John B. Morris,
Lee Stucki,
Richard M. Morgan, and
Nancy Bondy
National Highway Traffic Safety Administration 175

A Study on the Ride-Down Evaluation
Hiroshi Katoh, and
Ryoji Nakahama
Passenger Car Engineering Center
Mitsubishi Motors Co., Ltd. 190

Optimizing Knee Restraint Characteristics for Improved Air Bag System Performance of a Small Car
Hideo Takeda, and
Saburo Kobayashi
Honda R & D Co., Ltd. 195

On the Optimum Parameters of a Seat Belt Pre-loading Device
Koji Kurimoto,
Hayao Hirai, and
Tsutomu Sugawara
Toyo Kogyo Co., Ltd. 200

Mathematical Models for the Assessment of Pedestrian Protection Provided by a Car Contour
J. Wismans, and
J. van Wijk
Research Institute for Road Vehicles TNO
Delft, The Netherlands 205

Practical Vehicle Design for Pedestrian Protection
J.E. Fowler, and
J. Harris
Austin Rover Group Ltd., BL Cars PLC
Cowley, Oxford
Transport and Road Research Laboratory,
Crowthorne 214

Application of the Fiat Methodology for Characterizing Vehicle Structural Responses in Frontal Impacts
L. M. "Morrie" Shaw
Arndt & Associates
Carl Ragland
National Highway Traffic Safety Administration 225

Influence of Occupant Seating Posture and Size on Head and Chest Injuries in Frontal Collision
Tsuyoshi Aibe,

Kuniyuki Watanabe,
Tatsumasa Okamoto, and
Takashi Nakamori
Nissan Motor Co., Ltd. 231

Session Two: Biomechanics and Dummy Development
Mr. Dominique Cesari, Chairman, France

The European Communities' Programme for Promotion
of Biomechanic Research
Herbert Hennssler
Commission of the European Communities
Brussels 238

Side Impact Data Analysis
R.H. Eppinger
Head, Biomechanics Group
R.M. Morgan
Mechanical Engineer, and
J.H. Marcus
Mechanical Engineer
National Highway Traffic
Safety Administration 244

Human Head Tolerance to Lateral Impact Deduced
from Experimental Head Injuries Using Primates
Atsumi Kikuchi,
Koshiro Ono
Japan Automobile Research Institute, Inc.
Norio Nakamura
Department of Neurosurgery
Jikeikai University 251

Tolerance of Human Pelvis to Fralcture and Proposed
Pelvic Protection Criterion to be Measured on
Side Impact Dummies
D. Cesari,
M. Ramet, and
R. Bouquet
O.N.S.E.R. France 261

Intracranial Deformation Patterns Due to Impulsive
loading—A Model Study
B. Aldman
C. Ljung
L. Thorngren
Department of Traffic Safety
Chalmers University of Technology,
Göteborg,
Swedish National Institute for Testing
Boras, Sweden 269

Automative Neck Injuries
Ayub K. Ommaya, M.D.,
S. Backaitis,
W. Fan, and S. Partyka

National Highway Traffic Safety Administration
K. Landwieder, Ph.D.
HUK-Verband 274

Development of Neck Injury Tolerance Criteria in Human Surrogates. 1. Static Tensile Loading in the Baboon Neck: Preliminary Observations
John B. Lenox et al.
Southwest Research Institute
Howard W. Huntington
The University of Texas Health
Science Center at San Antonio
K. Dee Carey
Southwest Foundation for Research and Education
Mark P. Haffner, and
Ayub K. Ommaya, M.D.
National Highway Traffic Safety Administration 279

Part Two: Dummies
Description and Basis of a Three-Year-Old Child Dummy for Evaluating Passenger Inflatable Restraint Concepts
M.J. Wolanin et al.
General Motors Corporation 287

Lateral Dummy Comparison Testing
K.P. Glaeser
Federal Highway Research Institute
Federal Republic of Germany 299

Status Report

Side Impact: A Comparison Between HSRI-, APPROD-, and HYBRID II Dummies and Cadavers
G. Klaus
Volkswagenwerk AG, Wolfsburg
Chairman of FAT Working Group 5, "Biomechanics"
D. Kallieris
Institute for Forensic Medicine,
University of Heidelberg 307

Injury Criteria in Lateral Collisions, When an APROD Dummy is Used
B. Hue et al.
Laboratory of Physiology and Biomechanics,
Peugeot S.A./Renault
C. Got, and
A. Patel
I.R.O.-I.R.B.A., R. Poincaré Hospital
Garches, France 314

Proper Use of HIC Under Different Typical Collosion Environments
D. Lestrelin et al.
Laboratory of Physiology and Biomechanics
Peugeot S.A./Renault

C. Got, and
A. Patel

I.R.O.-I.R.B.A., R. Poincaré Hospital
Garches, France
J. Hureau
Laboratory of Anatomy-Biomedical U.E.R.,
Saints-Pères, Paris V University 321

Possible Position and Postures of Unrestrained Front-Seat Children at Instant of Collison
F. Montalvo,
R.W. Bryant, and
H.J. Mertz
General Motors Corporation 336

Frontal Impact Compact Test Evaluation of Current Anthropomorphic Test Device Technology
Roger A. Saul
NHTSA/DOT
Vehicle Research and Test Center
East Liberty, Ohio 342

Responses of Animals Exposed to Development of Various Passenger Inflatable Restraint System Concepts for a Variety of Collison Severities and Animal Positions
H.J. Mertz
General Motors Corporation
G.D. Driscoll, and
J.B. Lenox
Southwest Research Instiutute
G.W. Nyquist, and
D.A. Weber
General Motors Corporation 352

Interpretations of the Impact Responses of a Three-Year-Old Child Dummy Relative to Child Injury Potential
H.J. Mertz, and
D.A. Weber
General Motors Corporation 368

Clinical and Experimental Studies on Leg Injuries in Car-Pedestrian Accidents
D. Bunketrop et al.
Department of Traffic Safety
Chalmers University of Technology
Göteborg, Sweden
B. Romanus
Department of Orthopaedic Surgery II
University of Goteborg 376

Session Three: Side Impact Protection
Mr. James Hackney, Chairman, United States

Factors Influencing Structural Deformation and Passenger Loads During Lateral Collisions-Results of a Test Series
Rainer Hoefs
Dr. Ing. h.c.F. Porsche AG
Research & Development Center 388

Structural Improved Side Impact Protection In Europe
EEVC Working Group 396

An Approach for the Design of a Deformable Mobile Barrier to Evaluate the Protection Afforded to Occupants of a Passenger Car Involved in a Side Collision
E. Chapoux,
J.C. Jolys, and
R. Dargaud
Union Technique De L'Automobile,
Du Motorcycle Et Du Cycle (U.T.A.C.) 409

Compatibility Between Car Front and Side Structures to Improved Side Impact Protection
I.D. Neilson, and
P.M. Watson
Transport and Road Research Laboratory 420

Side Collision Tests and Simulations
E. Franchini
Former Director of Fiat Safety Center 427

Volvo Traffic Accident Research System as a Tool for Side Impact Protection Evaluation and Development
Hans Norin,
Anna Nilsson-Ehle, and
Christer Gustafsson
Volvo Automotive Safety Centre
Volvo Car Corporation 439

A Study on the Methodology to Evaluate Lateral Impact and Occupant Protection Measures
S. Morita et al.
Nissan Motor Co., Ltd. 449

The Status of the National Highway Traffic Safety Administration Side Impact Research
William T. Hollowell,
James R. Hackney, and
Thomas MacLaughlin
National Highway Traffic Safety Administration 458

A Force Measuring Mechanical Test Device for Estimating and Comparing the Energy Absorbing Characteristics of Vehicle Interior Side Panels
Roger P. Daniels, et al.
Ford Motor Company 465

Evaluation of Improved Protection and Dummy Biofidelity in Side Impact
Dominique Cesari
Organisme National de Securité Routière
Laboratoire des Chocs et de Biomecanique
Arnold K. Johnson
National Highway Traffic Safety Administration 469

Violence of Fatal Car-To-Car Side Collisions and Vulnerability of Population at Risk: A Challenge of Real-World Accidents
F. Hartemann et al.
Association Peugeot S.A./Renault,
Rueil, France
C. Got, and
A. Patel
I.R.O.-I.R.B.A., Hospital R. Paincaré
Garches, France 487

Dummy Injury Values Obtained in Side Collision Sled Tests
H. Tsujimura,
H. Isobe, and
K. Maeda
Nissan Motor Co., Ltd. 494

Side Impact Component Test Development
Charles J. Griswold
Fisher Body Division-General Motors Corporation 503

The Effects of Lateral Collision Speeds, Vehicle Side Stiffness and Occupant Spacing to the Vehicle Door Upon Initial Impact Speed of the Occupant
S. Backaitis
National Highway Traffic Safety Administration
D.H. Robbins
Highway Safety Research Institute
University of Michigan 513

Simulation of an Automobile Front End With a Movable Deformable Barrier
J. Provensal,
M. Balthazard, and
M. Petiot
Research and Development Department
Renault State Owned Works 525

The Reconstruction of Two Side Impact Accidents by Performing Moving Car-to-Car Crash Tests
Arnold K. Johnson
National Highway Traffic Safety Administration
Charles E. Strother et al.
Minicars, Inc. 545

The Effectiveness and Performance of Current Door Beams in Side Impact Highway Accidents in the United States
Charles J. Kahane, Ph.D.
National Highway Traffic Safety Administration 573

A Mathematical Analysis of Side Impact Using the CAL3D Simulation Model
Arvind J. Padgaonkar, and
Priyaranjan Prasad
Ford Motor Company 578

Vehicle Side Impact Structural Analysis
C.M. Ni
Engineering Mechanics Department
General Motors Research Laboratories
Warren, Michigan 585

Application Of The Fiat Methodology For Characterizing Vehicle Structural Responses In Side Impacts
L.M. "Morrie" Shaw
Arndt & Associates
Carl Ragland
National Highway Traffic Safety Administration 596

SESSION FOUR: ACCIDENT DATA COLLECTION AND ANALYSIS
Prof. Dr. Bernd Friedel, Chairman, Federal Republic of Germany

Review of MOT Vehicle Accident Investigation in Past Seven Years
Koshiro Ono
Japan Automobile Research Institute, Inc.
Takashi Sato
Traffic Safety and Nuisance Research Institute
Ministry of Transport 606

Hospital-Based Traffic Accident Registration and Analysis in Göteborg
O. Bunketorp and B. Romanus
University of Göteborg, Sweden
B. Aldman
Chalmers University of Technology
Göteborg, Sweden 616

Feasibility of Relating Laboratory Injury Measures in Simulated Accidents to Real-World Occurences in Side Impacts
W.A. Boehly, and
J.N. Kanianthra
National Highway Traffic Safety Administration 621

The Use of Insurance Material to Study Traffic Safety
Ake Mygren, and

Jan Wersäll
Karolinska Hospital
Bertil Aldman
Chalmers University of Technology
Hans Gustafsson, and
Claes Tingvall
Folksam Insurance Group 630

Pedestrian Injury Accidents
EEVC Working Group 638

Sources of Head Injuries and the Reconstruction
of Vehicle Head Contacts in Pedestrian Accidents
S.J. Ashton, and
T.A. Greetham
Ohio State University
Columbus, Ohio
H.B. Pritz
National Highway Traffic Safety Administration
M. Pereira
Transportation Research Center of Ohio 671

Some Principles of Large-Scale Accident Studies
Related to "Active Safety"—The Need for Providing
Adjusted Accident Material and the Limits of
Current Conclusions
M. Danner, and
K. Langwieder
German Association of Third Party Accident,
Motor Vehicle and Legal Protection Insurers 683

Restraint Use and Effectiveness as Estimated
From U.S. Accident Files and Observational Surveys
John van Dyke, and
Glenn Springer
National Highway Traffic Safety Administration 696

The Main Causes of Risk Differences for Restrained
Drivers and Their Restrained Front Passenger
in Frontal Collisions
C. Thomas et al.
Laboratory of Physiology and Biomechanic
of Peugeot S.A./Renault Association
C. Got, and
A. Patel
I.R.O.-I.R.B.A. Hôspital R. Poincaré
Garches, France 707

Field Performance of Volkswagen Automatic
Restraint System (Progress Report)
John D. States
Rochester General Hospital
Department of Orthopedics, USA
Wolfgang Rosenau, and
G.M. Welkey
Volkswagenwerk AG, Wolfsburg
W. Germany 720

The Influence of Vehicle Weight on the Risk of Injury to Drivers
G. Grimes, and
T.P. Hutchinson
University College, London 726

Evaluation of a Method for Determining the Velocity Change in Traffic Accidents
Anna Nilsson-Ehle et al.
Automotive Safety Centre
Volvo Car Corporation 741

Traffic Injuries in Göteborg-Registration of Accidents, Injuries, and Medical Costs
L. Lindstrüom et al.
Sahlgrens Hospital
University of Göteborg
B. Aldman
Chalmers University of Technology
Göteborg
B. Brismar
Huddinge University Hospital
Huddinge
O. Bunketorp, and
B. Romanus
East Hospital Goteborg
Å. Nygren Folksam
Insurance Company 751

Session Five: Auto Safety Ratings
Mr. Kenichi Goto, Chairman, Japan

Aspects of the Passive Safety Motor Vehicles
B. Richter, and
R. Zobel
Research Division, Volkswagenwerk AG,
Wolfsburg, Germany 759

The Increase in the Risk of Injury in Traffic Accidents as a Result of Higher Test Impact Speeds
Dr. Walter Schmid
Daimler-Benz AG, Sindelfingen 766

Data Integrity Assessment of the New Car Assessment Program Crash Tests
W.T. Hollowell
National Highway Traffic Safety Administration
R.H. Arendt
MGA Research Corporation 771

Analysis of 35 mph Barrier Crash Test Data
T.F. MacLaughlin, and
R.A. Saul
National Highway Traffic Safety Administration

Vehicle Research and Test Center
East Liberty, Ohio 782

A Crashworthiness Rating System for Cars
S. Penoyre
Transport and Road Research Laboratory 797

The New Car Assessment Program-Status and Effect
James Hackney, and
Vincent Quarles
National Highway Traffic Safety Administration 809

Relevance and Feasibility of a Vehicle Passive Safety Rating
B. Gauvin
Safety and Road Traffic Department
Ministry of Transportation 824

Session Six: Accident Avoidance and Driver/Vehicle Interaction
Mr. Franco Roberto Rossi, Chairman, Italy

Recent Trends in Handling, Stability and Braking Performance of Japanese Passenger Cars
Akira Aoki, and
Tomo-o Nishimi
Japan Automobile Research Institute, Inc. 832

Variation Ranges for the Handling Characteristics of Today's Passenger Cars
Klaus Rompe, and
Edmund Donges
Institute for Traffic Safety
TÜV Rheinland e. V, Cologne 842

The Driver Related Steering Characteristics of the New Volvo 760 GLE
Fredrich O. Jaksch
Volvo Car Corporation
Gothenburg, Sweden 849

Aerodynamics of Trailer Towing
John Zellner
Systems Technology, Inc.
Lloyd H. Emery
National Highway Traffic Safety Administration 863

Consideration About the Relation of Headlamp Glare and Driving Visibility
Hiroaki Shinkai, and
Yoshimasa Osumi
Toyota Motor Corporation 885

Vehicle Handling and Active Safety Alfa Romeo's Researches on Driver Vehicle System

Luciano Chidini
Alfa Romeo s.P.a. 889

Increase of Driving Safety Through New
Concept Four Wheel Drive Vehicle
Rempei Matsumoto et al.
Subaru Engineering Division
Fuji Heavy Industries, Ltd. 894

Performance of a Simplified Control Technique
for Antilock Brakes
Makoto Satoh, and
Shuji Shiraishi
Honda R & D Co., Ltd. 903

Stereo Radar System for Automobile Collision
Avoidance
Akira Tachibana et al.
Nissan Motor Co., Ltd. 909

Automotive Warning System Using 50GHz
Band Radar
T. Nogami
Toyota Motor Corporation
T. Sakamoto
Fujitsu Ten Limited 917

Accident Avoidance—How Age Deterioration
Can Affect Car Safety
M.A. Jacobson et al.
Chief Automobile Association
Fanum House, Basinstoke, Hants, England 924

Evaluation and Improvement of Indirect
Visibility in Circumferential Area of
Commercial Vehicle
Hiroshi Satoh et al.
Mitsubishi Motor Corporation
Makoto Yamashita
Ichikoh Industries, Ltd. 954

Performance of the Experimental Heavy Duty
Trucks with Improved Field of View
Hidehiro Daigo et al.
Japan Automobile Research Institute, Inc.
Ministry of Transport 960

The Volvo Electronic Traction Control (ETC) System—A Concept
for Safe Driving
Lars Lind
Volvo Car Corporation
Gothenburg, Sweden 972

SPECIAL SESSION: THE LEGAL SYSTEM OF JAPAN ON MOTOR VEHICLES

Part 1: Outline of Legal System on Motor Vehicles
Kazuhiko Morisaki

Kunio Takahashi
Motor Vehicles Department
Ministry of Transport 976

Part 2: Motor Vehicle Safety Regulations
Kazuhiko Morisaki
Kunio Takahashi
Motor Vehicles Department
Ministry of Transport 983

Part 3: Environmental Pollution Control Measures
and Energy-Saving Measures for Motor Vehicles
Ryoichi Mukai 995

Part 4: Type Approval System of Motor Vehicles
Masakazu Kume
Ministry of Transport
Haruo Omori, and
Kazushige Daiki
Road Transport Bureau
Kazuyoshi Matsumoto
Transport Department
Okinawa 1009

Part 5: Motor Vehicle Inspection and
Registration System
Hidemi Tozawa
Ministry of Transport, Tokyo
Hideyuki Kadono
Registry Division 1019

Part 6: Motor Vehicle Accident Prevention Measures
and Research System of the Government
Jun Masui
Ministry of Transport
Akio Sasaki, and
Toshinori Urano
Inspection and Safety Transport Division 1027

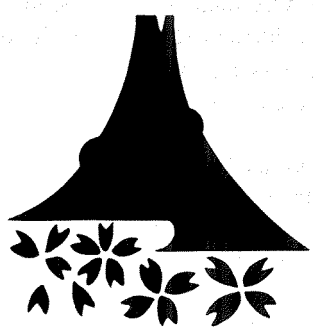
CONFERENCE CLOSING

Closing Remarks by the Heads of the Japanese
and American Delegations at the
Ninth ESV Conference

Noriyoshi Uno
Director-General of Traffic Safety and
Nuisance Research Institute
Ministry of Transport 1039

Michael M. Finkelstein
National Highway Traffic Safety Administration
Department of Transportation 1040

Section 1: Opening Ceremonies



Welcoming Address:

Mr. Manabu Shiga
Director General of the Machinery and Information Industries Bureau, Ministry of International Trade and Industry

On behalf of the Japanese government, I would like to welcome the delegates and other participants who have come to Japan for this Ninth International Technical Conference on Experimental Safety Vehicles.

Let me first thank both the government and automobile industry officials in the U.S. and other participating countries for their valuable assistance in organizing this conference. Special thanks must also go to the Japan Automobile Manufacturers Association and the Japan Automobile Research Institute for their help in preparations.

The first ESV conference was held in Paris in 1971, as part of an international cooperative effort proposed by the United States in 1970, aimed at developing an ESV. Since then, this conference has been held eight successive times, during which period there has been a marked improvement in automobile safety, due in large part to the contribution made by this conference.

We have an old saying in Japan that "Three heads put together are wiser than Buddha." I am sure that the next four days of lively discussion will prove the truth of this proverb, and that this joint government-industry effort will yield important results.

Kyoto, where we are gathered today, became the capital of Japan in the eighth century and prospered as such for over 1,000 years. The city is truly representative of Japan's historic past, and I sincerely hope that our friends from overseas will enjoy their visit to the full, despite the shortness of their stay.

Finally, let me express my best wishes for the success of the Ninth International Technical Conference on Experimental Safety Vehicles.

Welcoming Address:

Mr. Takashi Ishihara, President,
Japan Automobile Manufacturers Association

On behalf of the Japan Automobile Manufacturers Association, I would like to warmly welcome you all to the International Technical Conference on Experimental Safety Vehicles here today.

The First International Technical Conference on ESV was held in Paris in 1971. It has since been followed by successive conferences in a number of countries throughout the world, including the fourth, which was held in Kyoto nine years ago. It is, therefore, a special honor for us that Kyoto has been chosen again as the venue for the ninth conference.

This conference has been made possible by the collective efforts of the government officials and members of the automobile industry in the United States and other participating countries as well as Japanese government officials. I would like to pay tribute to their cooperation.

The automobile represents the most useful means of transport we have today. It is indispensable to our modern life. This product of modern civilization has played a major role in the social and economic development of many countries. But as you are all aware, many associated problems—traffic accidents, exhaust gas emissions, and

noise—call for solutions through technical innovations. The foremost problem of all, however, is and will continue to be safety, a question whose importance will grow as the interdependence of the automobile and society increases.

Safety is an issue of great concern to both governments and automobile manufacturers alike. We have already achieved many accomplishments, but I need hardly remind you that much work remains to be done in this area. I am keenly aware that the solutions to these common problems require closer international cooperation in the form of sharing research findings, information, and opinions.

This conference, bringing together experts from many countries around the world, is a splendid opportunity to realize such exchanges. I am certain that the next four days will be filled with lively discussion and prove very productive.

In conclusion, let me express my best wishes for the success of this conference. I also wish our friends from overseas a brief yet pleasant and memorable stay in Japan.

Thank you.

Keynote Address:

The Honorable Darrell M. Trent
Deputy Secretary
United States Department of
Transportation

I am pleased to keynote this Ninth International Technical Conference on Experimental Safety Vehicles. I wish to thank our hosts, the Government of Japan, and our co-hosts, the Japan Automobile Manufacturers Association and the Japan Automobile Research Institute for inviting us here to Kyoto to discuss progress in automotive safety research.

This confederation of concerned nations was founded 12 years ago in a common dedication to the principle that a safer car can be a better car, and in the growing universal acceptance of passenger safety as a viable and basic criterion of automotive design.

Due to the dedicated efforts of both governments and industries, today's automobiles are safer, less polluting, and more fuel efficient than those manufactured only a few years ago. Advances in automotive technology, many the result of our ESV/RSV work, have made the tradeoffs less difficult between safety, performance, fuel economy, and emissions control. What was considered impossible a few short years ago is now state-of-the-art technology in today's production cars.

We are not, however, replacing the older cars on our highways at the rate which we—and the manufacturers—would prefer. We have been suffering from a depressed auto market for the past 3 years—the result of inflation, high interest rates, and a stagnant economy.

The Reagan Administration has been working to correct the root causes of these problems. Prior Administrations operated on the philosophy of "spend today and pay tomorrow"—if it's income, tax it; if it's industry, regulate it; where there's a budget, break it; and whatever the problem, legislate it.

We have changed all of that. The present Administration has cut the growth in Federal spending by nearly two-thirds. The prime interest rate has dropped nearly 45 percent, and the inflation rate—once over 12 percent, is now running at an annual rate of 4.8 percent.

As the economy improves, the U.S. auto market will improve with it. Some industry leaders are predicting domestic sales in the 6 to 7 million range for 1983, and 8 million by 1985. As more new and safer cars take to the highways, the fatality rate will decline.

As one would expect, safer cars have contributed substantially to the reduction of deaths and injuries. We have awakened to the fact that highways and streets do not have to be places of sudden and violent death. We do not have to accept a particular death toll as inevitable, or any fatality rate as "acceptable." Government and industry must continue to treat death and injury on the highway as any other major national affliction—through aggressive research into the best means of prevention and corrective treatment of the causes.

In that regard, I cannot emphasize too strongly the Reagan Administration's firm and abiding commitment to transportation safety—we believe that this matter must be pursued in a way that takes advantage of the broadest possible spectrum of expertise. This must be a cooperative open-minded venture, not a restricted and parochial one. Our Administration favors an approach that

—emphasizes government-industry cooperation
—promotes global technology sharing
—enhances automotive safety without unnecessary, burdensome regulations, and
—facilitates international trade through harmonization of safety standards.

Government-Industry Relations:

Since President Reagan took office, we have made important strides in improving our general approach toward government-industry relations in virtually every economic and industrial area. Motor vehicle safety is no exception.

The Federal Government may conduct research, perform tests, and propose regulations, but the manufacturers have the practical and technical expertise and

experience in building the cars. Clearly the best approach to improving automobile safety is one in which government and industry cooperate and bring their respective expertise and experience to bear in solving mutual concerns.

We reject the view that automobile manufacturers would not care about safety unless the Government forces regulations upon them. The public demands and has a right to expect safe products. This is a highly competitive business and those who produce inferior, less safe vehicles won't be able to compete for long. The automobile industries in the U.S. and abroad have every incentive to work with their governments in developing safe, quality products. Therefore, a strident, adversarial relationship between regulator and manufacturer clearly makes no sense.

In this regard our colleagues from other countries are well aware of the many advantages of close government-industry relations because they have a long history of productive interaction. Our Administration agrees that this is the best course and we will pursue it with vigor.

Technology Sharing

In the area of transportation safety, no country has a monopoly on the best ideas or approaches. This is why we favor an active international research and development program to foster data and technology sharing.

Independent and uncoordinated R&D can prove wasteful, redundant, and lead to the development of safety technologies which may not always be suitable for worldwide application. International cooperation can lead to the development and expanded use of improved safety equipment on a global scale. Furthermore, as manufacturers employ similar safety systems, they can reduce the need for retooling to meet different safety standards in domestic and foreign markets. Through cooperative efforts the cost of international trade can be reduced and the safety of vehicles sold can be improved.

Our Department has a number of ongoing international R&D projects. But I would particularly like to call your attention to our recent initiative in which we proposed seven new collaborative R&D projects to our colleagues in Europe and Japan. Our technical experts are looking forward to receiving positive responses to these proposals in the near future and I personally believe that our expanded cooperation in the area of automotive safety research will yield high dividends for industry and consumers alike.

Emphasizing Safety Without Unnecessary Regulation

As we implement a comprehensive safety program, I want to emphasize that economic considerations are an important part of our planning. We do not live in a risk-free world, and regulations cannot be expected to protect us from every danger inherent in a modern society. Regulations are often expensive to implement. They can impede innovation and be counterproductive to longer term improvements in both the safety and utility of our transportation system.

The costs of imposing restrictions and regulations must be weighed against their contributions to safety. Our Administration believes that we have often promulgated rules of dubious safety value that are economically burdensome for the consumer as well as the automobile industry. We must avoid the "rush to regulate" syndrome. There must be sound and compelling safety advantages that justify the costs of regulation in both direct economic terms and in the effect on innovation.

For example, we rescinded the automatic restraint requirements for new cars because we thought the regulation would not achieve the originally projected safety benefits. Safety belts are now in virtually all cars. They provide comparable protection if used. The automatic restraint regulation was defended on the grounds that people could not be induced to buckle up. But we have initiated an unprecedented and sophisticated national campaign to inform the public of the benefits of using safety belts, and all of our results to date confirm our belief that it will be successful in persuading record numbers of Americans to "buckle up." If significantly more people will use belts available now, we can save thousands of lives without additional cost. For each 10 percentage point increase in safety belt usage within the U.S., we can save about 1,700 lives per year.

We are strongly committed to the orderly and prudent introduction of advanced forms of safety technology into the marketplace. For example, if manufacturers wish to offer air bags or automatic belts as optional equipment, we encourage them to do so. If the public wants and likes them, the marketplace will support their availability. Our studies and information confirm substantial levels of demand in the U.S. market. In this regard the Department is taking what we believe are appropriate steps to assist industry in the commercialization of advanced technology. DOT is ready to sign a contract to help develop a means to retrofit air bags into vehicles. These systems would be available to selected state police car fleets in the U.S. Our formal notification of this effort in the form of a Request for Proposals was published in the Department of Commerce Business Daily on October 25, 1982, and was being mailed to our contractor list as I left Washington.

Another means of improving highway safety without new technical regulations is to crack down on drunk drivers.

Each year an estimated 25,000 Americans die and 1.7 million are injured in crashes involving drunk drivers. More than 11 million American families have seen a member killed or injured in an accident involving a drunk

driver in the past 10 years. Society's loss in wages, productivity, medical and legal costs, and purchasing power caused by deaths and injuries in drunk driving crashes costs many billions each year.

In the United States, we are making major progress in this critical area. President Reagan has established a Commission on Drunk Driving to provide visibility to the problem and coordinate national and local emphasis, education, and prevention programs. Governors of more than half of our States have appointed task forces or special commissions on drunk driving to examine their States' anti-drunk-driving measures and to recommend reforms. Some of these task forces have already reported back, and many of their recommended reforms have been implemented with significant impact. Indeed some States have had fatality reductions of about 30 percent. This is one of our highest priority programs, and will receive major emphasis in the coming years.

International Harmonization of Safety Regulations

Finally, I want to stress our commitment to harmonizing our safety regulations with other countries. At present, nations often have incompatible test procedures, performance standards, compliance criteria as well as means of certifying compliance. These differing regulations make it technically burdensome for manufacturers to construct cars for domestic and foreign markets—they serve as nontariff trade barriers that restrict international commerce—they are costly to consumers and industry alike while providing no safety benefits.

Free trade is one of the principal cornerstones of the international economic system and automobile sales represent an integral part of that system. In this context, fair access to foreign markets is essential in order to preserve a congenial world trade environment. As you are no doubt aware, the United States is the largest and most profitable market for foreign automobile imports. In 1981, our country imported over two million cars from foreign suppliers and will again import more than two million this year. Imports now account for more than one quarter of total car sales in the U.S. We pride ourselves on being an open market without arbitrary trade barriers.

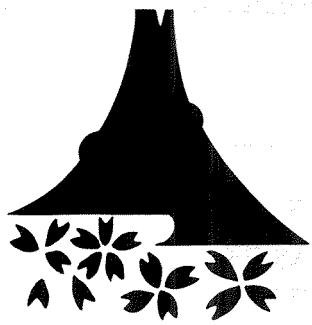
Fair access to foreign markets is particularly important for the U.S. because the automobile industry is a vital component of the American economy. Our companies are building reliable, safe, and fuel efficient vehicles that can compete if given a chance. But this is not always the case. Overly bureaucratic foreign safety regulations are often so costly and burdensome that they actually impede the normal course of international trade. American manufacturers and workers deserve and have a right to expect the same opportunities abroad as foreign suppliers have in our country. At present, many American automobile workers are unemployed and they have a difficult time understanding why our markets are open and other markets, which could help put them back to work, are restricted.

We live in an interdependent world economic system in which nontariff trade barriers cloaked as safety regulations have no place. The United States considers it a high priority to overcome these differences which hamper free market economics and is prepared to work diligently in both bilateral and multilateral forums to achieve near-term, substantive results.

Conclusion

In conclusion, let me commend this international conference as exactly the kind of cooperative effort we need to address important transportation safety issues. Less than 60 years ago, automobiles were almost a novelty. Today they are "fact of life" in modern industrial countries and they are now becoming more widespread in developing nations as well. Automotive and highway traffic safety have become issues of public concern on an international scale. As can readily be seen from the representation here today these matters are being accorded the priority consideration they deserve.

Awards Presentations



SAFETY AWARDS FOR ENGINEERING EXCELLENCE

In recognition of and appreciation for extraordinary contributions in the field of motor vehicle safety engineering and for distinguished service to the motoring public.

Federal Republic of Germany

Professor Dr. Ing. Max Danner

President of the Committee of Accident Prevention
HUK-Verband

Professor Danner initiated the HUK accident research program and developed a retrospective large scale analysis of real accidents based on insurance claims and accident data. The results of this outstanding work identified safety measures that could be implemented in a short time frame. Of special significance has been his work on the effectiveness of safety belts and restraint systems, simulation of motorcycle and car accidents, car crash tests with restrained volunteers, and the development of standards for rating vehicles with respect to crash damage and repairability.

Dr. Ing. Klaus Langwieder

Head of Automobile Engineering
Accident Research
HUK-Verband

Dr. Langwieder has made a significant contribution to vehicle safety by his in-depth analysis of large scale accident data. This analysis identified the connection between accident severity and mechanisms as well as the characteristics of injuries. These studies resulted in the development of safety criteria for passenger car occupants, motorcyclists, and pedestrians and the development of proposals for safety countermeasures—knee bars for motorcycles and front protection for trucks. Dr. Langwieder's work has also supported research in car-to-car compatibility and driver/vehicle interaction and has contributed significantly to our knowledge of vehicle accidents.

Dr. Ing. Ulrich Bez

Head, Vehicle Basic Research
Porsche AG

Dr. Bez has made significant research contributions in the areas of accident analysis, biomechanics, crashworthiness, vehicle compatibility, and cost/benefit analysis. In addition to his work in aspects of active and passive safety, Dr. Bez has investigated the basic medical and technical conditions influencing the physical condition of injured polytraumatized accident victims, and has developed a successful rescue system which also can be used in disaster control. Because of Dr. Bez's outstanding research work he was appointed in 1981 as Head of the Vehicle Basic Research Department, R&D Center, Porsche AG.

Wilfried Schwant

Passenger Car Development
Safety Engineering
Volkswagenwerk

Mr. Schwant was responsible for the development of the restaint system for the ESVW I. Within the scope of this effort he developed new components which led to eight patent applications. Following the research effort Mr. Schwant had responsibility in Safety Engineering for the development of occupant protection systems and seats for production vehicles. In addition to many novel approaches and engineering solutions that currently appear in production Volkswagens, the most recognized is the passive restraint system installed in the 1975 Golf/Rabbit—the first production automatically activating protection system in the world. For his impressive contribution to vehicle safety Mr. Schwant is deserving of special recognition.

United Kingdom

John Cart

Development Engineer
Lucas Girling Ltd.

Mr. Cart has made a major contribution to vehicle safety by the successful design, development, and application of an effective anti-lock braking system for motorcycles. Mr. Cart's system overcomes one of the greatest dangers facing motorcyclists during heavy breaking—wheel lock and the consequent loss of control. His enthusiasm and perseverance during more than 5 years of engineering evolution have resulted in an economical and reliable unit. This unit's impressive performance has been confirmed during evaluation trials in Europe and in Japan, and under contract by the National Highway Traffic Safety Administration. The introduction of this novel, unique braking system on series production motorcycles will provide a major contribution to road safety.

George Stephen Rothman

Managing Director
KL Automotive Products Ltd.

Mr. Rothman was instrumental in the design and development of an improved child safety seat which evolved in 1970 into the first modern child seat which restrained the car's seat back independently. Mr. Rothman's development was part of the first integrated range of child restraints (carrycot, seat, and harness) for all ages and was recognized by a Design Council Award and was rated best in United Kingdom and overseas tests for safety and ease of use. To date, over one million have been sold, and accident studies have shown that Mr. Rothman's child restraint is very effective in reducing accident risks. This major contribution to child safety is deserving of special recognition.

Italy

Dr. Mario Barile

Technical Director
Fiat Auto SpA

Dr. Barile has made a major contribution to vehicle safety by the design, development, and implementation of advanced vehicle test devices and protocol. As the Director of vehicle safety testing since 1966, he has been responsible for developing special systems for load measurements ranging from driver and pedestrian protection to structure evaluation by means of static tests and dynamic tests. Dr. Barile was a principal contributor in the Fiat accident analysis study and in the research on vehicle compatibility which led to the development of the Fiat crash methodology. In 1981 he became Director of the Fiat Safety Center.

France

Rene Larousse

Research Engineer
Citroen

Mr. Larousse has conducted research in all areas of passenger car safety. His work addressed the man/machine interface problem, the integration of the restraint system with the vehicle structure, the development of advanced vehicle structure concepts, the development and test of advanced restraint system concepts, accident reconstruction and pedestrian safety improvements. The results of Mr. Larousse's research are now in production Citroen cars, and he personally led the development of the small DYANE-ATP saloon car. Mr. Larousse has made a major contribution to automotive safety.

Jacques Provensal

Regie Nationale des Usines Renault

Mr. Provensal is responsible for secondary safety research within Renault's Vehicle Structure Research Department. He had major responsibilities in the development of test methods for defining and designing the Regie Renault's crash test track which is a test facility especially adapted to research in the field of secondary safety. After participating in the development of Renault's first Experimental Safety Vehicle, the BRV (Basic Research Vehicle), presented at the 1974 ESV Conference in London, Mr. Provensal headed the team which designed the second Renault safety vehicle, called EPURE, which was revealed in 1979 at the ESV Conference in Paris. The work performed by Mr. Provensal at the Research and Secondary Safety Testing Department, which he has headed since 1979, has principally concentrated on energy dissipation and preservation of the vehicle compartment in impact.

Sweden

Rune Almqvist

Senior Safety Engineer
Volvo Car Corporation

Mr. Almqvist has made a major contribution to automotive safety by his efforts to improve the crashworthiness performance of Volvo passenger cars. His work led to the development and incorporation of the concept of front and rear crash deformation zones and to improvement in the effectiveness of the Volvo three-point seat belt system. Mr. Almqvist was instrumental in the design and establishment of the Volvo Crash Safety Center, and he has been continuously involved in various international safety organizations. The results of Mr. Almqvist's safety design efforts contributed significantly to the successful crash test of the 1982 Volvo at the NHTSA Safety Research Laboratory.

Japan

Kenichi Goto

Research Director
Japan Automobile Research Institute, Inc.

Mr. Goto joined the Nissan Motors Company in 1956. He was appointed as a Research Director to the Japan Automobile Research Institute in 1979. He was responsible for the successful work on the evaluation of the Research Safety Vehicles, fabricated by both Calspan Corporation and Minicars, Inc. At the Japan Automobile Research Institute he directs the traffic accident survey and other important studies for prevention of large truck accidents, improvement of large truck rear bumpers, improved safety performance of front windshields, and improvements to impact dummies. In addition, Mr. Goto is Chairman of the Safety and Human Engineering Committee of the Japanese Society of Automotive Engineers, serving for improvement of automotive safety.

Hideo Takeda

Director
Honda R&D Co., Ltd.

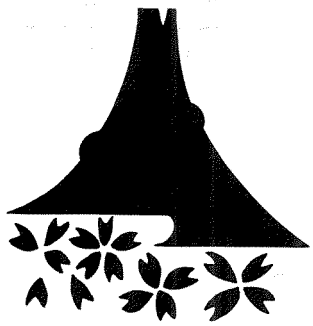
Since 1975 Mr. Takeda has been responsible for all safety aspects in the development of Honda automobiles. He led the engineering group with the responsibility to improve the occupant protection performance of Honda cars in 35 mph crash tests. This effort resulted in dramatic improvements in the 1981 model year production Civics. Mr. Takeda contributed not only to the introduction of new safety concepts in production Honda cars, but also was project leader of a basic research engineering group responsible for the development of air bag systems for small subcompact cars. The results of Mr. Takeda's work have made a major contribution to automotive safety.

Special Award of Appreciation

Michel Frybourg

Mr. Frybourg has had a long and distinguished career in support of improvements in highway safety. He is the senior government status report presenter, having made the status reports for France during all ESV Conferences. His support of the International ESV Program has been outstanding. His counsel on engineering approaches and direction has always reflected what is practical and producible. Mr. Frybourg has been personally responsible for the excellent cooperation of the French Government and the significant contributions of the French automobile industry. It is, therefore, appropriate that we recognize Mr. Frybourg's outstanding contributions to highway safety.

Section 2: Government Status Reports



Mr. Manabu Shiga, Chairman, Japan

United States Government Status Report

MICHAEL M. FINKELSTEIN
Associate Administrator for Research and Development, National Highway Traffic Safety Administration

INTRODUCTION

It is my distinct pleasure to present the United States Government Status Report, on our progress in automotive safety.

During the past 2 years, there has been no marked change in the general direction of our vehicle research program; but there has been a dramatic change in the management approach. Our objective is the early introduction of research results into production cars. To help accomplish this objective, we have (1) established a cooperative research program with the industry concentrating on technology transfer; (2) redirected research programs to address safety improvements in subsystems rather than complete vehicle systems; and (3) given more attention and priority to the crash avoidance research area.

We have recently completed a major effort to establish safety priorities in crash protection. Much of this effort was presented in technical papers at the February 1982 Society of Automotive Engineers Congress. Our updated Safety Priority Plan which is to be published in December 1982 will also reflect these new safety priorities.

Currently in progress is an analytical effort similar to the crash protection work to establish safety priorities in the crash avoidance area. The results of this effort will be reported during the SAE Congress scheduled for February 1983.

The recently established cooperative safety research program with our domestic manufacturers will also allow us and the industry to ensure that the limited research funds available are allocated efficiently. It will also encourage the development of safety improvements that can be incorporated into production vehicles in a timely fashion. We are currently proposing a similar program with the membership of the European Experimental Vehicles Committee and the Government of Japan. To date our domestic program has been extremely beneficial to all concerned. We are hopeful that our international cooperative program will also be mutually beneficial.

THE ACCIDENT ENVIRONMENT

Since the last conference, the death rate per 100 million vehicle kilometers traveled in the United States has decreased from 2.10 in 1980, to 1.97 in 1981, and to 1.69 through July 1982; these are decreases of 6.2 percent and 14.2 percent respectively.

In 1981 the number of licensed drivers and the number of registered vehicles in the United States continued their steady increase. Vehicle kilometers traveled also increased, reversing the downward trend of the past several years. That downward trend, it will be noted, was all in travel by automobiles and motorcycles; the rising truck and bus travel never faltered. Tables 1 and 2 show these environmental trends.

Despite the rise in kilometers traveled, the number of traffic fatalities is at a 3-year low (Reference Table 3). In fact, as Table 4 indicates the fatality rate in terms of kilometers traveled has dropped below the 1978 rate which was the low point in the decline experienced since 1966.

Of the 49,268 traffic fatalities in 1981, 26,545, or 54 percent, were passenger car occupants. Table 5 shows the distribution of these occupant fatalities by type of occurrence. Frontal and side crashes continue to account for three-fourths of the cases.

Table 6 illustrates one aspect of the interaction between

Table 1[1]. Licensed Drivers (millions).

Year	1977	1978	1979	1980	1981
	138.1	140.8	143.3	145.3	148.0

Table 2[1]. Vehicle Registrations[(a)] and Vehicle Kilometers[(b)].

	1977	1978	1979	1980	1981[(d)]
Autos					
Reg.	113.7	116.6	120.2	121.7	124.3
Km.	1800.3	1884.7	1835.5	1789.4	N/A
Motorcycles					
Reg.	5.0	5.1	5.5	5.7	6.0
Km.	36.3	37.2	35.4	29.0	N/A
Buses					
Reg.	0.5	0.5	0.5	0.5	
dKm.	9.5	9.8	9.8	10.3	35.4[(c)]
Trucks					N/A
Reg.	29.6	31.7	33.3	33.6	
Km.	530.2	559.9	580.2	618.9	
Total veh.					
Reg.	148.8	153.9	159.6	161.6	165.7
Km.	2376.3	2491.6	2460.9	2447.6	2502.5

(a) in millions.
(b) in thousand millions.
(c) buses and trucks combined.
(d) N/A = not available.

Table 3[2]. Traffic Fatalities.

	1979	1980	1981
Total	51,083	51,077	49,268
Passenger Car Occupants	27,788	27,433	26,545
Truck Occupants			
Light Trucks	7,119	6,563	6,129
Medium Trucks	254	285	235
Heavy Trucks	1,087	976	896
Motorcyclists	4,709	4,960	4,716
Pedestrians	8,090	8,071	7,836
Pedalcyclists	931	964	935
Other & Unknown	1,105	1,825	1,976

Table 4[2]. Fatality Rate.

	(Fatalities per 100 Million Vehicle Kilometers)				
Year	1977	1978	1979	1980	1981
Rate	2.03	2.02	2.08	2.10	1.97

Table 5[2]. Passenger Vehicle Occupant Fatalities by Type of Occurrence.

	1979		1980		1981	
	#	%	#	%	#	%
Frontal Crash	13,708	49.3	13,781	50.2	12,778	48.1
Side Impact	7,924	28.5	7,681	28.0	7,302	27.5
Top Intrusion	3,240	11.7	2,324	8.5	1,643	6.2
Non-Collision	1,308	4.7	2,095	7.6	2,152	8.1
Rear Impact	799	2.9	816	3.0	908	3.4
Other	266	1.0	214	0.8	306	1.2
Unknown	543	1.9	532	1.9	1,456	5.5
Total	27,788	100.0	27,433	100.0	26,545	100.0

Table 6[2]. Passenger Car Occupant Fatalities in Two-Vehicle Accidents.

Other Vehicle	1979	1980	1981
Passenger Car	6,919	6,694	5,080
Light Truck	2,862	2,680	2,049
Medium Truck	326	473	318
Heavy Truck	2,359	2,002	1,777
Other & Unknown	514	501	491
Total	12,980	12,350	9,715

Table 7[2]. Passenger Cars in Non-Occupant Fatal Accidents.

Year	1979	1980	1981
Number of Cars	5,937	5,916	6,112

passenger cars and trucks. Of the 9,715 passenger car occupants killed in two-vehicle accidents, 43 percent died in crashes with trucks. This ratio is about the same as it has been for the past 2 years, but the total number of cases has dropped sharply down 21 percent from 1980 to 1981 compared to a 5 percent annual decline the previous year.

Another interaction of interest is that between passenger cars and nonoccupants. According to the figures in Table 7, this aspect of the environment has changed little, at least in total magnitude, over the past several years.

Although fatal accidents are much better documented in the United States than are lesser accidents, they by no means represent the total societal cost of traffic crashes.

Table 8[3]. Involved and Injured Passenger Car Occupants.

	Annual Average 1979-80
Involved	13,979,000
Injured	2,574,000
Seriously Injured	146,000
Fatally Injured	27,623

Table 8, derived from the first 2 years of operation of the National Accident Sampling System, indicates that nonfatal injuries to passenger car occupants occur over 90 times as frequently as do fatalities. For serious injuries the ratio is about four to one (in Table 8 the number of each level of injury includes all higher levels). The eleven million uninjured occupants experienced an enormous amount of property damage (refs. 1, 2, and 3).

SAFETY PROGRAM STATUS AND PROGRESS

Accident Data Collection and Analysis

The accident data cited above are derived from the Fatal Accident Reporting System (FARS) and the National Accident Sampling System (NASS). Both of these major accident data collection systems are operated by Research and Development.

The FARS is a computerized data base containing information on all fatal motor vehicle accidents occurring in the 50 States, the District of Columbia, and Puerto

Rico. The system became operational in 1975. The FARS data are acquired directly from each State's operational records, including police accident reports, driver license records, motor vehicle registration files, State highway department records, and vital statistics (including data from medical examiners and coroners' reports). The FARS file provides the most comprehensive, detailed, and accurate data available on the U.S. national motor vehicle fatality toll.

The NASS is a network of experienced, highly trained accident investigation teams that collect a representative national sample of accidents and perform selected special studies. Data are compiled and evaluated from detailed accident site inspections, damaged vehicles, driver interviews, medical records, autopsy data, and other pertinent State records. The NASS system collects information in significantly greater detail, both in numbers of variables and precision of observations, than existing records or systems. In particular, the NASS file includes information on all accidents: fatal, injury and property damage, including light and heavy trucks, motorcycles, pedestrians, and passenger cars. NASS and FARS are thus complementary: FARS with limited detail on all fatal accidents, NASS with extensive detail on a sample of all accidents.

The analysis of such data improves the opportunity for problem identification and evaluation. The detailed data are particularly useful in support of countermeasure activities both in the public and private sectors. The original plan called for 75 sites throughout the United States when NASS is fully implemented. In 1982, 52 sites were operational as illustrated in Figure 1.

Products from both FARS and NASS are available in the form of annual reports, special interest reports, access to NHTSA data files, and selected annual computer tapes.

Crashworthiness

Crashworthiness Priorities

During the past year, NHTSA completed a major review of safety priorities including those for passenger vehicle crashworthiness. The results of this review have been used to focus on activities which are expected to contribute most to reducing harm to vehicle occupants.

Biomechanics

Biomechanics efforts have continued in many areas. Besides continued and extensive impact trauma research, several efforts have focused on the design, development, and evaluation of crash test dummies. The side impact dummy program has progressed from pendulum and sled type tests to an evaluation of dummy performance in actual car crash situations. The evaluation of the state-of-the-art of current frontal impact dummies has progressed from subcomponent tests to an evaluation of these devices in simulated crashes while restrained by either belts or air bag. A contractual effort for design and development of an advanced anthropomorphic test device has been initiated. This project is intended to advance dummy design by incorporating the most recent frontal and side impact characteristics into a single test device. Additionally, advanced instrumentation techniques will be pursued to increase the accuracy and reliability of the data output while reducing the complexity of the process.

Verification of the performance of NHTSA's proposed pedestrian bumper standard continues. These tests will not only provide confirmation of the injury mitigating potential of soft bumpers but provide a wealth of information to guide the development of potential injury countermeasures in the vehicle areas of hood, hood-edge, cowl, and windshield.

As reported at the conference at Wolfsburg in 1980, two dummies for use in side impact protection are being evaluated, one developed by the Highway Safety Research Institute at the University of Michigan (HSRI) and the other by Association Peugeot-Renault (APR). The complete evaluation as reported at the 1981 Stapp Conference (ref. 4) indicates that either device will provide responses that are very similar to cadaver responses. A decision to use the HSRI version of the side impact dummy for all NHTSA testing was made in February of 1982. This decision was based primarily on the availability of the HSRI dummy and the cost factors associated with the continued use of two devices. We will continue to monitor dummy development and dummy evaluation projects such as those that are being pursued by CCMC, APR, SAE, and others relative to any reassessment of this decision. The NHTSA encourages continued activities by all organizations to advance the state-of-the-art in anthropomorphic test dummy design and appreciates the participation of the many institutes in these efforts.

Frontal Protection

In the frontal crashworthiness area, more extensive efforts are under way to assess the effects of vehicle crash pulses on restrained and *unrestrained* occupants (ref. 5). The focus in past years has been on passive protection. Although this is still considered as a very important area, we have increased our emphasis on improved protection for the unrestrained occupants in many of our research projects.

The use of the instrumented crash barrier (load cell barrier) is playing an important role in this activity. Dynamic load deflection characteristics of frontal structures have been collected on 14, 1980 vehicles; 12, 1981 vehicles; and 24, 1982 vehicles that were crashed into the barrier at 35 mph. Concurrently, we have been exploring the use of deformable moving barriers in crash testing to provide more comprehensive data relative to vehicle aggressiveness and crashworthiness (ref. 5).

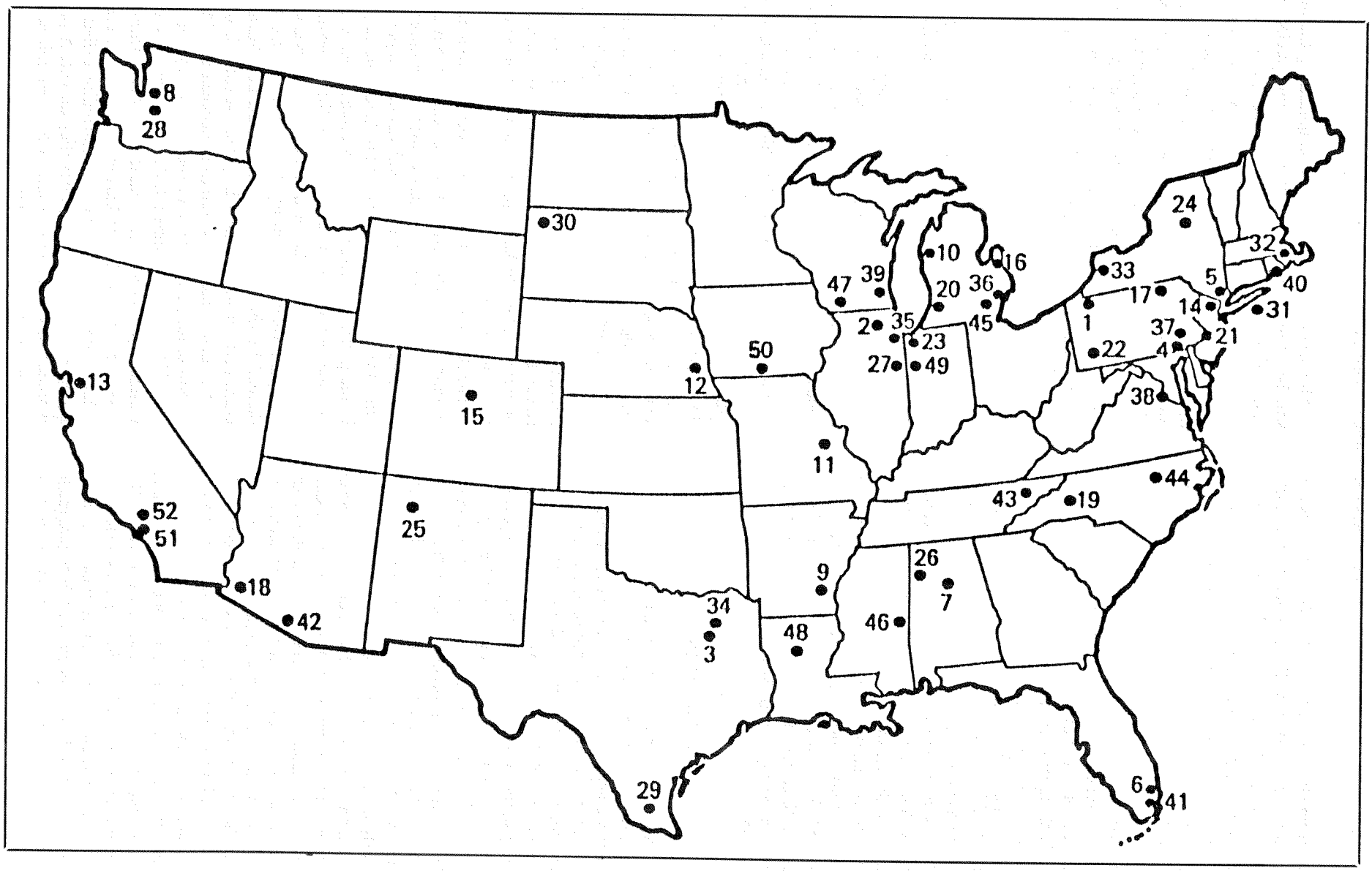


Figure 1. National accident sampling system implementation phases I, II, III, and IV.

The data from all tests conducted by NHTSA in recent years are contained in a standardized format in our crash test data base. Over 500 crash tests are in our files. These computerized files and the standardized format are available and may be obtained by contacting NHTSA.

For some time we have been encouraging all laboratories to standardize instrumentation, signal processing, and data formats so that ease in data exchange and review is possible. To aid in this standardization, NHTSA has developed electronic hardware for generating waveforms to evaluate test site equipment and data processing methodologies. These laboratories, under contract to NHTSA, will be required to exercise this equipment at their sites on a regular basis. We know that many organizations represented here are also utilizing this equipment. It is available for others to use if requested.

A study is being completed to develop test procedures and steering column performance criteria which will more closely simulate the crash environment than those called for in the current standard. The protective capability of several representative production steering columns is being assessed. The various designs are being assigned performance ratings, and minor improvements to enhance the steering assembly performance are being demonstrated (ref. 6).

Side Protection

In our work to improve side impact protection, we have concentrated on refining the full systems test procedures to more nearly reflect the accident environment. We have focused particular attention on the appropriate weight and force characteristics of the movable barrier impactor and on defining the impact speed and configuration. The status of test series to evaluate these parameters will be reported on in this conference (ref. 7).

Efforts have also continued on the development of complementary subsystem test procedures and devices. These approaches, if successful, could provide manufacturers with a tool to assess the side impact protection of their vehicles early in the design process.

The understanding of automobile side impact crash phenomena is being sought through several levels of simulation and test, including car crashes with dummies, reconstructed and staged car crashes of actual accidents, development of more realistic side impact dummies with deforming chests and shoulder girdles, sled tests with dummies and cadavers, sled tests with dummy components and padding elements, sled tests with door penetration simulation, and computer modeling of side impacts. The emphasis of these studies has been on the 50th-percentile male body size. We are now extending the computer simulation of side impact crashes to other body sizes, including a 6-year-old child, a 50th-percentile female, a 50th-percentile male, and a 95th-percentile male (ref. 8).

All current side impact efforts emphasizing the thorax will be completed and a summary report published by NHTSA during the coming year. New work involving subsystems tests and studies of other body regions is being performed jointly with the automotive industry as part of an MVMA/NHTSA task force. Results from the first phase of this joint effort will be published at the Society of Automotive Engineers meeting scheduled for Detroit in February 1983. Efforts to extend this cooperative program to non-U.S. manufacturers have been initiated, and we welcome discussions concerning ways to participate in a joint program.

Occupant Protection

Work is continuing on occupant protection, particularly for smaller cars. Over the past 2 years the following work has been initiated or completed.

A program has been initiated to develop and conduct component tests for the purpose of obtaining occupant and vehicle response on body region/vehicle interior impacts. A body form impactor capable of accelerating a wide range of body forms has been developed. The impactor is designed to be used within the vehicle and can be positioned to strike almost any surface within the vehicle. In addition, injury mitigation techniques are being investigated for the most severe problem areas.

A preprocessing program has been developed that substantially eases the burden of preparing the input data deck for the crash victim simulator (CVS) program. A postprocessing program has also been integrated into a complete CVS processing system. This program allows interactive selection of input data library elements to construct the CVS data deck and interactive selection of output variables to be displayed and plotted after each run is made (ref. 8).

The Agency for some time has been studying methods to improve the comfort and convenience of belt systems and thus encourage higher usage rates. A "comfort zone" has been proposed which would define acceptable belt "fit" for the 5th-, 50th-, and 95th-percentile occupants in the preferred driver seating positions. Since the angle and location of the shoulder belt on the occupant torso strongly influences the head and chest responses and the occupant kinematics during the crash event, the belt fit defined by the "comfort" zone should not degrade the crash performance of the belt system. A study is in progress to determine the relationship between shoulder belt fit and crash performance of the restraint system.

NHTSA has performed tests under the new car assessment program to determine the crashworthiness of passenger cars in 35-mph barrier tests. In some cases the vehicles possess the protective capability called for in FMVSS 208, and in some cases they do not. A program is under way to identify areas of the seat belt assembly and/or steering column and occupant compartment de-

sign which could be improved to provide 35-mph protection. Minor modifications of several vehicles have been made and 35-mph protection has been demonstrated (ref. 9).

Computer mathematical models have been developed which model the complex interactions and allow the study of many parameters affecting air bag deployment and restraint dynamics. These models have been used to predict the performance of air bag restraint systems in lightweight small cars with a subsequent dramatic reduction in the costs of system integration.

A series of tests using a 50th-percentile dummy and a simulated crash environment are being conducted to evaluate different types of windshield materials. The objective of the study is to determine impact resistance, penetration resistance, and laceration effects of laminated and plastic-coated windshields.

Crash Avoidance

The crash avoidance area has been receiving increased attention at NHTSA. Recent programs have emphasized improving mirror systems, rear-lighting systems, driver operated controls, headlighting, brake systems, vehicle stability, and generally addressing the accident avoidance characteristics associated with the new generation of vehicles which are generally smaller, lighter, have different dynamics, different geometries, etc., from passenger cars of a decade ago.

Our work on rear-lighting systems has shown that passenger car rear-end collisions can be reduced more than 50 percent by installing a single, high-mounted brake light. These lights provide the extra cues needed by following car drivers to detect the deceleration and position of the car ahead. Ongoing research is examining approaches to reduce truck rear-end collisions. This program is identifying means to increase heavy truck conspicuity using both reflectorization and signal lights that could be fleet tested to determine their real-world effect on accidents.

Past NHTSA research has shown that mirror system design can be improved to help drivers obtain needed information on the position and speed of vehicles approaching from the rear. One vehicle class that could greatly benefit from upgraded mirror systems is vans. In a current NHTSA study, a fleet test is being conducted to measure the real-world accident reduction benefits of mirror system improvements for vans.

NHTSA's headlight research is directed towards improving the light distribution pattern of low beams. A beam pattern has been identified which appears to have the potential for increasing visibility distance without significantly increasing the glare to oncoming drivers. During the next phase of this study, this proposed low beam will be evaluated in comparison with typical U.S. and European beam patterns.

In the brake system area, a program was undertaken to evaluate a prototype, electro-hydraulic motorcycle antilock brake system. Two other motorcycle projects involved the development of a new test procedure for FMVSS No. 122, *Motorcycle Brake Systems*. One focused on the refinement of general test equipment; the other is developing a new wet brake fade and recovery procedure.

Two programs relating to passenger car stability were completed. One involved the analysis of the effects of mixing various tire types (radial, bias-belted, and bias), sizes, and makes, and produced a system to rate tire lateral performance. The other project involved scale model wind tunnel tests to analyze the effects of cross winds on car-trailer combinations. Future research will investigate the differences in stability and braking characteristics of the new generation of small vehicles vis-a-vis the older full-size vehicles. Problem areas that will receive particular attention are the rollover propensity of small cars and their lateral spin-out characteristics under extreme braking conditions.

In the tire area we have begun a comprehensive effort directed toward improving the quality and consistency of the Uniform Tire Quality Grading treadwear test results. Refinements will be made in the basic test protocol, data acquisition methods, and vehicle maintenance that will significantly reduce the treadwear grade variability being experienced under current test procedures.

In the heavy truck program area, NHTSA is conducting a parametric analysis of the factors affecting heavy truck stability, which will be concluded in late 1982.

Work has begun on the development of an analytic framework for crash avoidance research that will be used to help define future research priorities and projects. The framework is patterned after one that was successfully applied in the Agency's Crashworthiness Program to establish program priorities by first estimating (for the country as a whole) the amount of harm (injury and death) associated with various vehicle components and crash conditions and then the potential for preventing that harm. In the crash avoidance area, estimates of accident loss will be derived for the leading crash problem types and the potential for preventing that loss by means of vehicle system improvements will be evaluated within the framework. The framework consists of three main elements: 1) crash data and system performance data analysis, 2) computer simulation, and 3) man-in-the-loop research.

Heavy Duty Vehicle Safety

The goal of the heavy duty vehicle safety program is to improve the accident avoidance capabilities and crashworthiness of vehicles with gross vehicle weight ratings

in excess of 10,000 pounds through improvements in vehicle performance and driver/vehicle interaction.

Truck and bus safety on the highway is a matter of increasing concern as the proportion of accidents and fatalities involving such vehicles continues to climb to the point where they could soon account for almost 20 percent of all highway fatalities. This is in light of the fact that all heavy trucks represent only 4.0 percent of all registered vehicles in the United States.

Research in the area of occupant protection focuses on three areas: seat belts to keep occupants in their seats during crashes, improved structural integrity of the cab to provide the occupant a survival space, and means to minimize occupant contact with cab interior appurtenances, especially the steering wheel.

Crash avoidance research concentrates mainly on improving the dynamic performance of heavy vehicles.

A core level brake research program continues to develop the necessary technical basis for improving the safety performance of both air- and hydraulically braked vehicles, i.e., improved stopping performance without compromising directional stability. The primary focus at present is directed at compatibility of braking systems used on vehicle combinations and ways to improve the adjustment of air brakes.

The existing heavy vehicle dynamics models will continue to be exercised to test the sensitivity of component/vehicle performance characteristics on overall vehicle safety. An attempt will be made to identify the probable "response curve" for individual components and to define the bounds and range of safe vehicle performance. In addition, the models will be utilized to develop prospective views of the likely changes in heavy truck safety performance which might result from new truck size and weight limits.

The heavy truck industry study initially is attempting to characterize the truck and trailer manufacturing industry and users of heavy vehicles, in particular, how this industry responds to change and how changes in vehicles and operating procedures come about. The next phase of this study will attempt to identify maintenance and operational procedures which improve truck safety.

Current research is nearing completion in the following areas:

- Evaluation of truck splash and spray suppression devices for improving the visibility for all vehicles traveling on wet roadways.
- Assessment of vehicle deceleration technique, mobile traction dynamometer, and in-door flat roadway tests to produce repeatable truck tire traction measurements.
- Evaluation of the performance characteristics and in-service costs of retarders for heavy vehicles. Work ongoing to quantify the controllability characteristics of retarder-equipped vehicles on snow and in other slippery road conditions and to develop a driver's manual to educate drivers how to extract the maximum safety benefits from retarders.
- Development of baseline truck driver anthropometric and seating preference data in cooperative effort with industry and labor.

Driver and Pedestrian Safety

Alcohol Safety

The goal of the alcohol safety program is to develop procedures/countermeasures that effectively reduce alcohol-impaired driving and related accidents. The alcohol/highway safety problem is of major importance. Each year approximately 60 percent of the fatal crashes involve a driver who has been drinking, and between 45 and 55 percent of such crashes involve a driver with a blood alcohol concentration above the legal limit (0.10 percent w/v).

Alcohol safety is focused on the following four areas:

- General Deterrence—Development of combined enforcement, public information, adjudication, licensing programs designed to increase public perception of DWI detection risk.
- Specific Deterrence—Development of programs directed at the identified/convicted drunk driver and designed to prevent future DWI.
- Prevention—Development of education, public information, and local community training programs designed to instill responsible attitudes towards drinking and driving and promote cooperative action for avoiding DWI.
- Intervention—Development of programs designed to identify techniques that will enable and motivate intermediaries, or third parties (e.g., bartenders, hosts/hostesses, drinking companions) to take action in a drinking situation that will deter potential DWI incidents.

Safety Belt Usage

Work in the safety belt usage area is directed to develop and evaluate effective approaches and materials to increase acceptance and usage of safety belts and child safety seats. Some of this research is aimed to improve the acceptability of belts in terms of comfort and convenience. In addition, levels of safety belt usage in traffic are being surveyed nationally—and, in special cases, locally—on a continuing basis as part of evaluative efforts of the Agency's overall protective system usage program.

The need for major programs to encourage safety restraint usage is obvious if present usage rates are considered. Safety belt usage nationally has been averaging about 11 percent for drivers and about 7 percent for adult passengers. Usage for younger passengers is around 5 percent

with no more than 15 percent of small children (ages 1 to 4) and 30 percent of infants properly protected in child safety seats.

NHTSA initiated a major program late in 1981 to encourage greater usage of protective systems in automobiles through public media efforts and, more importantly, through the support of a number of potentially influential networks in the private sector.

Research to support these programs has been designed to develop and assess the approaches and materials that are most cost effective in motivating members of these many networks to promote the use of safety belts and child safety seats.

REGULATORY REFORM

Many of the U.S. Federal Motor Vehicle Safety Standards date back to the 1960's or before. There have been many technological improvements in motor vehicles since that time, and our understanding of how highway losses occur has improved substantially. Other standards were promulgated more recently, but with less than optimal solutions to the problems they were addressing. Finally, changing conditions and technologies have made some Federal requirements inappropriate today.

The motor vehicle and equipment industries are more sophisticated about safety issues today than at the time of the passage of the National Traffic and Motor Vehicle Safety Act in 1966, and many requirements of Federal regulation have simply been adopted as standard designed practice in the industry. Furthermore, the industry is developing and adopting new safety designs independent of Federal requirements.

Some reforms of our motor vehicle standards were stimulated by petitions from the industry. Where recommended practices of private standards organizations have been referenced in Federal standards, the voluntary standards have often been updated without similar change in the regulation. We are, therefore, where appropriate, updating these references.

The major specific actions toward regulatory reform that we have taken thus far include:

- Rescission of the automatic crash protection requirements of FMVSS 208.
- Rescission of the forward visibility requirements of FMVSS 128.
- Rescission of the speedometer and odometer requirements of FMVSS 127.
- Reduction in the requirements of the bumper standard from 5 mph, no damage, to 2½ mph allowing damage to the bumper system itself.

The first and most controversial of these actions, recission of the automatic crash protection requirements, was a particularly difficult one, because motor vehicle fatalities and serious injuries continue to be a major public health problem, and enhanced safety technology is of high priority in this Administration. However, after consideration of all the facts and the year-long extensive public debate, the Administrator became convinced that, if implemented, the automatic restraint requirements would not have significantly improved public safety.

On the other hand, automatic belts for those who want them are and have been available on selected models for years. At the same time, the manual belts that are presently in virtually every car and truck could begin to save thousands of lives today, if people would only use them. Unfortunately, safety belt use in the United States has dropped to the level that only about one driver in ten wears a safety belt. In light of this statistic, we have initiated a major national effort to encourage increased voluntary use of safety belts. President Reagan's recent announcement of this effort emphasizes the strength of our commitment. This program can, in the near future, increase the safety of all motorists, not just that of new car purchasers. We are encouraged by the substantial support this program has received so far and by its potential to improve safety.

Other applications of new safety-related technology which the Agency has encouraged through testing and research programs and through revision of existing standards include the use of halogen headlamps and the study of effectiveness of center, high-mounted stoplamps.

We believe that such activity is in keeping with our responsibility to promote technological approaches to motor vehicle safety in addition to our other activities. The combination of these efforts to encourage new technologies while stimulating use of safety belts should provide substantial safety benefits to the public now and in the future.

INTERNATIONAL HARMONIZATION

The present Administration is committed to fostering international harmonization of motor vehicle safety standards. This policy is, of course, tempered by legal and procedural requirements that the Agency must follow, and by concern that motor vehicle safety in the United States not be compromised.

Harmonization refers to the degree to which the standards of different countries are similar. This is judged by the practical extent to which manufacturers can build the same or similar vehicles in conformance with Government requirements for different national markets. There are at least four levels at which motor vehicle safety standards can be harmonized:

1. The standards of different countries can be made compatible to ensure that cars can be built in compliance with all of them without altering design or construction.
2. The same test procedures can be used by various nations to reduce the cost of testing for compliance.

3. In addition to having the same test procedures, the levels of performance and specifications required in the standards of various countries can be made compatible or the same.
4. The means of determining compliance, whether by homologation, manufacturer self-certification, or other means, could be made the same in different countries.

The United States is currently in a good position to consider harmonization of its standards. We are presently reconsidering a number of requirements in our regulatory reform program. Thus, we have the opportunity to give harmonization a high priority as a part of this reform. Furthermore, the Agency is considering a number of new standards in areas such as side impact protection, pedestrian protection, truck rear underride protection, center high-mounted stoplamps, and headlighting. As with the vehicle identification number standard, serious consideration will be given to development of harmonized requirements for these new standards. Currently, we have active harmonization efforts on the hydraulic brake standard, the lighting standard, and the control location and identification standard.

While the crash avoidance analytic framework is obviously less precise than that used for crashworthiness, it does provide a reasonable basis for establishing project priorities.

REFERENCES

1. Data for 1977-1980 are from *Highway Statistics*, published annually by the Federal Highway Administration (FHWA). 1981 estimates of licensed drivers and vehicle registrations are from *Selected Highway Statistics and Charts 1980*, FHWA. The 1981 estimate of total vehicle kilometers traveled is from an unpublished communication from FHWA staff to NHTSA staff.
2. *Fatal Accident Reporting System* (FARS) published annually by the National Highway Traffic Safety Administration (NHTSA). FARS 1981 is in press.
3. *Report on Traffic Accidents and Injuries for 1979-1980*, The National Accident Sampling System (NASS), NHTSA, February 1982.
4. R. M. Morgan, J. H. Marcus, R. H. Eppinger, "Correlation of Side Impact Dummy/Cadaver Tests," Proceedings of the 25th Stapp Car Crash Conference, SAE, Warrendale, PA. 811008.
5. C. Ragland, *NHTSA Frontal Structure Research, An Overview*, NHTSA Technical Paper Seminar No. 1, 9th ESV Conference, November 1982.
6. J. Morris, *NHTSA Research on Occupant Protection from Impact with the Steering Assembly*, NHTSA Technical Paper, Results of ESV/RSV Development, 9th ESV Conference, November 1982.
7. W. Hollowell, *Status of NHTSA Side Impact Research*, NHTSA Technical Paper, Seminar No. 3, 9th ESV Conference, November 1982.
8. *Development of a User Convenience Package for the CAL-3D CVS Program*, Volume I and II, DOT-HS-806-122.
9. J. Hackney, *The New Car Assessment Program—Status and Effect*, NHTSA Technical Paper, Seminar No. 5, 9th ESV Conference, November 1982.

European Experimental Vehicles Committee Status Report

PROF. DR. BERND FRIEDEL
Chairman, European Experimental Vehicles Committee

After we came together in Europe last time, I am much pleased with the opportunity to be able to present to you the Status Report of the European Experimental Vehicles Committee in Japan this time. The fact that government representatives and engineers from many countries meet in Kyoto in the attempt to search for solutions together cannot be taken for granted, in particular not in these times of uncertain economic developments.

To exchange the knowledge acquired and discuss the progress made in the intervening two years in the area of improving the safety and economy of our motor vehicles will once again be a useful experience for all of us.

In the time that passed since the last ESV Conference took place, we noticed that the U.S. Government began to reconsider the terms of reference or some of the objectives of the development of future cars. Let me recall in this connection the "bumper standard" or automatic restraint systems. It is quite certain that the ideas developed in the U.S.A. will affect automotive engineering and car manufacturing in Japan and Europe as well. Therefore, we should take the opportunity of this Conference to carefully consider and examine old and new standards, and particularly also the effects to be expected thereof. The considerations in Europe with respect to occupant protection are based on the compulsory use of the seat belt—an issue on which general agreement has been reached. We will have to take care that, under the pressure of other urgent problems, the safety of our cars does not lose in importance in the public mind, in the consciousness of automotive engineers or administration.

There is no question that balancing the diverse interests on a national level is quite a difficult task; and the difficulties to be overcome in the harmonization of standards and objectives of several nations are greater still. As you know, the European Economic Commission (EEC) in Brussels and the Economic Commission for Europe (ECE) in Geneva, among other things, are dealing with these very problems. But it is up to all of us, above all in the interest of free trade relations all over the world, to see to it that these efforts are successful. In our opinion, the right course of proceeding in this matter would be considering the problems from the interpretation of research findings to the planning of large projects as tasks that should be dealt with by cooperative effort.

As you all know, the Biomechanics Program drawn up by the EEC was done so with the advice and assistance of the EEVC. The program took four years and among the most interesting activities let me mention the development and the evaluation of several test dummies for side impacts. The program is nearly finished and the work done is today under examination in order to assess the reliability and the applicability. The results of the whole program will be available next spring, but the results of some individual projects will be presented in the course of this Conference, as was done on the occasion of preceding ESV Conferences. Comprehensive biomechanical investigations, carried out within the frame of a Joint Biomechanical Research Project with the collaboration of the car industry, have additionally been successfully completed in Europe. Time has come to take stock; the new biomechanical knowledge acquired must be screened and compared. Tasks for the future will have to be defined to facilitate adjusting technical developments to the needs of the human being.

The proportion of small cars is on the increase in highly motorized countries; already at the last ESV Conference, the Americans pointed to the difficulties possibly arising in this connection. This question once again exemplifies the fact that it is the human being who provides the standard to go by in measuring the effects of technical progress and economic restraints; all efforts will have to be made to guarantee adequate occupant protection. Let me, at this point, mention the final reports presented by the following two working groups:

—Working Group 6: "Structures" had reviewed the available accident data in Europe concerning side impacts involving passenger cars. Furthermore a description of existing deformable barriers and a comparison is given. Based on these two kinds of information the working group proposes a first side impact standard test for possible future regulations. Within the proposal a mobile barrier with a deformable front face and a procedure based on biomechanical criteria are described in detail. This barrier is to some extent a synthesis of the elements defined by Italy, CCMC, United Kingdom, France and U.S.A. This important new work of EEVC was done under the chairmanship of Mr. G. Pocci from Italy and it is based on the contribution of Sweden, France, Italy, United Kingdom, The Netherlands and Federal Republic of Germany. The report is available during this Conference and the work will be presented in detail in seminar No. 3.

—After the last ESV Conference another working group, No. 7, under the chairmanship of Mr. J. Mo-

reau de Saint-Martin from France was established. This group was devoted to pedestrian injury accidents. As it was done in the just mentioned working group the available accident data concerning injuries to pedestrians of different ages involved in road accidents in Europe were reviewed. The current knowledge in injury mechanisms and human tolerances, appropriate means of improvement of vehicle design as well as test and assessment methods were considered and discussed. This group set up a list of priorities for future action and of recommendations for further research. All this important work was achieved by contribution of different European governments and advisers such as from Sweden, France, Federal Republic of Germany, United Kingdom and The Netherlands. The results will be also presented during this Conference in detail in seminar No. 4. The report is available.

The measures to improve pedestrian safety as well as side impact protection must be considered together because of the combined effects to car structure. The work of this compatibility problem must be enlarged in order to include the safety aspects of all road users; this is also true for two wheelers.

A new EEVC working group was therefore established for a more detailed study of the questions arising in accidents of bicycles and lower powered two wheels. About this new group and other concrete future activities of EEVC it will be reported at the panel discussion of this Conference in more detail.

Let me conclude my remarks by expressing the hope that, as was already experienced at past conferences, our joint efforts eventually will bring us all closer to being able to solve the questions needing to be settled. We welcome the willingness of the NHTSA's new administration for improving the cooperation with Europe and we offer our good will to take our part of this important task. I am sure that all of us will do our best at this Conference to ensure a successful outcome. Thank you.

Federal Republic of Germany Status Report

PROF. DR. HEINRICH PRAXENTHALER
President, Federal Highway Research Institute

I.

The improvement of the safety of motor vehicles, the conservation of energy and raw materials, and the alleviation of nuisances to the environment are now as ever the decisive demands of social and economic policy to be made to motor vehicles in our country. Already at the last ESV Conference we had made it clear that we see a real chance of meeting these demands, and although there are conflicts of objectives that they seem to be better solvable than had been originally assumed.

If the number of people killed on our roads has strongly decreased, if markedly less fuel is being consumed, and if progress is also being made in the field of environment protection, changes and further developments in automobile construction have undeniably contributed to all these improvements. Not all possibilities seem to be exhausted yet, however, that can be realized at reasonable expense. It is necessary to preserve this positive trend and to promote it in close co-operation with the motor vehicle industry. We see the benefit of and the justification for this Conference in the chance of being able, in our endeavours for an achievement of these objectives, to hold exchanges of opinion and experience with other countries.

II.

The accident situation in the Federal Republic of Germany during the period 1970 to 1981 is characterized by

—an increase in the total number of accidents by about 20%,
—a slight decrease in the number of accidents with personal injury by about 4%,
—a strong decrease in the number of fatal accidents by about 40%.

This development obtains particular weight in view of the total mileage which increased during the same period by about 60%.

Likewise clearly declining—namely by about 25%—is the number of people who are being killed as occupants of passenger cars. Related to 1,000 million vehicle-kilometres, it diminished from 45 to less than 20 since 1970. We are convinced that the safety belt has a very large share in this development, and we attach now as before great importance to it. Unfortunately, the use of the safety belt has since 1978 been stagnant at a level of about 80% on motorways, of somewhat over 65% on roads outside built-up areas and of just under 50% within built-up areas. Propaganda for the use of the safety belt has once again been greatly intensified this year.

It has not been decided yet whether and to what extent those who ignore the obligation in force to wear safety belts should be penalized in the future.

Soon it may also be made compulsory to use seat belts on the rear seats.

No special requirements are at present in force in the Federal Republic of Germany concerning the admission of restraint systems for the protection of children. It is intended, however, to put the relevant ECE Regulation into effect soon.

If drivers of low-powered motorcycles will also have to wear crash helmets is to be decided in the course of this year still. Their protective effect is indisputable, the doubts about the introduction of mandatory wearing are related with aspects of acceptance and enforcement.

Important modifications to the Road Traffic Regulations of the Federal Republic of Germany have taken place since the last ESV Conference. They provide above all increased protection for the weaker road users. So drivers must reduce their speed and must be ready to brake in places where children, old people, and people in need of help are or might be. They are required to drive with utter care, and they can normally no longer plead that they observed the speed limit.

It was furthermore established that children under eight must use the pavement where there is one when cycling, unless there is a cycle track.

For residential neighbourhoods which fulfill certain conditions the possibility was introduced in the Road Traffic Regulations of imposing traffic restraints in certain areas. There vehicles must drive at walking speed and pedestrians may use the street in its whole width.

III.

The project of a "research passenger car," which was promoted by the Federal Government, was already reported upon at the last ESV Conference. A short time ago, this project which extended over a period of four years was concluded. The objective of the project was to find trend-setting technical solutions which fulfill the conflicting demands for the conservation of energy and resources, the improvement of safety and environmental protection, while at the same time taking account of the utility and the economy of the motor car. AUDI-NSU, DAIMLER-BENZ, VOLKSWAGEN, and a working group of several universities developed four prototypes. The project led to very different and technically interesting solutions, some of which will certainly be made use of in possible future series production. Impulses were above all given for aerodynamic design, for engine-gearbox units which ensure low fuel consumption and for their electronic control, for material substitution, and for enhancing the safety of the occupants and among "traffic partners" generally. At the same time a reduction of fuel consumption and a diminution of the nuisance to the environment could be achieved. Part of the results of the project will be reported on later at this Conference.

With effect from February 1, 1980, additional highmounted stop lights for passenger cars are permitted in the Federal Republic of Germany. In March, 1982, 4% of the vehicles were equipped with those lights. What effects the highmounted stop lights fitted inside the vehicle will have are being investigated by a study which relates chiefly on the following questions: Recognizability of different types of signal display, limits of the luminous intensity, the danger of getting used to the signal display and of overexposure to stimuli, impairment of the conditions of vision inside the vehicle, especially due to reflection, as well as any possible risk of injury. It is intended to observe accidents over a longer period of time, with the possible compensation of the positive effects by the risks due to smaller headways between vehicles being taken into consideration. The results of the study will presumably be made available during the first half of 1983.

IV.

In the field of accident research, activities have hitherto been undertaken by the Federal Government, motor vehicle industry, and motor vehicle insurers. One of the main fields of research is the further improvement of the protection of the occupants and especially also of the protection of the "outside traffic partners"—pedestrians and drivers of two-wheeled vehicles—on the basis of a detailed accident analysis. The essential thing here is to develop structures for the front and the sides of passenger cars where deformations will be optimized, especially also with regard to the "outside traffic partners." For this purpose crash tests are being made where representative types of collision are simulated.

In the research into the causes of accidents, the HUK-Verband* has concluded a series of studies during the years 1981 and 1982, among which is also an analysis of 1,500 collisions between lorries on the one hand and passenger cars, two-wheeled vehicles, and pedestrians on the other. From this analysis indications on the order of priority of safety measures concerning lorries were obtained; basic requirements to be met by a front guard of a lorry were demonstrated in crash tests.

The still largely unknown characteristic of single-vehicle accidents of passenger cars—this accident category accounts for about one third of all occupants of passenger cars killed—gave reason for a study by the HUK-Verband of 3,000 single-vehicle accidents. This study was to some extent promoted by the Federal Government. The most significant type of collision with regard to frequency and accident consequences has been the lateral collision with a tree in the area of the passenger compartment, in accordance with the pole test. In almost one third of single-

*) German motor vehicle insurers

vehicle accidents the passenger car overturned; in 17% of the investigated cases the main damage to the car was caused by this overturning.

A comparison of the studies carried out by the NHTSA and the HUK-Verband of injuries to the cervical vertebral column showed largely the same results with regard to the type of injury and above all the enormous decrease in the number of serious injuries due to the wearing of the safety belt. Generally, investigations by the HUK-Verband on the basis of new material on accidents have confirmed the high protective effect of the safety belt in the case of head-on collisions and overturnings, but likewise for the passenger not sitting on the side of the impact in the case of lateral collisions.

Accident research by the Government was concentrated since the last ESV Conference on the continuation of our current tasks. The investigations at the scene of the accident carried out in Berlin and Hannover since 1973 were continued; since 1980 accidents involving two-wheeled power-driven vehicles are increasingly being recorded. The investigation of the kinetics of impact as well as of the injury patterns resulted in the demand to extend the mandatory wearing of crash helmets to all power-driven two-wheeled vehicles. If the realization of this demand will be possible politically cannot yet be decided at present.

Research results furthermore suggest to oblige drivers of two-wheeled power-driven vehicles to switch on their dipped headlight by day.

To clarify biomechanical problems for the evaluation of the safety of passenger cars, seven institutions participated in a European joint biomechanical project, which was also financed from funds of the European Communities. Sixteen selected accidents were reconstructed in 87 dummy tests and 46 cadaver tests. A final report has already been submitted. Changed limit values have been proposed for a couple of protection criteria which are used in vehicle tests. The dummies, especially those for the lateral impact and for accidents with pedestrians, will have to be further developed.

For the further development of regulations also cost-benefit estimates for front and lateral installations on lorries were carried out, which are intended to prevent moped riders, cyclists, and pedestrians being run over. It appears that here the protection on the kerbside of the vehicle is the most important one.

Proposals for simplified test procedures have been developed for the dynamics of passenger cars with caravans.

Further investigations were made with regard to the problems of brake systems and relevant test procedures.

The driver-vehicle behaviour in critical situations had been the subject of a project group in 1979. We consider such research as necessary as ever. For cost reasons these projects had to be largely postponed, however.

Further research concerning information processing by the driver is at present being planned together with the motor vehicle industry. Here not least possibilities of how to utilize vocal information systems in the motor vehicle for road safety are of interest as well as, among other things, also the question in how far the already heavily employed channels of visual and auditive perception can possibly be relieved by means of haptic information.

The wide range of activities of the motor vehicle industry in our country will find expression at this Conference in a series of contributions.

V.

The intended objectives of the Federal Government for the abatement of traffic noise were already mentioned at the last ESV Conference; they are also valid for the future. The Federal Government endeavours to take administrative measures which would make it possible for low-noise vehicles to increase their share in road traffic, notwithstanding their higher purchase price. Here we may, for example, think of objects of demonstration in health resorts which only low-noise motor vehicles are allowed to enter.

In 1981, several manufacturers of lorries presented fully encapsulated low-noise lorries, which to some extent were promoted by the Federal Government and were developed more or less close to series production. A fleet test is being made at present with 50 prototypes with the Federal Postal Administration. With the prototypes of the project "Forschungs-PKW" sponsored by the Federal Government, two technical possibilities of solution could be shown, which make it possible to achieve noise emissions of less than 73 dB(A).

The attitude of the Federal Government has not changed either as regards the limit values for the emission of harmful substances by motor vehicles. It considers lower limit values necessary. The repeated reduction of limit values has clearly diminished the emission per vehicle; the situation concerning emissions, however, presents a different picture, among other things also because the vehicle population has increased at the same time. Although with CO concentrations a markedly diminishing tendency can be recognized, the level is still about that of 1970. With hydrocarbons and especially with nitrogen oxides on the other hand the tendency is continuing to rise. Since lead-free fuel is not available in Europe, a further marked reduction of harmful substances in the exhaust gas of motor vehicles is much more difficult technically than in the United States and Japan. Thus a focal point of research is also in the future development and operational testing of catalysts which retain their effectiveness also when using lead-containing petrol.

In view of the protracted harmonization processes in the further development of international provisions the Federal Government endeavours to gradually achieve—through voluntary agreements with the German motor vehicle industry and motor vehicle importers—improve-

ments in the situation concerning emissions. In July, 1981, the German motor vehicle industry promised the Federal Government to introduce the next phase of the reduction of limit values for harmful substances step by step already before the relevant ECE Regulation enters into force officially.

VI.

As far as the reduction of fuel consumption is concerned, the motor vehicle industry has declared that they started out from the assumption that the reduction of the consumption by 10-12% as compared with 1978 envisaged for 1985 can in all probability be realized earlier. They declared moreover that they will make efforts to try to achieve a reduction of the consumption beyond what they promised.

The average fuel consumption of the passenger cars supplied by German car manufacturers and sold in the Federal Republic decreased in 1981 by about 6% as compared with 1980. Compared with 1978, the decrease was about 11%. The figures for driving in town as well as for driving at a constant speed of 90 km/h and of 120 km/h were weighted with one third each, in accordance with the measuring technique customary in Europe. The average figures for 1981 were as follows:

—driving in town	10,4 litres/100 km
—driving at a constant speed of 90 km/h	6,6 litres/100 km
—driving at a constant speed of 120 km/h	8,9 litres/100 km

The yearly change in the national fleet of passenger and estate cars was + 5,7%, + 2,4%, and + 1,6% for the years 1979, 1980, and 1981 respectively, while the corresponding figures for fuel consumption during these years were + 1,3%, + 1,8%, and − 6,1% respectively. This divergence gives our country a prominent place in an international comparison, without legal provisions having been introduced. The reason for this is above all that vehicles have become more economic, that they have to some extent been equipped with devices which make it easier for the motorist to drive more economically, but also the fact that motorists have adopted a more sensible driving style. According to our information, the mileage has decreased in 1981, too, namely by about 3%.

The German Shell AG in their latest forecast start out from the assumption that in private transport the amount of fuel consumption of 1980 will not be attained any more this century.

VII.

Today motor vehicles are sold worldwide by many manufacturers. Therefore, we demand again also within the framework of this Conference to try with intensified efforts to achieve a harmonization of provisions. Co-operation in research and exchange of the latest results are steps on the path towards this harmonization, and this Conference is a new chance to achieve it. As far as the intervals between these worldwide exchanges are concerned, it would in our view be best to convene the next ESV Conference not before 1985 or 1986, for research in our opinion requires and is more and more performed over longer periods of time. Another point is that questions of the further development of the motor vehicle are also dealt with at various other conferences.

With our proposal we want to enhance the efficiency of the ESV Conferences and to counteract a lack of substance due to too short intervals between the conferences. We do by no means question the previous endeavours in this field; we think that we can prove this by our enthusiasm during the past years, which is based on the conviction that the ESV Conferences have to a higher degree influenced automobile technology and increased road safety for the benefit of society than is noticeable from outside.

United Kingdom Status Report

J. W. FURNESS
Chief Mechanical Engineer
Department of Transport
United Kingdom

It is an honour for me to present the United Kingdom Status Report at this, the Ninth ESV Conference. Over the years we have witnessed remarkable progress in the development of safer vehicles, and these ESV Conferences have been a major instrument for the achievement of this progress.

In the UK we consider that the improvement in vehicle safety has been a significant factor in our ability to reduce road casualties, or at least hold them steady for the last 20 years, in spite of a rapidly rising vehicle population. Our most recent figures show that there were 5,846 deaths on public roads in Great Britain in 1981—three percent fewer than in 1980, whilst the number of serious injuries at 78,000 was one percent less than in 1980. However, this fall in casualties occurred mainly in the first half of 1981. Casualties in the second half of the year were higher than in the second half of 1980, suggesting that the downward trend that began near the end of 1978 has come to an end.

Whilst in terms of road deaths, both per 100,000 population or per 100 million car kilometres, our roads are amongst the safest in the world, anything that signals an increase in the toll of death and serious injury must concern us. We may be witnessing something of a watershed as the UK's programme of major new road building slows down and vehicle manufacturers come under pressure to reduce vehicle weight in the interests of fuel economy.

This situation is spurring us on to renew efforts in many road safety areas, some of which will be reported on during this conference. I will not 'steal the thunder' from the presenters of the UK papers, but some of the work deserves special mention.

Frontal Crash Protection

The trend towards more and more lightweight structures is involving both the UK manufacturers and the TRRL in seeking out what may be possible in using advanced materials and changed seat belt performance. We do not believe current vehicle safety legislation will be adequate to encourage further development in this field and sadly, it is anticipated that both current requirements and the proposed 'Integrated Test' will only allow vehicle safety to backslide towards the legal minima in force. Thus this is a subject that will receive our close attention in the coming years.

Pedestrian Protection

The relative safety of UK roads only helps to contrast the problem of pedestrian casualties. In this area we look forward to better definition of what can be considered as good vehicle design, and a joint UK government/industry study is in hand. It is being suggested that mathematical modelling of the pedestrian impact is worthwhile and in fact could be considered for part of the verification process required by any legislation that may be evolved.

Biomechanics and Dummy Development

Although there is no UK contribution to the conference on this subject, we have been active in cooperation with our European colleagues in this important area. There is a feeling in the UK that the current lack of suitable dummies is a serious drawback to the use of 'whole vehicle' (integrated) systems testing for legislative purposes. It is hoped that the present EEC sponsored programme will be successfully completed and quickly carried through to the introduction of an internationally acceptable side impact dummy with associated tolerance criteria.

Side Impact Protection

The pattern of accidents in the UK may not show that great emphasis should be placed on the problem of side impact protection, but we are acutely aware of the continuing lack of any form of minimum standard of protection applied legally. As far back as the 5th ESV Conference in 1974 cars such as the BL Marina Safety Research Vehicle demonstrated the techniques to provide protection and our continuing work shows how important are interior padding and strength and shape of the vehicle structure. As a matter of urgency the UK is considering ways in which protection provision can be measured in a way suitable for incorporation into domestic requirements for side impact performance.

Accident Data

The UK programme of crash injury accident studies is being reorganised during 1982 with two similar studies being carried out at the Universities of Birmingham and Loughborough with a strict methodology to get representative samples of accidents in which those not injured as well as the injured are recorded for the purpose of estimating the probabilities of various injuries as functions of impact severity. Separate studies are being arranged to investigate head injuries with crash helmets, and articulated vehicle underrun bumper and sideguard performance among other problems.

Auto Safety Ratings

As I have mentioned earlier, there is a risk that current legislative requirements for crash protection may not be adequate to ensure a continuing improvement in car crashworthiness. The concept of introducing some sort of rating scheme to encourage competition amongst manufacturers is attractive, and a TRRL paper will be presented at this Conference outlining how this might be achieved.

Accident Avoidance

Primary safety—the ability to avoid accidents—has always been considered as of utmost importance in the UK. There can be no better way of protecting road users than to avoid accidents in the first place. However, human error is continually with us, and there is a possibility that road users find a particular level of risk acceptable and thus absorb much of the benefit of enhanced primary safety by driving faster.

Other Areas of Work

It has become the practice of the last two ESV Conferences to consider the safety of vehicles other than motor cars, and I should like to deal, in turn, with both motorcycle safety and heavy commercial vehicle safety, and then cover some other topics of interest to this Conference.

Motor Cycle Safety

The present level of two-wheeled motor vehicle casualties is a matter of serious concern worldwide. Two-wheeled motor vehicles in the UK accounted for only 2.6% of total vehicles mileage, but 21% of road user casualties in 1981. The UK continues to work towards improving safety standards, both to prevent accidents and to minimise injuries to riders once they do occur. In the short term, we are looking for improvements in braking—particularly in the wet—and conspicuity. In another area, the British Standard for safety helmets continues to be up-dated as our knowledge of the subject increases. Consideration is also being given to the development of a British Standard for protective clothing. Longer term possibilities include the provision of some form of leg protection for riders in the event of accidents and the development of an effective and commercially viable anti-lock braking system.

Heavy Commercial Vehicle Safety

The heavy commercial vehicle will always impose a greater environmental impact on the general public than perhaps pure statistical evidence may indicate. Of course safety performance is one key environmental factor. Thus we are investigating the basis for UK national requirements for underrun and sideguards for these vehicles. We are also continuing to encourage the fitment of anti-lock brakes by exempting vehicles thus fitted from the stability requirements that would usually mean the fitting of load sensing equipment. To date some 14,000 sets of equipment have been fitted to heavy goods vehicles in the UK, and this number is increasing rapidly. A recent study of the braking grip available from commercial vehicle tyres has shown that the locked wheel values are well below peak values at higher speeds on dry as well as wet surfaces, and serves to emphasise the desirability of anti-lock equipment on these types of vehicles.

Compulsory Seat Belt Wearing

I am pleased to report that, as from January 31, 1983, the wearing of seat belts by the front seat occupants of most cars and light commercial vehicles will be a legal requirement in the UK. This brings us in to line with most of the Continent of Europe, and I believe this to be one of the best measures in road safety legislation with the potential for so much good. It is certainly the case that the great majority of the safety research that is being reported at this Conference assumes that vehicle occupants are restrained, and without measures to ensure that in the real world these restraints are being used, then this work is neutralized.

UK Domestic Standard Making

Our fundamental belief in the efficiency of occupant restraint is reflected in the effort that has been made to plug gaps in the International regulatory scene with national standards. These cover such items as passive restraints (of the conventional, 3-point seat belt configuration), carry-cot restraints and booster cushions—devices that we consider particularly valuable in encouraging the proper restraint of children on the rear seat.

Rear Seat Belts

The UK does not at present require the mandatory fitment of seat belts at the rear seating positions of cars. Now that front seat belt wearing is becoming compulsory we intend to look very closely at the additional need for making provision for protection of those complying with the law who may nevertheless be put at risk by unrestrained passengers occupying the seats behind them.

Pedal Cycles

Improving the safety of pedal cycles is another area that requires our attention, and recent studies have led to better blocks for exposed brakes and indicated the need for more effective lighting and better conspicuity of the machine and its rider in various detailed respects.

In Conclusion

The UK is maintaining effort in all the areas that are concerned with road and vehicle safety with our priorities reflecting our view of where greatest progress can be made. We may be moving towards encouraging market demand for safer cars, but the "unprotected" road users, i.e., pedestrians, motorcyclists and pedal cyclists need special attention as do all those who might be affected by the presence of heavy goods vehicles and trailers.

Department of Transport
September 1982

Italian Government Status Report

DR. FRANCO R. ROSSI
Civil Motorization Ministry of Transportation

Expansion of the automotive sector in Italy has partly been affected by recession which to a greater or smaller extent has hit every part of the world. Increment of expansion in the past two years has barely exceeded 4% per annum. The number of estimated in-use vehicles with four or more wheels is 20 million but, accident rate has practically been constant in the past three years. This can be due to lower mileage and to better vehicle and driver behaviour. For example, fatality rate per 1,000 accidents, which was 33.7 in 1970, dropped to 29.7 in 1981, with a 12% reduction.

These results, however, do not lead the Italian Government to slow down efforts in road safety. These efforts are instead being extended to various other sectors such as driver control, traffic rules and their coding, motoring education and practice and vehicle inspection.

As regards vehicles, the Italian Administration has carried on efforts to acquire adequate equipment for technical inspections. In particular, a new motor vehicle "Centro Superiore Prove e Ricerche" (Advanced Testing and Research Centre) has been inaugurated in Rome and many Facilities with equipment for motor vehicle inspection have been opened to the motorists.

It is believed, in fact, that road accidents can be reduced by adequately combining resources and efforts in various directions.

In this connection I wish to point out that comprehensive investigations are being started to evaluate the effectiveness of the various actions, namely the cost/benefit ratio, and that the field of actions is being widened by addressing the problems of costs, pollution and fuel consumption along with that of safety.

In the ESV Status Report presented in Wolfsburg in 1980 we had already indicated that our efforts were directed to "studies on safety (the very basis of the ESV Programme), costs, pollution (emission and noise) and consumption, aimed at an intelligent compromise or, even better, a harmonic equilibrium."

Interaction of these often clashing factors already gave rise to a series of severe problems that have further been aggravated by the economic crisis (market, occupation, financing) exploded in the past three years and, unfortunately, not yet over.

With regard to each of these problems, Italy has carried on, indeed increased, its efforts.

An example of overall approach to the problems is represented by the FIAT-VSS (Experimental Subsystem Car), designed with a view to achieving such serviceability, use and mass production characteristics as to be adopted practically. The basic VSS concept is to separate structural function of mechanical component support and occupant protection from envelope and shape function.

With same external dimensions, the bodywork of the VSS prototype weighs over 20% less than a conventional sheet metal car.

The main characteristic of the VSS project, in addition to use of plastics and weight reduction, is the possibility of building the car with subsystems.

Its manufacturing concepts can be applied to any class of cars, preferably to small cars, where weight savings are more important and manufacturing simplicity is more widely accepted.

With regard to active safety—namely safety which aims to avoiding accidents—European and particularly Italian manufacturers have long since taken into account the physical configuration of our country and consequent road network structure, past and present. They were compelled to give much weight to the so-called road holding of the vehicle, and have hence advanced regulations that, in some cases, were a simple record of performances already obtained.

Consequently, in the field of active safety, regulation has not had either appreciable effects on weights and, therefore, on consumption, or considerable effects on price increases.

However, research on active safety in Italy continues to be greatly developed along two major lines:

—Basic theoretical research with development of mathematical models which simulate behaviour of car and of its components.
—Experimental research to correlate vehicle response (transient and steady state) to its geometrical, inertial and dynamic characteristics and to continuously improve the mathematical models.

The main research subjects are:

a) Study of driver-car system

The target of such activity is to find any correlation between subjective opinion of the driver and car response parameters.

Complexity of this subject has not yet permitted a clear definition of dynamic characteristics of a safe car.

b) Research on car handling and directional stability

This activity is aimed at the establishment of new open-loop test technologies capable of characterizing car performance.

The results obtained, at times found to be contradictory, evidence the need for more exhaustive studies. These latest presently concern in particular the research on car dynamics under particular adhesion conditions. This research area is very important from the viewpoint of active safety. Steady-state and transient behaviour are studied under precarious adhesion conditions (wet road surface, aquaplaning, etc.) or under external perturbing factors (wind gusts, road surface irregularities, sudden loss of tyre adhesion, etc.). This approach is followed with particular care at Alfa Romeo and the results obtained are being shown by a film in Session VI.

All such aspects were evaluated keeping into particular account the basic requisite of limiting, or better, reducing weights.

Along with the search for new materials and structures, utmost attention and interest were devoted to the achievement of improved occupant protection in accident events through the definition of appropriate configurations for passenger compartment interiors and restraint systems, tailored to the individual cars, thus providing better performance of the car/restraint system combinations.

Thanks to the development work by Italian Manufacturers, it was possible to pinpoint four basic activity approaches for implementation of passive safety, represented by:

1) Analysis of real accidents and statistical evaluation of the more typical accidents.
2) Computer simulation of the behaviour of vehicle, occupants and, possibly, struck pedestrians, through mathematical models, for the purpose of acquiring a preliminary series of information and guidelines, fundamental for the definition of design solutions.
3) Car subsystem experimentation by static (presses, etc.) or dynamic (pendulums and deceleration sleds) tests which are useful for providing support data for the definition of the magnitudes in mathematical simulations as well as of the design as a whole.
4) Final assessment by collision tests using complete vehicles for an overall verification of design concepts.

A uniform synthesis of all the discussion topics (passive safety, active safety, pollution abatement, fuel economy, comfort improvement) will allow the definition of "Synthesis" cars as forebears of future generations of automobiles.

A positive example of Alfa Romeo's efforts along these lines is represented by the SVAR car on display at this Conference.

As regards passive safety, it should be remembered that much has already been done in the fields of both research and proposed rulings. In fact, a crop of regulations has resulted which had important effects on vehicle structure, especially with regard to body weights and costs, these being also serious problems for fuel economy.

In Italy, work on passive safety has, and is, continued with great commitment.

The recently tackled passive safety aspects are oriented and focused by bearing in mind the latest trends emerging from the activities and research work conducted by the specialists in the trade.

Particular attention was devoted to the substantial evolution exhibited, during the latest years, by the various ESVs which have gradually transformed into prototypes synthesizing the many aspects and requirements now irrevocably demanded of future cars; in particular, cars must offer low fuel consumption rates, low emission and noise pollution; and all this, to be suitably compromised and consistent with current occupant protection criteria.

As regards experimental investigations which always prelude to interesting results, progress was made with current cars in side collision studies, in cooperation with EEC and FIAT; being shown in Technical Session No. 3—Side Impact Protection are car/car and moving barrier/car collision test results, as well as evaluation methodology improvements and relevant validation of calculated-to-experimental results trade-offs.

Additionally, Italy has actively cooperated with EEVC (European Experimental Vehicle Committee) WG 6—

"Structures" on moving barrier test methodology, reports on which are given under Technical Session No. 3.

Significant contributions with regard to the more general and specific problems in passive safety are on record with the work by GRCS (Groupe Rapporteurs Comportement Structure) and WP 29 of UNO-ECE (Geneva) under the Chairmanship of the Representative of the Italian Administration.

Regarding the restraint systems, these latest years in Italy all new type-approved cars are sold with 3-point belts conforming to EEC Directive requirements. More particularly, in regard of amendments to be introduced in existing regulations to allow for the installation of passive restraint systems and of some given devices, our viewpoint is:

—Passive restraint systems of the airbag kind carry a number of drawbacks such as difficult installation on small cars, high costs, incomplete protection (so much so that airbags must be used at least in combination with lap belts).

—Belt type passive systems afford protection levels, at most parallel with those of conventional belts and involve greater design/construction limitations (anchorage locations), and possibility of remaining undeployed (thus imposing unnecessary added costs on users); for this reason we are not interested in introducing this possibility in existing regulations and standards.

—Belt pre-loading devices, given particular vehicle interior arrangements, may improve occupant protection; we do not object to such devices provided their optional use is guaranteed and occupant tolerance limit values are specified.

—Finally, we think the adoption of buckle automatic release devices is premature and that further investigations are needed.

EMISSIONS

Italy has adopted amendments 03 and 04 to the Geneva ECE 15 Regulation.

Whereas in many Countries such amendments have not been adopted and while in the other Countries it is still too early to feel their effect, strong pressure is being put to further increase drastically regulation severity.

A similar situation is experienced for noise limits. Italy, along with some other European Countries, has requested that no new reduction be imposed on the exhaust emission limits without prior assessment of such need from the health standpoint as well as of possible effects on costs, consumption and performance. A tremendous amount of work along this line was initiated by EEC with the ERGA-Noise and ERGA-Pollution groups. The DGM participates in the work of both groups to which it has provided a valid contribution of research conducted at the national level.

French Government Status Report

JEAN MOREAU de SAINT-MARTIN
Director, O.N.S.E.R.

The efforts that have been made in France with a view to increasing road safety have made it possible to reduce very considerably the rates of risk in relation to traffic, since during the space of ten years the number of those killed per 10^8 vehicle-kilometers has fallen from 9 to 4.5. This improvement has, however, slowed down during the last few years and, taking into account the increase in traffic flows (which has to some extent been maintained in spite of economic difficulties and oil supply problems), the annual number of road accident victims has remained practically stable since 1975. In 1981, the figures were 12,428 killed and 334,289 injured as a result of 239,734 personal-injury accidents, 90,973 of those injured sustaining serious lesions.

This is why since the Autumn of 1981 the French Government has set in hand a stepped-up effort to combat accidents and their consequences.

One of the first areas selected for improvement concerns drivers' behaviour. In parallel with a tightening up of enforcement (especially concerning speed limits), it has appeared necessary—in order to achieve a durable improvement in patterns of behaviour—to bring about a real mobilization within Society as a whole concerning the goal of improved road safety. With this in view, the programme entitled REAGIR anticipates performing administrative and technical investigations concerning all fatal accidents so as to show up possible countermeasures and to overcome the tendency of public opinion to view road accidents as something quite unremarkable. Central Government will enter into contracts with local authorities which will motivate the latter to act with the aim of reducing the number of killed by 10% in 1983.

So far as driver training is concerned, an overall reform of this and of the driving licence itself has been made the subject of research, and the creation of a National School for Driver Training is envisaged in 1983.

The Minister of Transport has set up consultation arrangements with motorcyclist groups, as well as with heavy goods vehicle drivers and transport enterprises, this with a view to getting progress made in relation to the specific safety problems that concern these two road user groups.

In the field of vehicle safety, a number of decisions should be mentioned:

- Mandatory laminated windscreen glass in all new cars from July 1, 1983.
- The equipping, with effect from October 1, 1983, of all new bicycles and mopeds with reflectors visible from the side, and the tightening up of enforcement of moped lighting rules.
- In harmony with international codes, public transport vehicle safety rules (especially concerning their seats and emergency exits) have been revised.

Finally, in-depth examination of the means of defining the strategy and tactics for controlling road user behaviour, as well as a strategy for social communications in relation to road safety will be developed. Road safety research will be the subject of a renewed thrust.

Research concerning vehicles will, of course, be called upon to contribute to this national effort to improve safety. Several research studies that are being performed with the help of Governmental funds can be particularly mentioned.

So far as heavy goods vehicles are concerned, an articulated vehicle with greatly improved stability characteristics so as to reduce the probability of roll-over is now being developed. Besides this, the 'Truck of the Future' project, which is designated VIRAGES (the abbreviation of a French phrase meaning 'industrial research vehicle improving energy and safety management') has to incorporate safety objectives as well as those others concerned with energy consumption, noise and pollution. This vehicle will include various devices and design characteristics to improve its dynamic behaviour, to lessen its aggressiveness in impact and to improve both the truck driver's own visibility and the conspicuity of the truck for other road users.

Other research concerns the improvement of car occupant protection in side impact. Current concern being to move towards an integrated test with an evaluation on the basis of biomechanical criteria, this research has made it possible to establish the specification of a moving deformable barrier which simulates the striking vehicle in a way that is representative of the vehicle mix. The results of this are presented by UTAC in Technical Session No. 3 of this Conference.

The establishment of protection criteria for use in integrated tests has been the subject of several research studies performed with French Government financial aid. In particular, the problem of cranio-cerebral lesions has been systematically tackled by the Peugeot-Renault laboratory and, under the title 'Proper Use of the HIC under Different Collision Environments', this is the subject of a contribution to Technical Session No. 2.

Faced with the challenge of meeting energy economy and environmental quality objectives, both manufacturers and all those responsible for safety will have to respond to the question of what level of protection can be provided to road users: can this level continue to progress or will we have to be satisfied with preventing its deterioration? This is a difficult political problem in which the consequences of the decisions must be weighed up in a number of different fields (concerning industrial production effects and vehicle use) and brought into the making of an overall judgment.

However this may be, it will be necessary to pursue research that will help to establish improved and more sensitive indicators of the level of safety. Thus, the coming into use of new materials raises the problem of their behaviour at impact. Certain impact modes cannot yet be tackled with satisfactory solutions; for example, those in which cars strike pedestrians or two-wheelers; in the case of side impacts, progress must be made in dummy design which will allow a more precise evaluation of injury risks. It is however more generally towards a global approach to safety over a diverse spectrum of accident and impact conditions that we have to move.

On such a basis, those responsible for road safety will be able to develop a rule-making procedure which will enable everyone to benefit from a traffic system that is as safe as possible.

Swedish Government Status Report

PROF. DR. BERTIL ALDMAN
Professor, Swedish Transport Research Delegation
Chalmers University of Technology

In recent years a fortunate reduction in the total number of police-reported road accidents and casualties has been observed in several countries. A similar trend has been noticed in Sweden over the last fifteen years. For this reason some statistical figures regarding this development may be of interest to this audience.

At the end of 1981 the population of Sweden was 8.3 million of which 53 per cent were holding a driver's licence. The total number of registered motor vehicles was 3.1 million. Of these, 93.5 per cent were private cars. The number of motorcycles increased by more than 20 per cent during each of the last two years to 86,000. The number of mopeds has been decreasing over the last few years, and in 1981, only 215,000 were recorded as being insured in Sweden.

Effects of Present Regulations

From the beginning of the period of motorization in the early years of this century and until the middle of the 1960's there was an almost continuous increase in the number of people killed in road traffic accidents in Sweden. This development more or less paralleled the increase in the numbers of registered motor vehicles, as can be seen in Figure 1. In spite of the fact that the motor vehicle registrations continued to increase at about the same rate until the late 1970's, the fatality trend had been broken more than ten years earlier.

At that particular time there was a growing concern in the country about road safety problems. After some

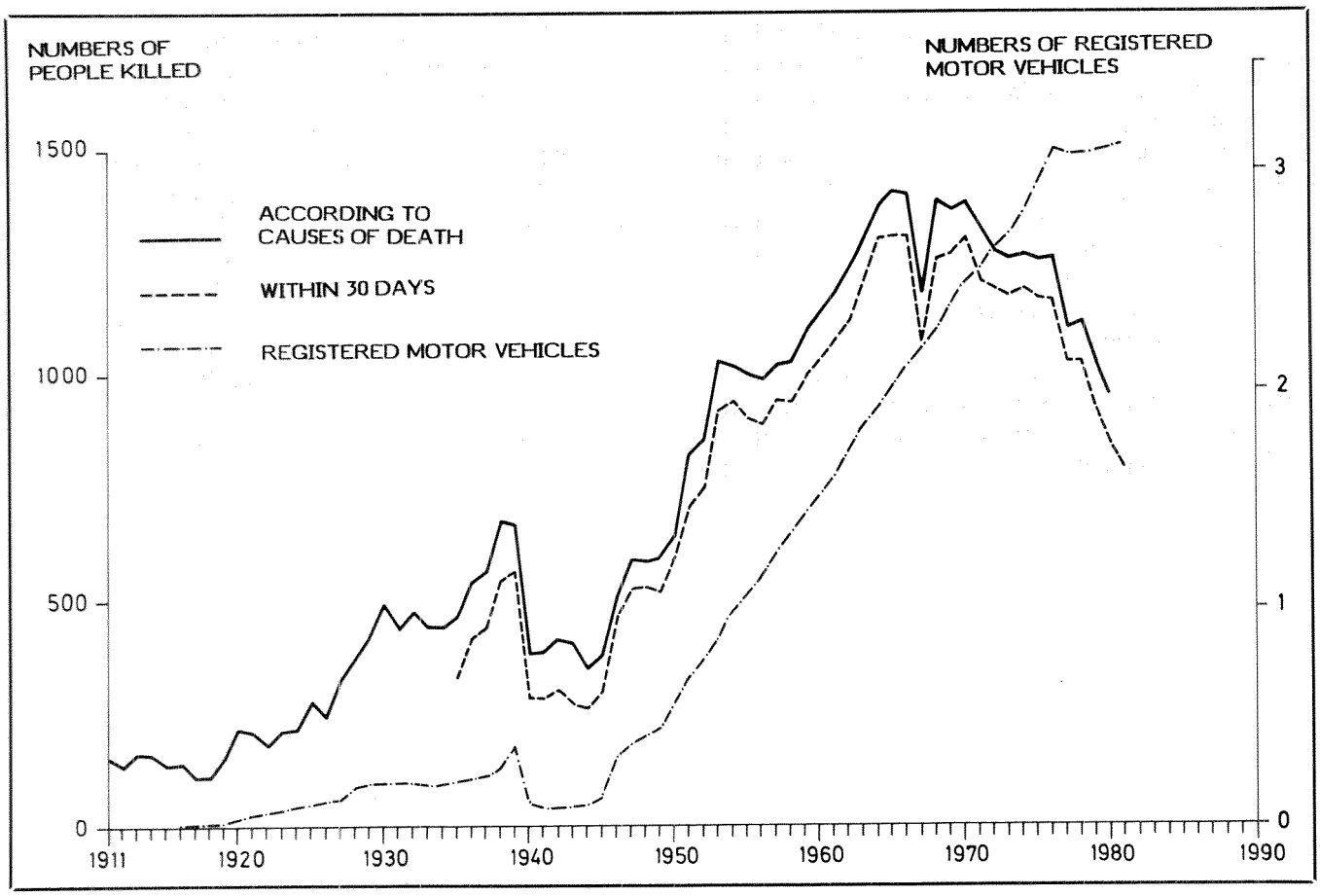


Figure 1. Numbers of people killed in road accidents according to causes of death and within 30 days of the accident, respectively, and numbers of registered motor vehicles 1911-1980.

years of preparation and considerable emphasis on road safety measures, a change-over to right-hand traffic was made in 1967. Since 1968 Sweden has promulgated a number of national regulations concerning vehicle safety and emissions. Some of these have been more stringent than the corresponding provisions in other European countries. Examples of such are the Swedish provisions concerning brakes and exhaust emissions.

In the period after 1970 the greatest reduction in the numbers of fatalities is seen among car drivers, car passengers, and pedestrians (Figure 2). For moped riders there is also a marked decrease in recent years, while the number of killed motorcyclists has increased during this time.

The numbers of injured road users show similar fortunate trends regarding car occupants, pedestrians, and moped riders. However, during the last three years the numbers of injured pedal cyclists and motorcyclists have increased and the safety of these categories is now given more attention.

The overall positive trend for road safety regarding the total number of casualties can also be noted when these numbers are related to the size of the population, the number of licence holders, the number of motor vehicles in actual traffic, or to the total motor vehicle travel. It is believed that the safety precautions taken during the last two decades have contributed to this favourable development in road safety, but also that this has increased the motoring costs. A harmonization of the national provisions with the corresponding ECE-regulations and EEC-directives has been considered beneficial and for this reason the Swedish rules have for some time now been subject to revision.

Still the losses on our roads are a matter of great concern to the Swedish Government. Of those who lost their lives in road accidents, 70 per cent were males. Among children and young people this is the most frequent single cause of death. For the group 1-24 years of age, between 40 and 50 per cent of the fatalities by accidents, and 25 per cent of all fatalities, are caused by road accidents. Those who are killed on the road have on the average their lives shortened by 35 years.

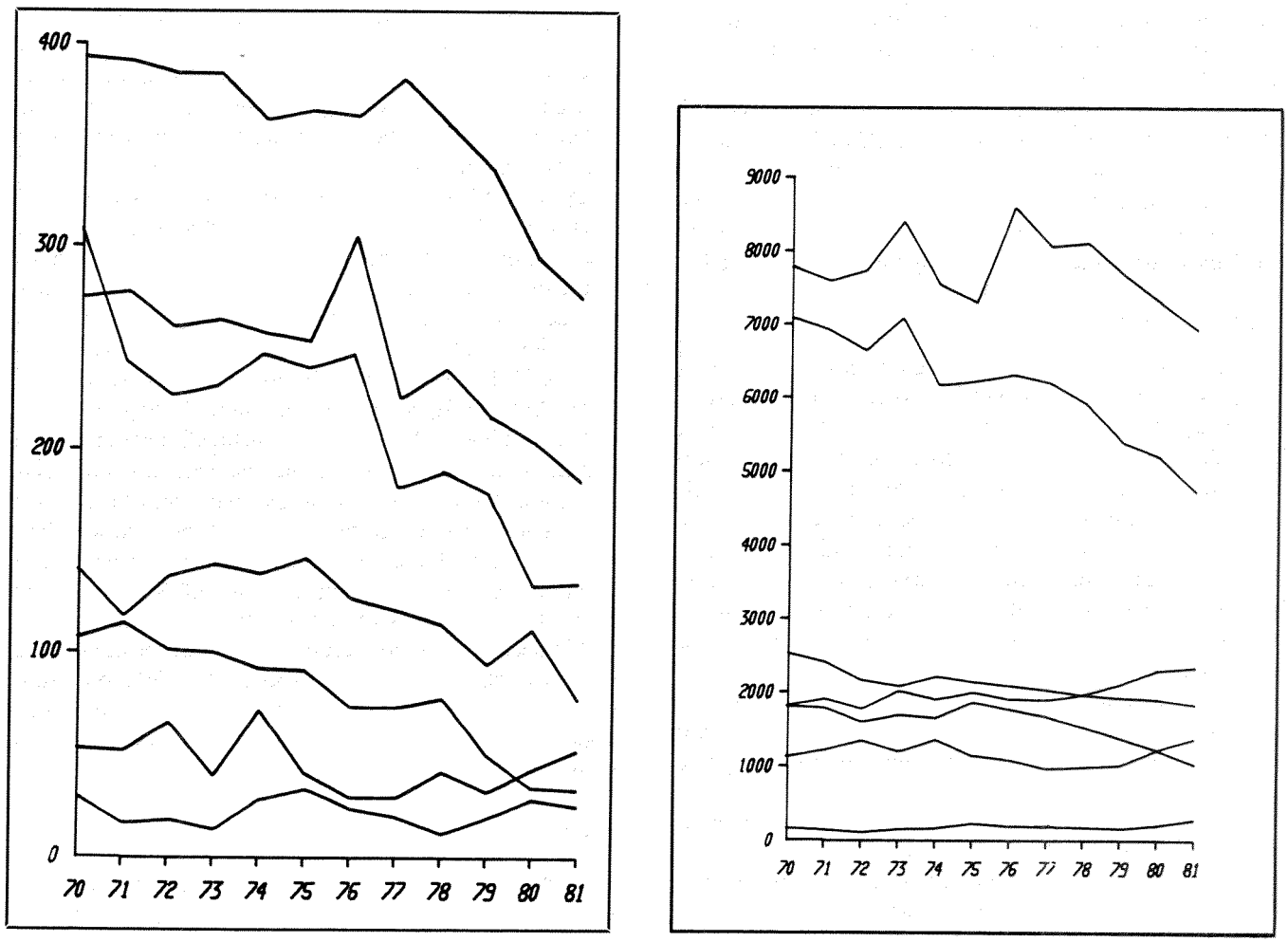


Figure 2. Numbers of people killed (left) and injured (right) in road accidents 1970-81 according to road user categories. a. car drivers, b. car passengers, c. pedestrians, d. pedal cyclists, e. motorcyclists, f. moped riders, and g. others.

Research Projects

It appears that many of the current ECE-regulations could be improved and as part of the Swedish contribution to Working Party 29 and its groups of rapporteurs, a number of research projects has been started in recent years.

Heavy-Vehicles.

A research programme with the aim of investigating heavy-vehicle, anti-lock system performance has been carried out, as well as test procedures concerning steerability and stability under winter conditions. Four different European anti-lock systems were used in these tests.

A project concerning bus transport systems in urban areas is being carried out by Volvo in cooperation with the Swedish Government. New types of low-energy, low-polluting, and silent buses are being tested on separate bus-roads. The bus stops are specially designed with a platform which is level with the bus floor. This makes it much easier for disabled persons, even in wheel-chairs, to enter the buses. Special seats are designed for the handicapped and areas with arresting devices for wheel-chairs are available. An electronic system aids the driver in steering the bus very accurately to the platform and braking it gently at the stop.

The general adaptation of public means of transport to the needs of people with different kinds of handicaps is at present the subject of another large study. Included here are not only road vehicles, but also railway cars, aircraft, and ships in order to make it easier in the future for handicapped people to travel by these different modes.

Restraint Systems.

Drivers of heavy trucks are seldom seriously injured in collisions with other vehicles. In single truck accidents, however, they are sometimes ejected, and since this is very dangerous, there has been an increasing demand from drivers and their unions in Sweden for seat belt installations also in these heavy vehicles. However, the combination of a suspension seat and a conventional belt leads to comfort problems. Prototypes with belts incorporated in the suspended part of the seat have been developed and laboratory-tested, and are now being tested under real traffic conditions.

A campaign aimed at increasing the usage of seat belts by rear seat occupants of passenger cars is now in its final stage of preparation and will be launched in the Spring of 1983.

Two types of child restraint systems are dominating the Swedish market. For children between 1 and 4 years of age the rearward-facing child seats are now being used by more than 50 per cent of the children of this age group when travelling in cars. During the fifteen years these systems have been in use, no injuries to their users have been reported in collision accidents. For the older children several types of booster seats, allowing the child to use an adult seat belt, have been developed and are now being used by approximately 15 per cent of the children in this age group.

Restraint systems for infants and for handicapped children have now also been developed and were recently introduced on the Swedish market. Based on the experience gained at the application of ECE Regulation 44 "Child restraints," some proposals for changes will be made in the near future.

The large second-hand market of child seats in Sweden has made it necessary to start an investigation of the aging effect of plastic materials used in such seats.

A prospective study of the use and protective effects of all child restraint systems in real accidents is now in progress, using an insurance material of about 80,000 accidents a year, which produced injury or damage only. It is expected that this study will reveal under which conditions children are injured in car accidents and what protection against such injuries the various systems offer.

Behavioural Studies.

Accident studies have revealed that difficulties to perceive other vehicles is a major cause of road accidents. In several years of behavioural studies, efforts were made to improve the conspicuity of vehicles. Daytime running lights were found to be a practical and effective measure and were made compulsory in Sweden for cars and motorcycles in 1977. Mopeds and tractors were later included in this law. Accident analysis shows that as an effect of this law, there has been a reduction of daylight collisions in the order of 10-15 per cent. The reduction in collisions between motor vehicles and nonoccupant road users is even higher. The increase in petrol consumption due to the use of daytime running lights is about 1 per cent.

The Swedish legislation pertaining to driving under the influence of alcohol permits routine breath tests of vehicle drivers to be taken even without suspicion of drunk driving. Some 2 million breath samples have been taken since the law was passed, and the results indicate that less than 0.2 per cent of the drivers, at any one time, drive with a blood alcohol concentration in excess of 50 mg per 100 ml (0.05%), which is the legal limit in Sweden. In road traffic accidents, approximately 3 per cent of the drivers are above the legal limit, and in traffic violation cases, approximately 5 per cent are above this limit. By international comparison, the Swedish figures seem very favourable.

Noise.

Studies on crash helmets, which have been going on for some years, have indicated that aerodynamically generated noise levels are very high, reaching about 100 dB at 100 km/h. This, together with the attenuation of outer sounds by the helmet construction itself, makes it im-

possible for the wearers to hear warning signals from other vehicles at speeds in excess of 50 km/h.

However, these studies have also indicated that current full-face helmets are poorly ventilated at low speeds. This results in high carbon dioxide and low oxygen levels inside these helmets, which is particularly dangerous after accidents for those who are unconscious with brain injuries. In view of the previously mentioned high noise levels, however, the problem of improving the ventilation is not easily solved. Studies of this problem are therefore being continued.

A vibration-noise-infrasound simulator study has been performed, which showed that infrasound of 110 dB at 15 Hz and 3 hours of exposure, impaired driver performance at the end of the exposure if noise and vibration levels were low. The drivers also felt sleepier after this exposure than if the infrasound level was low also. An increased noise level, however, of 80 dB (A) was also found to counteract the performance impairment caused by the infrasound.

Projects concerning tyre noise and possible steps in the future to improve the present situation are in progress and Sweden is closely following the work carried out within the framework of ECE regarding noise reduction. It is expected that an agreement can be reached about reasonably low noise levels and suitable measurement methods.

CONCLUDING REMARKS

The Swedish Government has been participating closely in the ESV programme and is pleased to notice that the results gained during the last decade gradually are being introduced into the automobile manufacturers' production models. The Swedish Government is convinced that more can be done to reduce the hazards on our roads and emphasises the need for improved regulations in this field. In view of the economic problems ahead, it is hoped that the regulations needed to reduce the number of casualties caused by road accidents can be harmonized all over the world for the benefit of all road users.

Japanese Government Status Report

KAZUO TAKASE
Director, Automobile Division
Ministry of International Trade and Industry

1. I would like to take this opportunity to welcome all of you to the Ninth International Technical Conference on Experimental Safety Vehicles. This is the second ESV Conference to be held in Japan. The first, being the Fourth ESV Conference, was also held here in Kyoto in 1973. I wish to express our heartfelt thanks to the representatives from abroad who have made the long journey to Japan, and to sincerely hope that this Conference will prove to be a success.

(1) As you are aware, the 2,000-pound class experimental safety vehicles constructed by three Japanese manufacturers, and the test results obtained by the Japan Automobile Research Institute were presented at the Fourth International ESV Conference. The results of the development of these ESV's have been utilized by manufacturers in the field of body design technology, and, consequently, the emphasis in body design has been changed from one of improving durability on poor roads to improving passenger protection during collisions. Additionally, the Japan Automobile Research Institute carried out various tests on the RSV experimentally produced in the United States and these test results were presented at the Eighth ESV Conference. Research is still being carried on in this area.

(2) A recommendation concerning the Japanese administration of vehicle safety was issued in October 1980 by the Transportation Technology Council, an advisory body to the Minister of Transport. This recommendation presents the second-stage objectives for expanding and strengthening safety standards for motor vehicles. Research activities on the basis of this recommendation for further advancement of vehicle safety are being carried out. The principal objectives referred to in the recommendation are designed to cope with traffic conditions in Japan, particularly the expanding highway system, higher speed of motor vehicles, truck safety, and fire prevention.

i) In order to meet the problem of the expanding highway system and higher vehicle speeds, studies are being carried out to improve headlamp performance, to strengthen brake regulations and to adopt HPR glass for front windows.

ii) As for safety measures for trucks, research is being carried out on bumpers for large trucks which can prevent cars and other small vehicles from getting lodged underneath the trucks in the event of accidents; research is also being made towards strengthening the cabs of cab-over-engine vehicles, and improving night-time visibility for

the rear of large trucks. Also, in order to prevent accidents caused by large trucks turning left, several experimental vehicles have been manufactured with the purpose of improving the direct field of vision through lowering the position of the driver's seat, increasing the size of windows, and installing the steering wheel on the left-hand side. These vehicles have been subjected to technical assessment and study. Photographs of these vehicles are now on display at this Conference Hall, and I hope you will find the time to examine them.

iii) In connection with measures for the prevention of fires, research is being carried out into areas such as the establishment of standards for the prevention of fuel leakage during collisions, the direct causes of fires, and methods to prevent them.

iv) Research is also being carried out on the problems of the driveability and stability of two-wheeled vehicles and of the driveability, stability, and methods for testing vehicles with trailers attached. Research into the various characteristics of tyres during cornering and the setting up of eye-points for drivers is also being carried out.

(3) Although not concerned directly with safety measures for motor vehicles, research is being carried out into total traffic control systems for motor vehicles. Experimental operations are under way in certain limited areas. In the broad sense, we regard this also as a contribution to safety.

2. I should like now to touch upon the ownership of motor vehicles and the present state of traffic accidents.

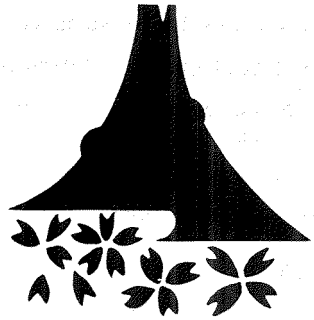
(1) As of December 1981, there were a total of 39,620,000 four-wheeled vehicles on the roads including 24,610,000 passenger cars, 13,960,000 trucks, 230,000 busses, and 820,000 special purpose vehicles. There were 13,230,000 two-wheeled vehicles including 1,160,000 over 50 cc, and 12,070,000 of 50 cc and less. These figures represent an increase over the previous year of 4.6% in the case of four-wheeled vehicles and 10% in the case of two-wheeled vehicles.

(2) There were 8,719 traffic fatalities in 1981. Over the past five years since 1977, the number of fatalities has consistently been around the eight thousand per year. This figure is approximately one half of the peak recorded in 1970. As the number of motor vehicles is now twice what it was in 1970, it is clear that there has been a dramatic decline in the number of accidents, and this may be ascribed in no small measure to the efficacy of the various road safety measures which have been implemented. However, in 1982, there has been a considerable increase in the occurrence of fatal accidents involving motorcycles and motor-driven cycles, and there is a danger that the number of fatalities may approach the nine thousand mark for the first time in six years. The Government is thus determined to reduce the increase in fatalities through the implementation of intensive safe driving education. Of the fatalities during 1981, 37.3% involved four-wheeled vehicles, 20.2% involved two-wheeled vehicles, 11.4% involved bicycles, 30.7% involved pedestrians, with others accounting for 0.4%. These figures indicate that the proportion of fatalities accounted for by those with the least protection (i.e., cyclists and pedestrians) is very high at 42.1%.

3. Since the formation of the GATT Standard Code, there has been an international trend towards the harmonization of regulations and standards. The Japanese Government is giving due consideration toward harmonization with ECE regulations and FMVSS. In addition, efforts are being directed towards the adjustment of Japanese Industrial Standards with the standards of the International Standards Organization. Harmonization with ECE regulations and FMVSS has recently been developing especially in respect to standards concerned with brakes and lamps. Japan intends to offer positive cooperation for international unification of regulations at ECE-WP29 and upon other occasions.

4. I should like to conclude this status report by expressing my wish that this Ninth International Technical Conference on Experimental Safety Vehicles will prove to be a great success with the presentation of highly significant research activities concerning motor vehicle safety, and with the impression in the minds of all participants from various countries that this Conference has been thoroughly worthwhile.

Section 3: Results of ESV/RSV Development



Mr. Michael M. Finkelstein, Chairman, United States

Results of the United States Research Safety Vehicle Program

FRANK G. RICHARDSON
National Highway Traffic Safety Administration

ABSTRACT

The United States Research Safety Vehicle Program has been completed. Technical data on safety performance of two RSV designs is available. These data shows that the crash performance of these vehicles exceeded the performance of cars available on the market and that the aggressiveness of these RSVs to other road users was less than production cars. Steering and handling performance was not improved over production cars although some other advanced crash avoidance features were superior. Consumer interest in "safe" cars was evident in marketing studies. Program management problems were mainly associated with the technical specification of crash avoidance requirements, the lack of resources for a full demonstration program, and the inability to transfer technology to the market place.

INTRODUCTION

The United States Research Safety Vehicle (RSV) Program has been completed with fabrication and evaluation testing of complete RSV vehicles. Results, or products, of this seven-year program include an extensive amount of engineering data from a large number and variety of tests, design information on materials properties and processes, structural and mechanical component performance data, and systems integration data. Participants in the program also developed analytical methodologies as part of their specification and design studies. In addition to these technical outputs the RSV Program also compiled data on public attitudes towards automobiles emphasizing safety features.

This paper provides an overview of these results at the Program level for the Minicars and Calspan RSV projects. The evolution of the overall program plan and technical goals is briefly reviewed and the two RSV designs are summarized. Results are summarized for safety performance and design integration and the response of the general public to the RSV designs is presented as a market factor. Comments are offered on some of the major issues relevant to government sponsorship of such programs.

RSV PROGRAM

A project for an RSV-class passenger car was included in the original U.S. Experimental Safety Vehicle Program presented at the First ESV Conference (1)*. Described as an "Intermediate Sedan—3,000 pound class" the preliminary technical performance specifications for this project were distributed in 1973 prior to the Fourth ESV Conference. At that Conference the overall plan was reviewed (2) and many of the participants commented on the specification and on the program. In the implementation of the program many of these suggestions were accepted and incorporated either into the program or into one of the specific projects. The General Motors comments, for example, on the major issue of trading off crash protection against other design parameters and on the minor issue of lighting systems (3), were recognized and essentially adopted.

The Program objectives can be divided into two major areas (Figure 1). The first effort was the design and fabrication of experimental vehicles which would demonstrate improved levels of safety performance without negative effects on fuel economy or emissions, and, hopefully, with some enhancement of this performance. These vehicles were then used to assess the market acceptability

*Numbers in parenthesis are references.

- **Develop Experimental Vehicles To:**
  - **Demonstrate Improved Safety Performance**
  - **Improve Fuel Economy and Emissions Performance**
  - **Assess Market Acceptance of Safe Cars**
  - **Identify System Integration Problems**
- **Test Vehicles To:**
  - **Acquire Engineering Data for Rulemaking**
  - **Guide and Support Added R&D**

Figure 1. Research safety vehicle program—objectives.

of "safe" cars. The second major objective was to test these vehicles to acquire data for rulemaking support and to direct or assist other R&D efforts. This was done both at the total vehicle level and at the subsystem/component level (e.g., single beam headlights, soft bumpers). Throughout both areas, but primarily in the development work, a number of system trade-off and integration problems were identified and analyzed. This need to reconcile the frequently conflicting design demands of improved safety, better fuel economy, emission control, and economic feasibility in the market place was a key factor in initiation of the RSV Program.

Some of the underlying philosophy of the Program was that:

a. there should be continuous dissemination of information from the contractors involved,
b. industry should be substantially involved in order to assist in the technology transfer, whether voluntary or through regulation, and
c. safety was not viewed as a competitive selling feature and unless this could be changed voluntary improvement was unlikely.

Major phases or stages of the Program are shown in Figure 2. Five parallel studies were made in 1974 to define the broad concepts of the RSV and to further develop the performance specifications first proposed by NHTSA. As noted earlier, extensive review of the proposed specifications led to a number of changes in requirements. Two contractors, Calspan and Minicars, were then competitively selected to proceed with the design and development phase and subsequently moved on to systems integration and fabrication.

Frequent reports on the Program were presented as shown in Figure 2. These conferences were keyed to completion of major phases or milestones. References 4, 5, and 6 present results through the second phase and References 7 and 8 provide the contractors' status midway through the fabrication phase.

Evaluating testing began early in 1979 and was sup-

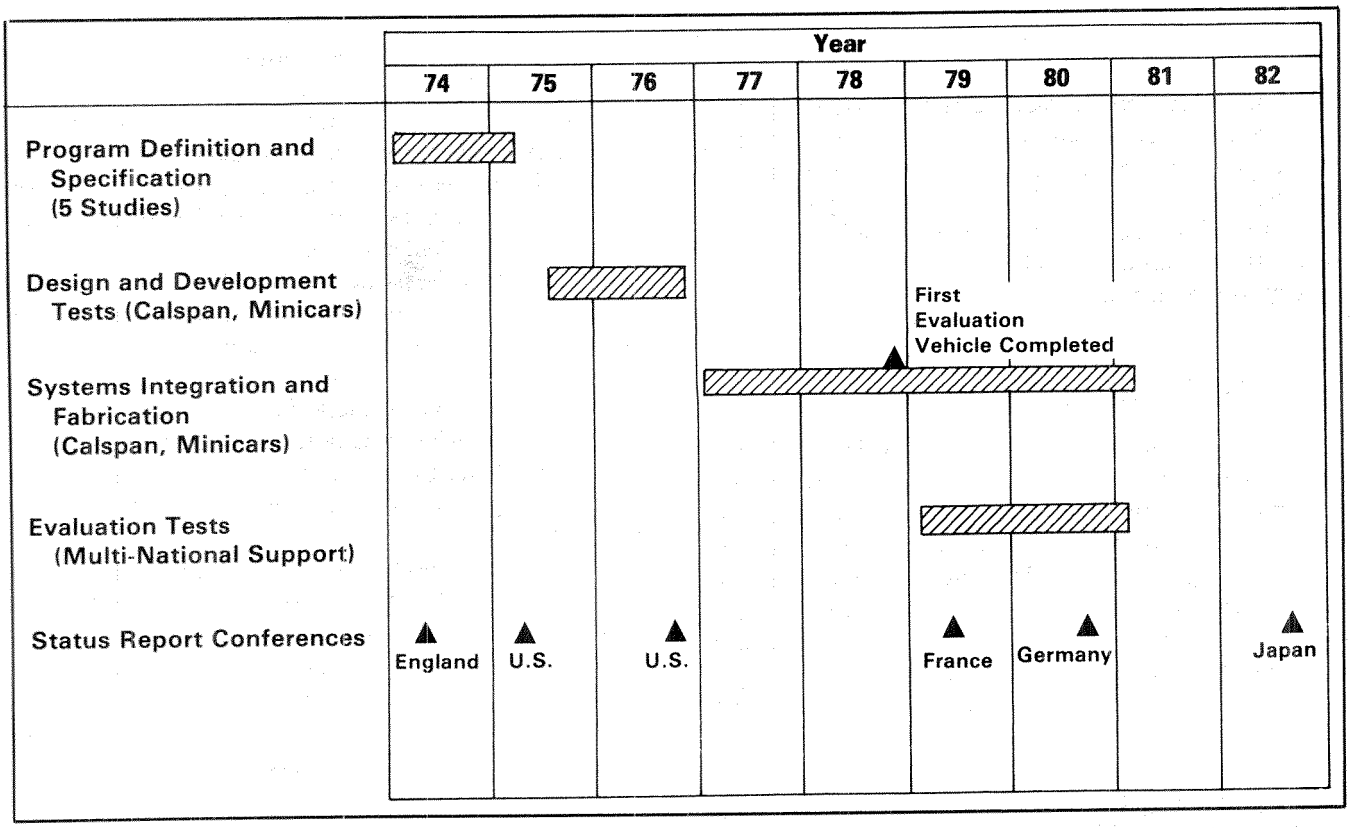


Figure 2. Research safety vehicle program—activity schedule.

	(U.S. $000's)
• Program Definition and Specification (5 Studies)	2,200
• Design and Development Tests (Calspan, Minicars)	7,000
• Systems Integration and Fabrication (Calspan, Minicars)	18,000
• Evaluation Tests	*2,900
Total	30,100

* Does Not Include Extensive Test Costs Incurred by Germany, Italy, France, United Kingdom, Netherlands, and Japan

Figure 3. Research safety vehicle program—program costs.

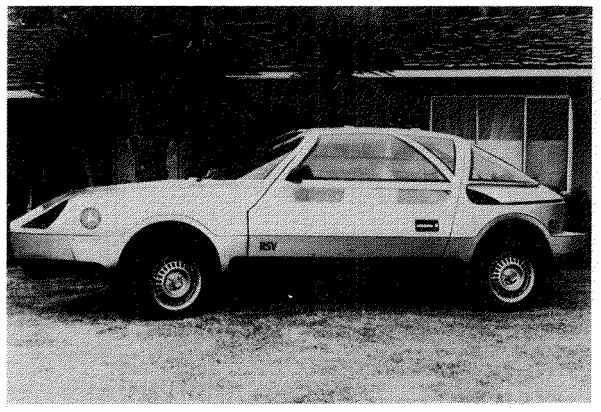


Figure 5. Minicar RSV.

ported extensively by most of the countries and many of the manufacturers participating in the International ESV work. France, Italy, Germany, The Netherlands, the United Kingdom, and Japan all performed significant evaluation tests and reported on these tests beginning with the Seventh International ESV Conference in Paris in June 1979.

Costs of the RSV Program incurred by the United States are shown in Figure 3. Note that the total cost of $30 million does not include costs to other countries or the manufacturers who participated in the evaluation testing phase. For comparison, the cost of the U.S. Family Sedan ESV program was $15 million.

DESIGN SUMMARY

The design features of the Minicars and Calspan/Chrysler RSVs have been extensively reported earlier (5, 6, 7, 8, 9). Briefly, the Minicars approach, as shown in Figure 4, was to develop an all new body structure applying an innovative fabrication technology of foam-filled, thin gauge sheet metal sections for body structure. Designed from the basis of reducing societal cost from crashes, the design ended up at 2,550 pounds curb weight and achieved 50 mph barrier crashworthiness. Fuel economy achieved with the modified Honda engine was 29 mpg (City) and 41 mpg (Highway). The Minicar RSV is shown in Figure 5.

The approach for the Calspan/Chrysler RSV is shown in Figure 6. This RSV was evolved from a 1976 Model Year Chrysler Simca and thereby represents a conventional, near-term State-of-Art technology. Extensive use was made of simulation analyses in the structural design process. The RSV, as shown in Figure 7, weighed 2,675 pounds. Major crash performance levels achieved were 40 mph Frontal Car-to-Car protection and 34 mph Side protection. The turbocharged engine with 5-speed gearbox and feedback carburetor installed by Volkswagen provided 26 mpg (City) and 42 mpg (Highway) and reduced emissions significantly over the standard Omni/Horizon engine installation.

PERFORMANCE RESULTS SUMMARY

Nearly 60 complete RSV test vehicles of various types were built and tested throughout all phases of the RSV Program. Many different types of tests were performed—aerodynamic drag, handling, braking, crash repairability, low speed damage protection, and others, as well as high-

- All New Vehicle
- Innovative, Near-to-Midterm Technology
- Societal Benefit Basis for Design
- 2,550 Lb. Curb Weight
- Crashworthiness
  - Frontal: 50 MPH Barrier
  - Side: (Impact by Large Car) 35 MPH Each Car (90°)
- Fuel Economy
  - 29/41/33 MPG
  - 0.4/2.5/0.7 HC/CO/NO_X GPM

Figure 4. Research safety vehicle program—minicars approach and performance.

- Modification of Production Vehicle (Chrysler Simca)
- Conservative, Near-Term Technology
- Analytical Basis for Design
- 2675 Lb. Curb Weight
- Crashworthiness (Car-to-Car)
  - Frontal: 40 MPH (Each Car)
  - Side: 35 MPH (Each Car, 90°)
- Fuel Economy/Emissions
  - STD Engine: 23/34/27 MPG; 0.5/4.87/1.03 HC/CO/NO_X GPM
  - T/C Engine: 26/42/32 MPG; 0.13/2.1/0.9 HC/CO/NO_X GPM

Figure 6. Research safety vehicle program—Calspan/Chrysler approach and performance.

Figure 7. Calspan RSV

speed car-to-barrier and car-to-car crash tests. Detailed results of these tests have been reported at previous International Technical Conferences on Experimental Safety Vehicles beginning with the Sixth. This report summarizes these results at the Program Level.

OCCUPANT PROTECTION

Both RSVs developed crashworthy structure and integrated these structures with automatic restraints, padding, seating systems, and other body and chassis elements to provide safety performance as shown in Figure 8. Using either conventional (Calspan/Chrysler) or innovative (Minicars) technology as described earlier, these vehicles were able to demonstrate occupant protection in various crash modes.

Both RSV designs integrated automatic restraint systems for drivers and front seat passengers. Two distinctly different air bag designs were developed for the drivers. The Calspan/Chrysler RSV driver restraint incorporates a steering wheel-mounted air bag with a pyrotechnic inflator, porous nylon bag, primary and back-up crash sensors, and a dash-mounted diagnostic box. Knee blockers are used but an active lap belt is available. The Minicars RSV driver restraint system has a dual air bag configuration mounted in the steering wheel assembly. The inner and outer bags are cylindrical and are constructed of low permeability nylon. Venting in these bags is accomplished by the fabric porosity. This system also has inflators, primary and back-up crash sensors, and a diagnostic system. The system generally works with a collapsible steering column and additional knee restraints. Satisfactory structural integrity, controlled collapse of the front end, and adequate energy dissipation are achieved through proper design of the frontal structure.

It was in matching front structure performance with restraint performance and in integration into the RSVs that most effort was required.

The Calspan RSV system has demonstrated protection up to 80 mph closing speed in head-on crashes against equal weight cars. The Minicars RSV system users will be protected in frontal impacts as severe as a 50 mph barrier crash. Of approximately 9,500 driver fatalities that occur annually, in the U.S., it is estimated that almost 6,200 of these could be eliminated if all cars were equipped with similar systems.

The Minicars RSV also uses a dual bag concept for automatic passenger restraints. Two bags separated by a thin membrane serve as a torso and head cushioning device. The torso bag is smaller than the head bag and the volume and design features of each are tailored to meet chest and head loading requirements. The system consists of dual chamber bag, solid propellant inflator, crash sensors, energy absorbing dash, and knee pad. In the event of a crash the torso bag fills very quickly and maintains a high pressure. As the torso comes in contact with the bag, the gas is forced into the bag for the head through a vent in the membrane. Then the upper bag inflates and retards the head as it starts to move. The system includes passenger knee restraints.

The Calspan/Chrysler RSV uses an inflatable torso belt system for passenger protection. The belt uses an auxiliary drive system to automatically position the belt on the passenger. Knee blockers or an active lap belt are used in conjunction with the belt.

An inflatable belt distributes the crash loads on the occupant torso over a large area thereby reducing chest injuries. It also cushions the head and restrains occupant forward motion. The same system functions as a conventional shoulder belt system when low-level crash forces are encountered as in minor accidents which do not deploy the air belt. A pyrotechnic inflator automatically inflates the belt to an 8-inch-round bag during crashes. Force limiting webbing is used on the ends of the belt to limit the belt loads to 2,000 pounds. An advantage of this type of system is that it is not unique for any particular model and therefore can be used in a full line of production car models, thereby reducing costs. The air belt is obviously more susceptible to consumer complaints about discomfort, inconvenience, and appearance than are air bags.

The RSV Side Impact Occupant Protection Systems

- **Developed Both Conventional and Innovative Structures for Front, Side, Rear, and Rollover Crash Protection**
- **Demonstrated Automatic Protection For:**
  - **80 MPH Car-to-Car Frontal Crashes With Conventional Structures Technology**
  - **50 MPH Frontal Barrier Crashes With Innovative Structures Technology**
- **Demonstrated Car-to-Car Side Crash Protection at 50 MPH Closing Speeds**
- **Demonstrated Rear Crash Protection at 45 MPH With Conventional Technology — No Fuel Leakage**

Figure 8. RSV results summary—occupant protection.

utilize improved door structure, strengthened pillars, interlocks between the door and the vehicle structure, door beams, and interior padding. The purpose of these components is, first, to reduce the gross deformation of the passenger compartment caused by an impacting vehicle, and secondly, to control the impact forces on the crash victim.

The Calspan RSV Side Structure utilizes conventional design combined with application of high-strength materials to prevent the intrusion into the occupant compartment. Having reduced the intrusion, the occupant impact forces are controlled by utilizing foam door trim pads which enclose aluminum honeycomb. As the door is moved inwards towards the occupant, the honeycomb and padding deform to limit and control the forces imposed on the occupant.

In addition to the design features of the Calspan RSV, the Minicars RSV embodies a heightened door sill. The purpose of this sill is to interact with a striking vehicle's front structure, thereby reducing the magnitude of collision force applied to the door itself.

The Calspan and Minicars RSV Side Impact tests have demonstrated that front seat dummies could survive in a car-to-car crash at up to 50 mph closing velocities with each vehicle traveling at 35 mph. Survival is defined as injury measures on the dummies being less than those required by Federal Motor Vehicle Safety Standard 208. If all vehicles in the U.S. car fleet provided front seat occupant protection in side impact accidents at speeds of 50 mph, fatalities would be reduced by approximately 40%, assuming no change in the accident pattern. This is based on an analysis of the side impact test data of the Calspan RSV.

Rear crash protection of the Calspan RSV was gained not only by modest strengthening of the rear structure but also through careful redesign of the fuel tank and fuel filler systems. The tank was strengthened and moved forward on the vehicle and attached with wrap-around straps. The fuel filler neck was also moved forward over the rear wheel and out of the impact zone. These steps were essential to reducing fuel leakage in rear impacts.

AGGRESSIVENESS

A principal requirement of all Experimental Safety Vehicle research has been the reduction of aggressiveness toward other road users—pedestrians, bicyclists, and cars. RSV results in this respect are summarized in Figure 9.

Low speed aggressivity toward pedestrians or other cars was achieved by designing a "soft nose." This soft nose design developed for the RSVs consists of a high density reaction injection molded (RIM) skin which encloses a low density foam. Engine cooling air slots are provided, together with cut outs for headlamps and parking lamps. The shape of the unit, and the foam properties, can be tailored to meet specific design requirements. With this concept, vehicle aggressivity toward both pedestrians and other vehicles is simultaneously reduced. This front end design provides clear cut reduction of pedestrian injuries compared to current front-end designs. It is also less aggressive in low speed (less then 10 mph) impacts with other cars. The weight of the unit, as designed for the Calspan RSV, for example, is approximately 35 pounds; one half that of a conventional bumper, grill, valance, etc., which it replaces.

- **Demonstrated Technology To Reduce Pedestrian Injury Levels at Impact Speeds Up to 25 MPH**
- **Demonstrated Low Speed Damage Protection to Struck Cars up to 8 MPH**
- **Demonstrated Technology To Reduce Injury Levels of Struck Car Occupants in Side Crash Tests at 50 MPH Closing Speeds**

Figure 9. RSV results summary—aggressiveness.

The National Highway Traffic Safety Administration has estimated that up to 13,000 pedestrian injuries would be reduced in severity and up to 340 pedestrian fatalities per year would be eliminated if the entire U.S. car fleet was equipped with soft bumpers.

High speed crash aggressivity reduction, of course, involves front end structural design rather than just the soft nose. In a series of paired car-to-car tests the RSVs showed the ability to reduce the level of dummy measurements in the car struck in the side by the RSV as compared to the paired car. Such benefits in reduced aggressiveness are, of course, gained at the expense of occupant protection and the RSV design development and evaluation tests provide valuable data for understanding this concept.

In the paired tests the reduction in front seat dummy measures was significant. Chest and pelvic accelerations were reduced 30 to 40%. Rear seat dummy measures were not improved, however, to the same degree and this behavior has not yet been explained.

ACCIDENT AVOIDANCE

A number of well-established concepts related to accident avoidance were integrated into the RSVs. Some of these are noted in Figure 10. Anti-lock brake systems, flat-proof tires, low tire pressure warning systems, and high level rear lighting were used but were not specifically evaluated under this program. A light-weight, single beam headlight system was developed by CIBIE for the Calspan RSV and was evaluated under a separate NHTSA project

- **Integrated Crash Avoidance Subsystems:**
  - **Anti-Lock Brakes**
  - **Advanced Lighting**
  - **Conspicuity Stripes**
  - **Tires**
- **Developed Radar-Activated Crash Mitigation System**
- **Identified Issues With Crash Avoidance Performance Specifications**

Figure 10. RSV results summary—accident avoidance.

(10). A radar-activated Crash Mitigation System was developed for the Minicars RSV but was not extensively evaluated beyond the design development phase.

Probably the most important contribution of the RSV Program to Accident Avoidance was to focus attention on the problems of crash avoidance specifications. While the RSVs met the technical specifications for steering, handling, and braking performance that had been proposed and accepted at the beginning of the Program, they were considered by many to be inadequate in this performance category (11). The quantified RSV performance requirements were not sufficient or complete enough to avoid this negative judgment. Further definition of these requirements must be made in future R&D work.

SYSTEMS INTEGRATION

A prominent feature of the planning for the RSV Program was the broad objective of examining the tradeoffs and integration demands of the various subsystems or requirements. Indeed, early descriptions of the Program focused on the so-called "S3E" concept of balancing *S*afety, *E*nergy conservation, *E*nvironmental protection, and *E*conomy of purchase and operation for the consumer. The principal focus of these efforts became the development of weight efficient body structures using either conventional production processes with new applications of materials, or the development of the innovative Minicars structure. Very limited engine, drive line, and emissions control development was carried out in this Program and so the tradeoffs and integration were limited to packaging the various power plant components and subsystems.

Some other integration efforts were made on Safety/Fuel Economy issues as shown in Figure 11. Aerodynamic tests were carried out on the RSVs not only to explore external shapes but also to investigate specific details of front dams, external mirror size and shape, wheel covers and wheel parts, etc. It was on the basis of such data for example, that decisions were made to use headlight covers

- **Designed Weight Efficient Conventional and Innovative Structures — 2500 to 2700 Lbs.**
- **Identified Aerodynamics Benefits/Tradeoffs**
  - **External Shapes**
  - **Design Details: Front Dam, Mirrors, Glazing, Spoilers**
- **Methodology for Systems Optimization**

Figure 11. RSV results summary—systems integration.

and small external mirrors that failed to show FMVSS compliance, in order to enhance fuel economy at the expense of some *possible* degradation of safety performance.

Finally, the development of analytical methodologies for design optimization were initiated in the RSV Program. Simulation methodologies for vehicle level and fleet level analyses were started in the first phase of the Program and continued expansion of some of these is continuing. Other methodologies were developed for projecting vehicle engineering characteristics and for cost-benefit assessments.

MARKET FACTORS

A summary of RSV work in the general area of market factors—price to the consumer, safety benefits, and acceptance of the concepts—is given in Figure 12. Throughout all phases of the Program an attempt was made to estimate the MSRP (Manufacturer's Suggested Retail Price) for the RSV designs. In some cases, automatic restraints for example, alternate price estimates were obtained from sources other than the RSV designs. As expected, the cost estimates for some systems varied by as much as 3 to 1. Obviously, the baseline for price estimates varied, different technological assumptions were made, and in fact, technology has changed over the course of the Program. Slight variations in performance could be accepted for reduced price. In fact, simplified versions of

- **Estimated MSRP for RSV Designs**
  - **Range of Price Estimates**
  - **Evolving Technology (Materials, Designs)**
- **Estimated Crashworthiness Benefits**
  - **Evaluation Technology (Dummy, Test Modes)**
- **Assessed Consumer Reaction to RSV Concepts**
  - **Market Research (Focus Groups)**
  - **Safety Valued at $300 to $1500**

Figure 12. RSV results summary—market factors.

such RSV concepts as side door interlocks and secondary hood latches are now appearing in production cars.

Similarly, various estimates of crash benefits were made. These are obviously heavily dependent on the human surrogates and test modes utilized in the evaluations. The improved designs for dummies now being utilized in side crashes would probably alter both the RSV designs and the anticipated benefits. It is NHTSA's judgment that substantial reductions of fatalities and serious injuries could be achieved with RSV-type structures and restraint/padding systems.

The RSVs were widely exhibited to the general public and to technical audiences. Media interest was high and, in fact, TV and magazines are still reporting on the Program. Public response covered a wide range of issues ranging from technical details to practical considerations of ownership to the philosophy of U.S. Government sponsorship of such programs. While classification of the responses is difficult, they signify a broad interest in highway safety and 95% of respondents who commented on market availability indicated a desire to purchase such safe cars. Such response obviously correlates closely with expected price.

A more concentrated marketing survey was made with the Minicars RSV using focus group discussions (12). Twenty-three such groups were assembled in 10 cities across the U.S. While results are not statistically valid the research did show an increased value of safety features after some education on automobile safety performance. Price and fuel economy (the study was conducted in 1980) were the strongest factors in purchase decisions.

A conclusion might well be that consumers are much less informed on safety than on fuel economy, comfort, or styling and that increased awareness of safety could alter these priorities.

PROGRAM MANAGEMENT

Finally, a number of program management issues became apparent during the eight-year span of the program. These are listed on Figure 13. One major issue was the incompatibility of goals and objectives with the resources available, and the variation in some objectives with changing administrations. Funding and schedules were clearly not compatible with the ambitious goals for emissions and fuel economy performance.

Similarly, as the emphasis changed from one of technical evaluation of advanced safety concepts to total demonstration, resources were insufficient. For example, a major problem in the Calspan/Chrysler RSV active safety or handling performance was the "cramped" driver environment. This occurred because resources were not available to widen the base Simca when side crash padding protection was added and the interior space was reduced.

RSV design reviews were lacking in two important areas. There was insufficient emphasis on production

- **Ambitious Goals, Objectives**
  - **Fuel Economy, Emissions Goals**
  - **Demonstration vs Evaluation**
  - **Inadequate Resources**
- **Inadequate Design Assessments**
  - **Production Technology**
  - **Operational Requirements**
- **Wide Dissemination of Information**
  - **Technical Conferences**
  - **Media**
- **Inadequate Technology Transfer**

Figure 13. RSV results summary—program management.

technology projected by the RSV designers and there was a failure to explore necessary parallel changes in operational requirements for such things or license plates, tax or inspection stickers. The soft front bumpers and modified windshields would necessitate changes that, while considered feasible, were not explored or widely recognized and acknowledged.

These deficiencies in design reviews were partly overcome, however, by the frequent wide dissemination of program information to the technical community. In the U.S. the SAE included papers on the RSVs and technical displays in almost all of their national meetings from 1976 through 1980. Internationally, the ESV conferences and displays continued to provide the means for technical data exchange. General dissemination of data to the nontechnical public in the U.S. has been discussed earlier.

And, finally, a disappointment of the RSV Program Management has been the inability to transfer the technical results either to the market place or even to the NHTSA rulemaking engineers. Only one element unique to the RSV design—the St. Gobain "Securiflex" (TM) windshield—has been considered for rulemaking action. None of the fuel economy/safety tradeoff issues (e.g., headlight covers, external mirrors) are being considered for change. Utilization of the vast amount of engineering data has been minimal.

CONCLUSION

The RSV Program was responsible for acquiring a great deal of technical data on the safety performance of complete integrated vehicles in a wide range of crash conditions. The crash performance of these test vehicles exceeded the performance of cars available on the market. Similarly, the aggressiveness of these RSVs to other road users—cars and pedestrians—was less than production

cars. Crash avoidance performance was not improved over production cars and in some aspects was considered less satisfactory. In the U.S. there would appear to be some consumer demand for "safe" cars as determined through market assessments with the RSVs. Transfer of improved safety technology to production cars is not being accomplished.

REFERENCES

1. "The United States ESV Program—Overview," John A. Edwards, Report on the First International Technical Conference on Experimental Safety Vehicles, January 1971.
2. "The Optimized ESV Performance Specifications," William E. Scott, Report on the Fourth International Technical Conference on Experimental Safety Vehicles, March 1973.
3. "Conclusions and Projections on ESV Development," Louis C. Lundstrom, Report on the Fourth International Technical Conference on Experimental Safety Vehicles, March 1973.
4. "U.S. Status Report on ESV Programs," John W. Snow, Report on the Sixth International Technical Conference on Experimental Safety Vehicles, October 1976.
5. "A Status Report on the Calspan/Chrysler RSV," Dr. Patrick M. Miller, Report on the Sixth International Technical Conference on Experimental Safety Vehicles, October 1976.
6. "A Summary of the Minicars RSV Program," Donald E. Struble, Report on the Sixth International Technical Conference on Experimental Safety Vehicles, October 1976.
7. "Status Report on Minicars Research Safety Vehicle," Dr. Donald Struble, Report on the Seventh International Technical Conference on Experimental Safety Vehicles, June 1979.
8. "Status Report on Calspan/Chrysler Research Safety Vehicle," G. J. Fabian and G. Frig, Report on the Seventh International Technical Conference on Experimental Safety Vehicles, June 1979.
9. "The Minicars Research Safety Vehicle," D. Friedman, Report on the Eighth International Technical Conference on Experimental Safety Vehicles, October 1980.
10. "Evaluation of the Feasibility of a Single-Beam Headlighting System," DOT-HS-805-219, December 1979.
11. "Results of Handling, Stability and Braking Tests of the Minicars RSV," Dr. A. Zomotor, Report on the Eighth International Technical Conference on Experimental Safety Vehicles, October 1980.
12. "Consumer Acceptance of RSV Features," DOT-HS-805-454, June 1980.

Minicars RSV: Results of Angled Barrier and Headform Impact Tests and a Comparison with Those of the Calspan RSV and Chrysler Alpine

S. P. F. PETTY
Transport and Road Research Laboratory

ABSTRACT

A Minicars RSV was impacted into a 30° wood-faced angled barrier at a speed of 60 km/h and subsequently its interior was impact tested using a free flight headform. The results of these tests are compared with those from similar tests on the Calspan RSV and a Chrysler Alpine car which was the baseline production car used to develop the Calspan RSV. All the tests were carried out at MIRA.

In the angled barrier test the Minicars RSV met the requirement of ECE Regulation 33 with regard to occupant survival space. There were two Part 572 dummies in the front seats. Despite a delay in the deployment of the drivers airbag, all the dummy acceleration and femur loads complied with the requirements of FMVSS 208. The car met the full system integrity requirement of FMVSS 301 with regard to the 30° angled barrier impact but failed to meet the static rollover requirements because of a minor design error in the fuel filler.

The headform tests showed the need for more protection in secondary vehicle impacts when the occupants are not fully restrained.

The comparison of the results from the different cars showed an improvement in survival space and occupant injury criteria of the RSV designs over the production car.

INTRODUCTION

This is a report of a frontal angled barrier crash test of the Minicars Research Safety Vehicle (RSV) (Ref 1) followed by a series of interior headform impacts. The tests were carried out at the Motor Industry Research Association (MIRA) (Project officers Messrs. B F Smith and K Clemo) upon instructions from the Transport and

Road Research Laboratory (TRRL). The tests are part of the continuing co-operation between the USA and the UK in the field of vehicle safety.

The testing procedures were similar to those used for the Calspan/Chrysler RSV test (Ref 2). The results of the two sets of RSV tests and those from a standard Chrysler Alpine upon which the Calspan RSV design was based are compared and highlight some of the differences in design concepts.

Object

To assess the performance of the Minicars RSV in the context of crashworthiness, with particular attention being paid to occupant protection. Detailed objectives were:

a) To subject the Minicars RSV to a 60 km/h, 30° angled wood-faced barrier crash test, primarily to check its performance with regard to FMVSS 208 occupant protection and FMVSS 301 fuel integrity.
b) To measure the noise generated by the airbags of the passive restraint systems.
c) To subject the front of the Minicars RSV passenger compartment to impacts by an instrumented aluminium headform and analyse to FMVSS 208 with regard to the head injury criteria.
d) To compare the results with the Calspan RSV and Chrysler Alpine tests.

The Test Vehicle

The test vehicle was a Minicars Research Safety Vehicle, (Fig 1) and was identified by the figures M5-10. The vehicle structure consisted of a frame that was built of large thin-walled box sections, most of which were foam filled. The outer skin was manufactured from a non-reinforced plastic, except for the luggage compartment lid and its surrounding panel, which were manufactured from glass-reinforced plastic, (GRP). Some of the inner wing weather covers were also produced from a thin GRP. Minicars have aimed at providing for the needs of pedestrian safety and the reduction of low speed impact vehicle damage. To achieve this both the front and rear bumpers had been manufactured from urethane foam covered with a soft plastic skin. Access to the passenger compartment was by means of two gull wing doors that were hinged at the roof line. To allow the doors to reinforce the structures during a frontal impact, loads were transmitted between the door and the frame by location pins attached to the front and rear of the doors, which picked up on striker plates on the A-post and B-post.

The vehicle had a rear-mounted engine and transmission unit, giving rear-wheel drive. The road wheels were fitted with Dunlop Denova run flat tyres, that were inflated to 2.07 bar (30 psi) for the front wheels and 2.41 bar (35 psi) for the rear wheels. There was no spare wheel supplied with the vehicle. The windshield was of the laminated type, and was bonded to the vehicle. The fuel storage tank was located inside the central spinal box section, just forward of the rear seats.

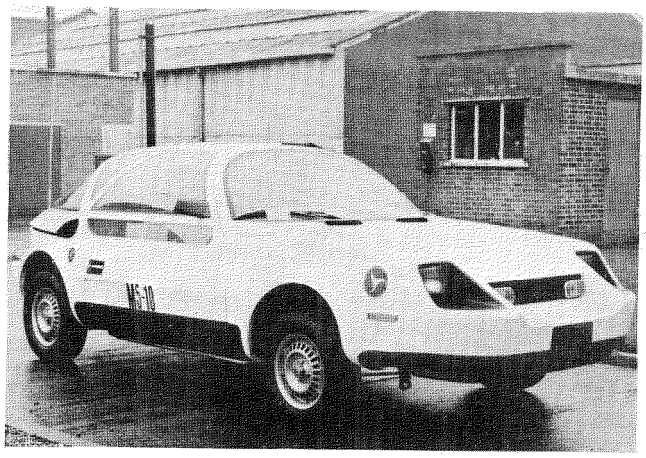


Figure 1. The vehicle on arrival for testing.

The driver's side restraint system incorporated a steering-wheel mounted airbag that consisted of non-porous nylon bag vented into the outer bag. The inner bag was inflated by a sodium azide squib. Also, the system incorporated a urethane foam energy-absorbing knee bolster. The front passenger restrains system incorporated a double non-porous airbag. The lower bag was vented into the upper bag, which in turn was vented to the atmosphere by two 62.5 mm diameter holes. The bags were inflated by a sodium azide inflator. Again a urethane foam energy-absorbing knee bolster was used. Both these systems were activated by three parallel crash sensors, two of which were mounted on the port and starboard sides at the front of the body structure, and one on the top of the left front suspension strut tower. The system also incorporated a diagnostic box to warn of any malfunction in the squib firing circuitry. In addition to the primary crash sensors a contact switch was located on the bumper blade at the point of first contact. This switch, combined with an electronic time delay circuit, was built and installed by MIRA staff to activate the restraint system in event of the primary system not firing.

Vehicle Preparation

The vehicle was painted in contrasting colours to assist in the analysis of the high speed colour films. Markers 250 mm apart, were fixed along the side of the body at the waist line and along the bonnet and roof on the vehicle centre line. Before the test the vehicle was drained of all fluids and, in compliance with FMVSS 301, the petrol tank was completely filled with 32 litres of stoddard solvent fuel substitute; then 5% was removed leaving 30.4 litres. The vehicle was fitted with contact event switches and 23 unbonded accelerometers. The vehicle complete with onboard camera and two 50th percentile dummies

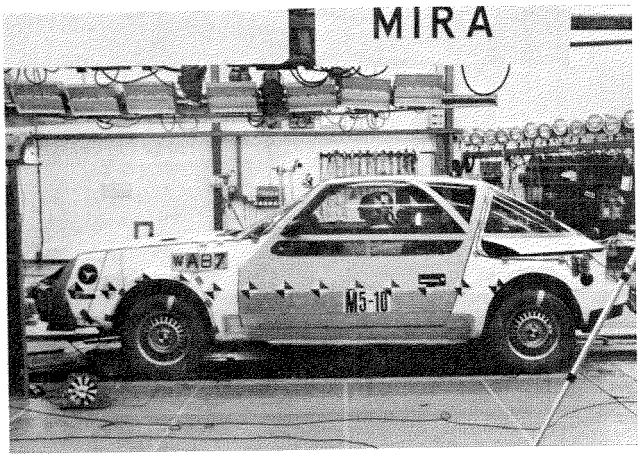


Figure 2. Port side of the vehicle pre-test.

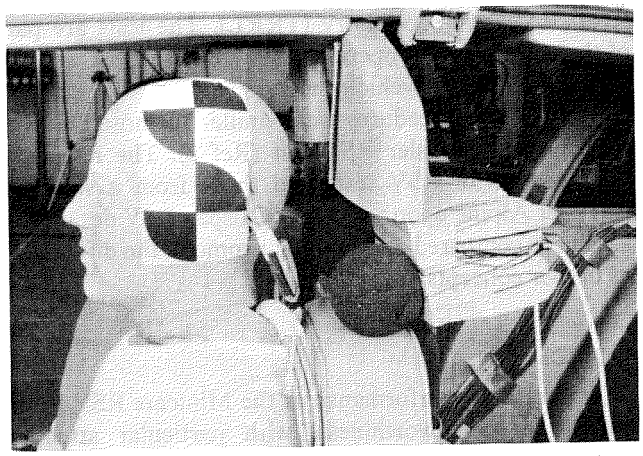


Figure 3. The microphone installation.

in the front seats was weighed before the test (Fig 2). The loads on the wheels were:

Port front	295 kg (651 lb)
Port rear	363 kg (800 lb)
Starboard front	298 kg (657 lb)
Starboard rear	372 kg (820 lb)

This gives a total of 1328 kg (2929 lb) distributed with 45% on the front wheels.

Before the crash test the front seats were put in their most rearward latched position and an SAE three-dimensional seat deflection manikin was used to determine the front seat H-point, so that ECE 33 pre-test dimensions could be taken. Then the seats were repositioned to the instructions of Minicars Inc., Report No. 5010 FI (Check-out procedures in RSV Frontal Impact Crash Testing, Figures 3-1 and 3-2), and left in this position for the crash test.

BARRIER IMPACT TEST

Test Method

Using the MIRA linear induction motor crash facility the vehicle was impacted into a steel barrier set at 60° to the vehicles axis of motion and faced with a sheet of 20 mm plywood. The vehicle's and the dummies' instrumentation was to SAE Recommended Practice J211a. Fourteen high speed cameras were used to give colour film coverage of the impact.

Noise measurements were recorded during the impact to determine the noise level generated during the inflation of the restraint systems. For this purpose two condenser microphones, Type 4136, mounted in a foam block were fixed to the rear of the drivers seat head rest. The microphones were positioned so as to be adjacent to the driver's ears (Fig 3). The signal from each microphone was fed to an FM tape recorder via two channels with gains differing by 20 dB. This ensured a high signal to noise ratio for the test. Two forms of analysis were carried out on the recorded signals. The pressure waveform versus time was plotted to show the instantaneous peak pressure measured during the crash test. Repeated analysis showed that the essential detail of the waveform was obtained with a bandwidth of 6.4 kHz. The frequency content of the signature was obtained in octave bands from 2.5 Hz to 10 kHz using a Gen-rad 1995 integrating real time analyser set to "max hold." The "max hold" facility enables a spectrum to be obtained of the maximum level (with a time constant of 0.125 s) in each octave band over the record length. It should be noted that the sum of the octave band levels will generally exceed that of the maximum overall level because the maxima in the octave bands do not occur at the same time as the overall maximum.

Two FMVSS Part 572 dummies fitted with additional back up accelerometers in the head and chest were installed in the front seats following the procedures as defined in FMVSS 208 (Figs 4 and 5).

At the request of Minicars Inc., a squib firing circuit was fitted as backup to the existing air bag inertia switch

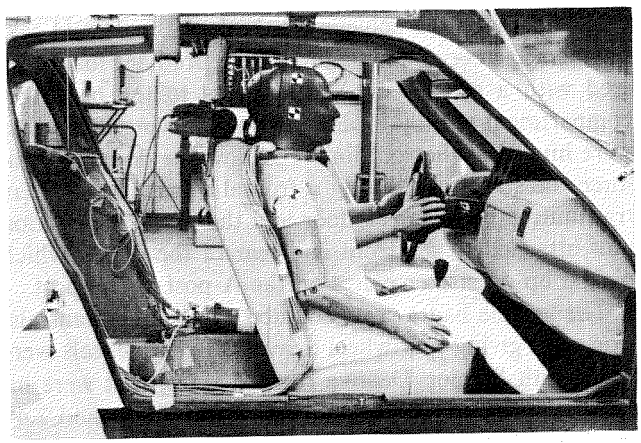


Figure 4. Starboard dummy pre-test.

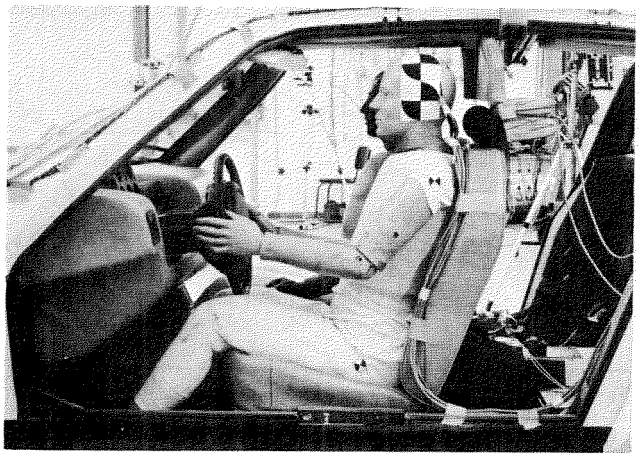


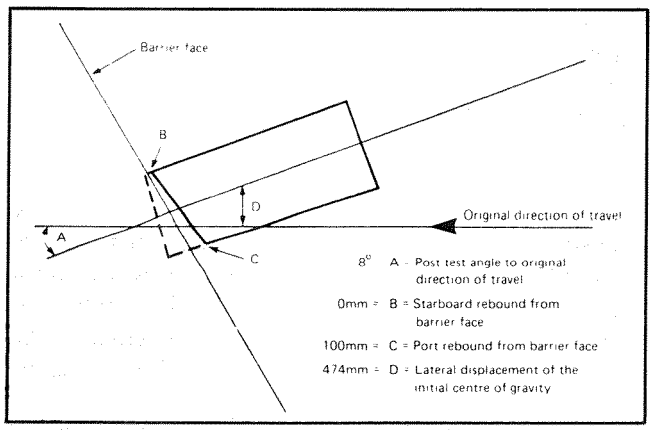
Figure 5. Port dummy pre-test.

circuit. The requirement was for squib firing current to be provided by the circuit 15 ms after impact.

The barrier test was followed by a static rollover test. The vehicle was rotated on its longitudinal axis to each successive increment of 90° (Fig 6).

Test Results

The vehicle speed just prior to impact was measured to be 60.3 km/h. The position of the vehicle after the test is showed in the diagram below and in Figure 7.



The Vehicle Structure

A measurement of the static crush showed a shortening of 235 mm on the starboard side and 1135 mm on the port side. These dimensions were taken from the metalwork as there was some considerable recovery of the urethane foam front of the vehicle.

The wheel base had lengthened by 14 mm on the starboard side and shortened by 262 mm on the port side. This was due mainly to the displacement of the front wheels. The rear wheels were still free to rotate.

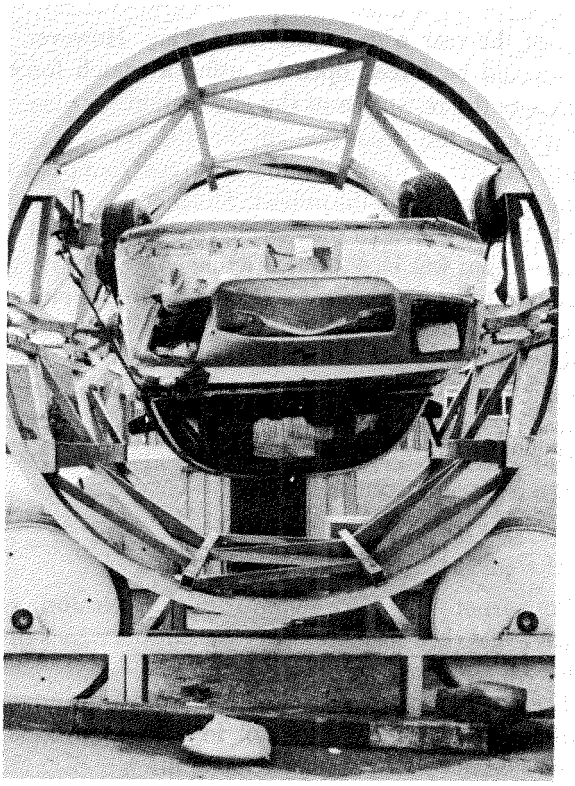


Figure 6. The vehicle installed in the static rollover rig in the second increment position.

The laminated windshield that was bonded to the vehicle was 100% retained, but examination showed that there were some cracks that radiated from the lower edge immediately behind the port side air intake. This appeared to be due to being hit from the inside by the left hand front corner of the dashboard instrument console.

Both of the gull wing doors remained closed and unlocked during the impact. The starboard door could be opened by using the normal force required for this operation. The port door catch released by using the normal force, but the door was partially jammed by the overlap-

Figure 7. Port side of the vehicle post-test.

ping of the rear edge of the front wing. However, the door could be forced open by using a snatch force to overcome the resistance of the obstruction.

Before the test it was thought that the fire extinguisher might break from its fixing and fly into the front passenger compartment during the impact. The first precaution was to have it weighed and then discharged and re-filled with water until it was back to its original weight. It was then anchored to one of the rear seat belt anchorage points by a cord with 200 mm of slack, so as to allow the fire extinguisher to break free if it was going to, but then to restrain it from entering the front passenger compartment. However, the fire extinguisher did not leave its fixing during the impact, and therefore did not present a hazard to the front seat occupants.

The Passenger Compartment

Both front seats were retained in position during the impact, and their displacement mechanisms were still operational after the test.

The resultant accelerations at the base of the port and starboard A-posts are shown in Figures 8 and 9 as examples of vehicle accelerometer outputs.

The survival space that remained available in the passenger compartment could be assessed against the requirements of the proposed ECE Regulation 33, although the test was an angled barrier impact and performed at a higher impact speed. The regulation specifies the minimum dimensions of the passenger compartment which must remain after a 48.3 km/h perpendicular frontal barrier impact. Paragraph 5.2 of the regulation relates to the horizontal distance between the R-point and the instrument panel; paragraph 5.3 relates to the horizontal distance (through the brake pedal) between the front of the passenger compartment and the R-point; paragraph 5.4 relates to the width of the footwell (through the brake pedal); and paragraph 5.5 relates to the floor to roof dimensions through the R-point. The numerical values of

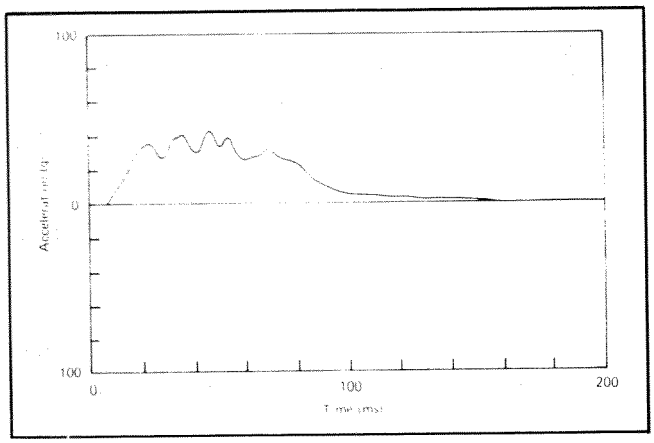


Figure 8. Resultant acceleration of the base of the port A-post.

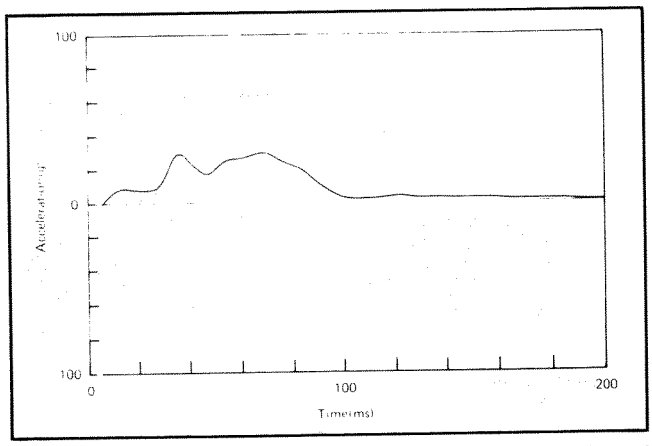


Figure 9. Resultant acceleration of the base of the starboard A-post.

the requirements and the results are shown as part of Table 1 which compares the vehicle measurements of the three cars tested. The figures show that the Minicars RSV meets the requirements of ECE Regulation 33 with regard to front occupant survival space.

Dummy Analysis

The signals from the transducers in the dummies' heads, chests, and femurs were analyzed to the requirements of FMVSS 208. The analysis results are given in Table 2 and Figures 10 to 17 and show that both dummies pass the requirements of FMVSS 208. It should also be noted that the femur loads pass the levels as defined in Reference 3 (12 kN may not be exceeded, 10 kN may not be exceeded except for duration of less than 3 ms, and 7 kN may not be exceeded except for durations of less than 10 ms).

The head of each dummy in the Minicars RSV was fitted with a chamois leather mask, so as to assess any lacerations that might occur in the test. The masks were painted just prior to impact, the left sides red and the right sides blue. This was to give witness to any head contact during the test. The post-test examination showed that there was no evidence of lacerations on either of the masks. The paint witness showed that both heads made contact with the airbags only. The driver's mask showed evidence of the steering wheel airbag rotating clockwise during the head contact which is confirmed by the high speed films, and the post-test position of the steering wheel. During the impact both dummies slid to the left of the centreline of their airbags, the driver sliding towards the A-post and the passenger sliding towards the space between the two airbag systems. The post-test examination found the driver dummy back in its seat more or less in its normal sitting position with the passenger dummy leaning towards the driver, shoulder to shoulder but with the passenger dummy slightly forward.

The impulse to the drivers head at 122.5 ms as shown

Table 1. RSV and Chrysler Alpine Vehicle Results.

Vehicle		Mini cars RSV	Calspan Chrysler RSV	Chrysler Alpine
Test date		21.1.81	10.7.80	14.2.77
Impact speed	km/h	60.3	60.3	59.4
Test weight	kg	1328	1436	1188
Weight distribution	% front	45	55	56.4
Steering wheel side		Port	Port	Starboard
Barrier face angle		30°	30°	30°
Side of first contact		Driver	Driver	Driver
Static crush. driver's side	mm	1135	800	900
Static crush. passenger's side	mm	235	60	115
Rebound driver's side	mm	100	150	380
Rebound passenger's side	mm	0	0	0
Lateral displacement of the centre of gravity	mm	474	825	135
Final yaw attitude (from original line of travel)		8°	20°	12°
Fuel leakage during impact		None	None	10 ml/min from fuel tank filler tube
Fuel leakage during static roll		200 ml/min (see text)	1 ml/min from fuel filler cap	Not rolled

ECE Regulation 33 Survival Space			Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Parameter	Requirement	Position						
5.2 Instrument panel to R-point*	>450 mm	Driver	560	550	462	460	521	390
		passenger	590	590	460	480	521	490
5.3 Front of compartment to R-point*	>650 mm	Driver	1118	1115	950	822	1003	630
		passenger	1120	1120	940	940	991	935
5.4 Width of footwell	>250 mm	Driver	480	475	705	690	597	0
		passenger	480	480	705	750	597	598
5.5 Floor to roof height	<10% reduction	Driver	1210	1205	1972	1970	1041	984
		passenger	1210	1215	1970	1970	1041	1027

*No R-point was specified for the RSV vehicles, so the pre-test H-points were used.

in Figure 10 was entirely from the head vertical accelerometer. At this moment the head was nearly horizontal and the top of the head was in the steering wheel airbag near the wheel structure. There was no evidence of wheel deformation due to a head impact. The chest accelerometers showed no impulse at this time but the pelvis lateral accelerometer had a pulse of over 100 g for 20 ms. The exact dummy kinematics cannot be determined. It is possible that the dummy while rotating round the partially inflated airbag with its knees held by the foam restraints started to slide sideways out of the seat and was hit back by an impulse from the door padding.

Airbag Deployment

Airbag firing time evidence was provided by two electronic circuits, one monitoring the current in the squib circuit at a point inside the primary system diagnostic box, and one monitoring the voltage output of the secondary (back-up) system. The signals showed that the primary system gave a current approximately 0.001 s in duration of 6 a at 0.017 s after first contact and this coincided with the film evidence of the start of deployment of the passenger's airbag. The primary system then gave a current approximately 0.003 s in duration of 2 a at 0.045 s after the first contact and this coincided with the deployment of the driver's airbag. It appears from film evidence that the driver's airbag was not fully deployed at the time of the dummy making contact with it, which was due to the delay in the start of deployment. This delay is also evident in the difference in the times of the deceleration of the two dummies after the start of the impact. The secondary (back-up) system showed that a voltage was switched to the squib circuit at 0.07 s after first contact, but at this time both squibs had already been fired by the primary system. Therefore, the secondary (back-up) system was not involved in the firing of the squibs. After consultation with the Engineering Staff of

Table 2. RSV and Chrysler Alpine Dummy Results.

	Normal Criteria to FMVSS 208	Minicars RSV		Calspan Chrysler RSV		Chrysler Alpine	
		Driver	Passenger	Driver	Passenger	Driver	Passenger
Type of dummy	Part 572	Part 572	Part 572	Part 572	Part 572	OPAT	OPAT
Head							
HIC over 250 m sec.	<1000	638	222	289	591	665	1744
HIC during contact	<1000	638+	222+	289+	No contact	665	1697
Gadd SI.	<1000	745	278	341	813	881	2279
Chest	<1000	367	177	488	402	463	315
SI over 250 m sec.							
Acceleration over 3 m sec.							
	<60 g.	46	35	51.5	44.5	55	40
Time over 60 g.	>0.003 sec.	0	0	0	0	0.001	0
Peak g.	—	48.5	33.3	54.3	49	63	44
Femurs load	2250 lbf (10 kN)						
Left (kN)		6.32	3.48	8.84	3.54	2.7	0.6
Right (kN)		8.52	4.55	5.72	5.75	1.8*	2.9
Pelvis resultant acceleration	—	133.5	36	67.3	67.8	54	55
Seat belt loads							
Shoulder (kN)	—	Airbag	Airbag	Airbag	8.4	4.8	7.3
Lap (kN)	—	No lap belt	Airbag	Airbag	No lap belt	4.4	8.4
Peak resultant**							
Acceleration at A-post g.	—	69	35	109	49	175	44
Time sec.	—	0.062	0.037	0.06	0.059	0.062	0.057

+ Contact with airbag.
* 1.8 kN was measured just prior to the load cell being damaged.
** Filtered at 180 Hz.

Minicars Inc., they conclude "that the driver's inflator did indeed receive current at the same time as the passenger's inflator, but that due to some inflator malfunction, the gas generator did not ignite until 0.03 second later." The post-test examination of the airbags revealed a small hole burnt in the passenger side airbag, approximately two cm. long and one cm wide. This would have had no significant effect on the restraint performance of the airbag as this hole is small compared with the airbag vent hole. However, the hot material that caused the burn could injure the passenger, and may present a fire hazard.

Fuel Integrity

The vehicle was assessed with regard to the requirements of FMVSS 301 in the 30° angled frontal barrier impact. The requirements of this standard are intended to apply to lower speeds of up to 48.3 km/h. The fuel spillage rates allowed by the standard are 1 oz. by weight from impact until cessation of motion and a total of 5 oz. by weight in the 5-min. period following cessation of motion. For the subsequent 25-min. period fuel spillage during any 1-min. interval shall not exceed 1 oz. by weight. The post-test examination showed that there was no fuel spillage during or after the impact.

The crash test was followed by a static rollover test as specified in FMVSS 301; the vehicle was rotated on its longitudinal axis to each successive increment of 90°. The vehicle was rotated first in the anti-clockwise direction looking from the front, which was with the fuel filler pipe down first. Immediately the fuel level was raised above the fuel filler pipe, fuel started leaking at a rate of 200 ml per minute (5.25 oz.), which exceeded the limit set in this standard.

At this point it was decided to abandon the test. On examination it was found that the leak was due to an inadequate seal between the metal fuel filler neck and the flexible rubber hose that leads to the fuel tank. The rubber hose was of the type that has a steel wire reinforcing wrapped spirally around its outer surface; this caused the inner seal to have a spiral indent, which made it difficult to make a good seal. First of all, the hose clip around this joint was tightened, but this did not stop the leak. It should be pointed out at this stage that when the fuel

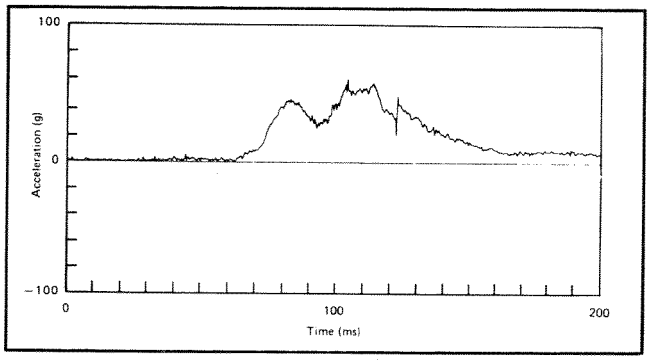


Figure 10. Resultant acceleration of the driver's head.

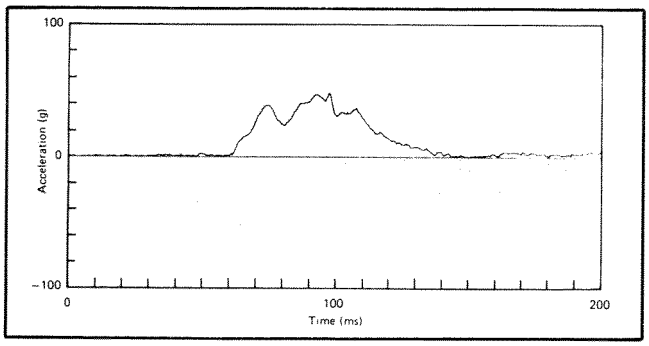


Figure 11. Resultant acceleration of the driver's chest.

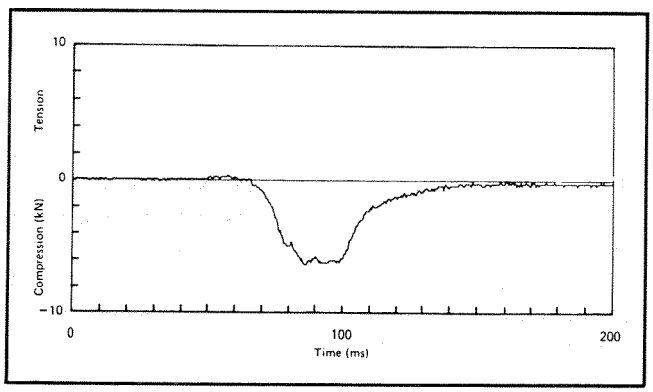


Figure 12. Axial force in the driver's left femur.

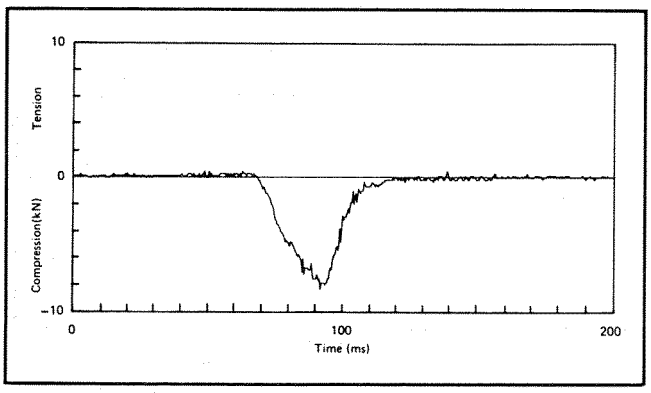


Figure 13. Axial force in the driver's right femur.

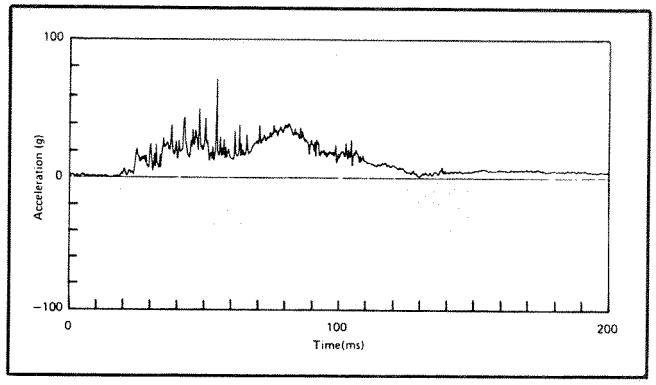


Figure 14. Resultant acceleration of the passenger's head.

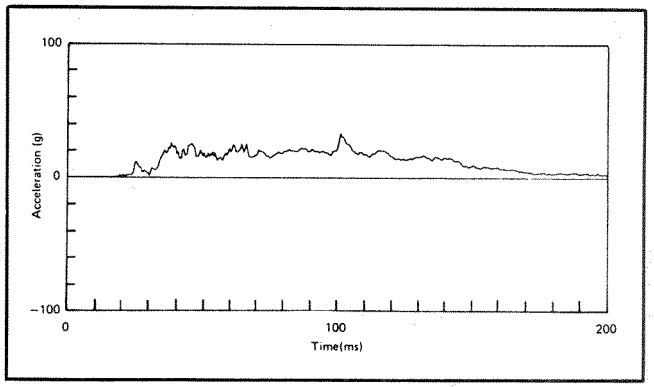


Figure 15. Resultant acceleration of the passenger's chest.

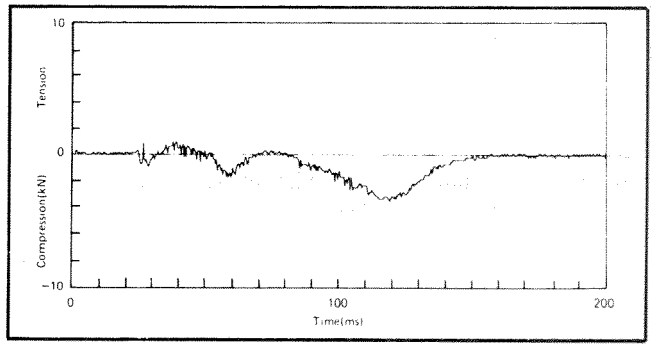


Figure 16. Axial force in the passenger's left femur.

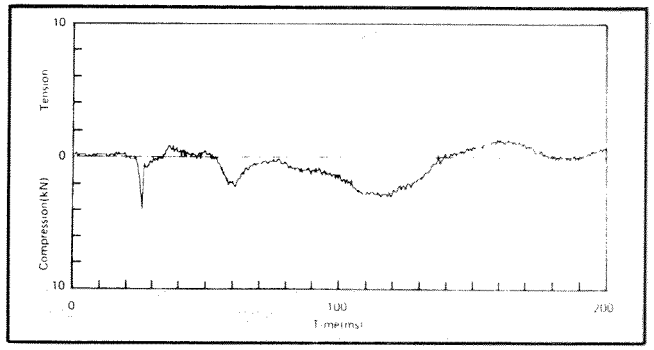


Figure 17. Axial force in the passenger's right femur.

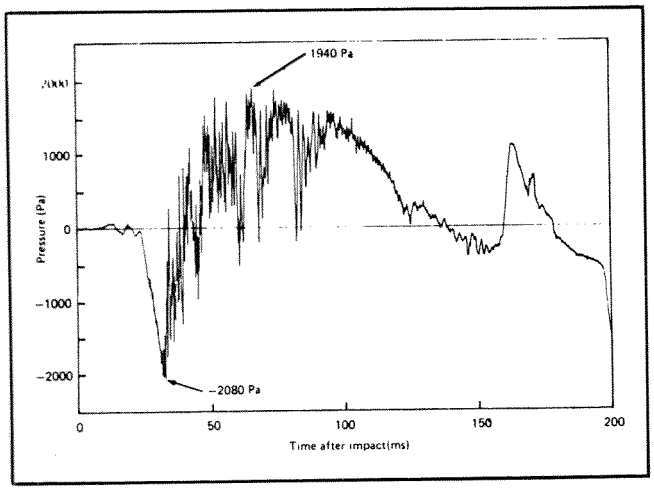


Figure18. Pressure vs time: microphone on left side of driver head position.

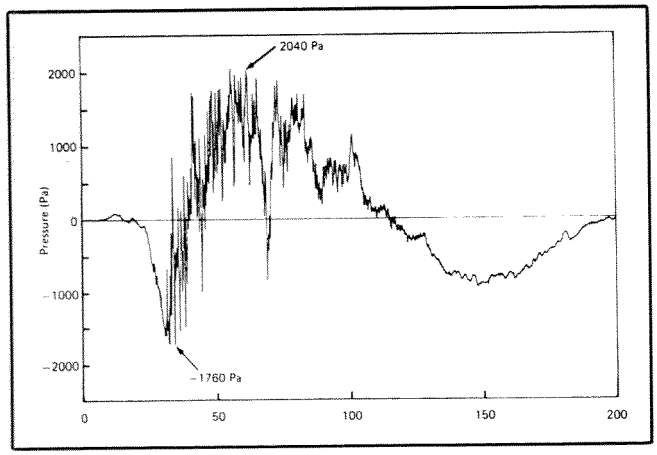


Figure 19. Pressure vs time: microphone on right side of driver head position.

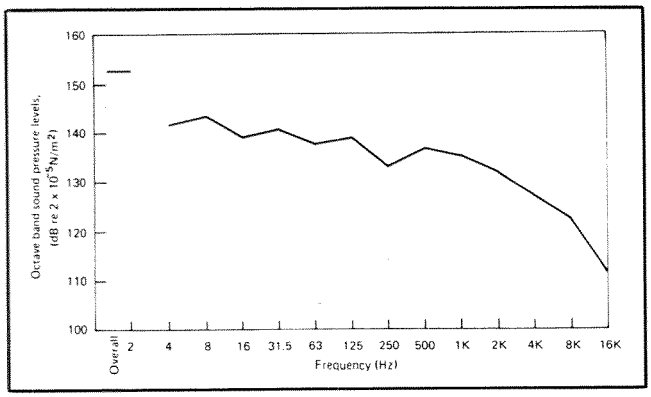


Figure 20. Maximum octave band sound pressure levels occuring during first 150 ms after impact (0.125 s time constant) left hand microphone.

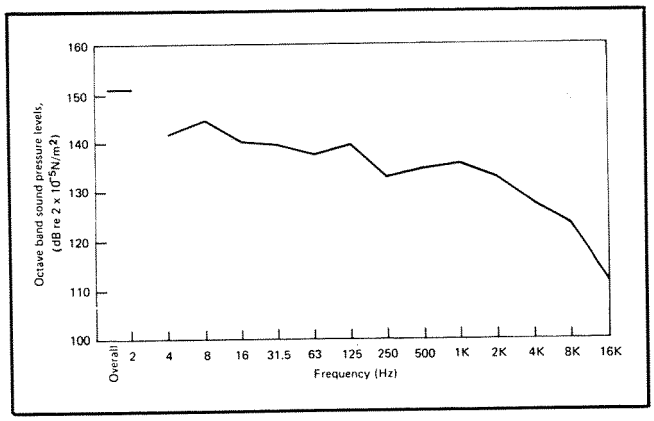


Figure 21. Maximum octave band sound pressure levels occurring during first 150 ms after impact (0.125 s time constant) right hand microphone.

filler pipe was below the level of the fuel, there were no fuel leaks from the filler cap or its interface with the filler neck, only from the connection of the rubber hose to the filler neck. It was then decided to insert a rubber bung into the end of the rubber hose and retest. In this repeat test there were no fuel leaks. The test was also carried out in the opposite direction of rotation and again there were no fuel leaks. Therefore if a better seal can be made at the fuel filler neck to the rubber hose connection, the vehicle would meet the requirements of the standard in this crash test mode.

Noise Measurements

The sound pressure levels are shown in Figures 18 and 19, the results of the octave band analysis are shown in Figures 20 and 21, and the 'A'-weighted octave band levels are shown in Figures 22 and 23. The instantaneous positive peak pressure of 1940 Pa for the left side of the driver's head and 2040 Pa for the right side of the driver's head is equivalent to an instantaneous sound pressure of

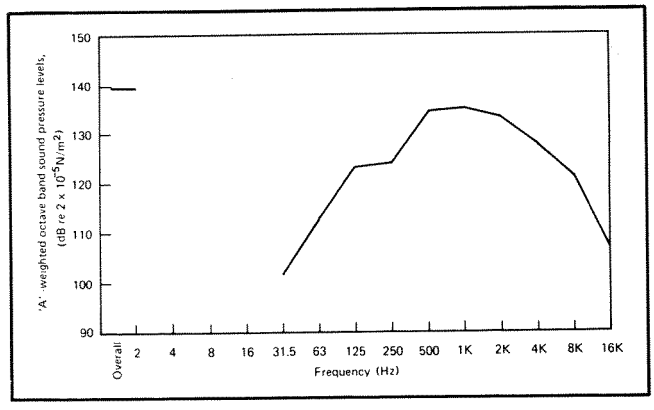


Figure 22. Maximum 'A'-weighted octave band levels occurring during first 150 ms after impact (0.125 s time constant) left hand microphone.

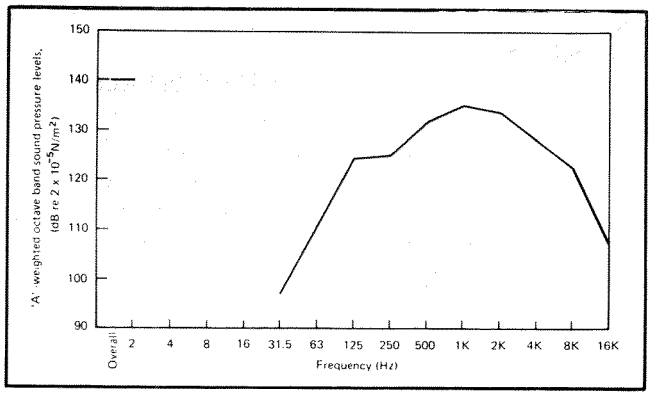


Figure 23. Maximum 'A'-weighted octave band levels occurring during first 150 ms after impact (0.125 s time constant) right hand microphone.

159.7 dB and 160 dB respectively. The figures were recorded with all of the windows closed.

This result can be compared with the over-riding limit of 150 dB of an instantaneous sound pressure in an impulse noise as quoted in the U.K. Code of Practice for reducing the exposure of employed persons to noise. (Ref 4).

HEADFORM IMPACT TESTS

Test Method

The crash test was followed by a series of impact tests on the interior surface, using a modified form of the test specified in Annex 4 of Regulation ECE 21 (Procedure for testing energy-dissipating materials). These tests were conducted at 14 specified points on the vehicle, distributed over the upper and lower facias, the header rail, and the windscreen pillars. The impact tests were carried out using an unrestrained spherical headform containing three accelerometers aligned with the impact direction and two other mutually perpendicular axes. This was fired at the impact point by a pneumatic launcher. The system incorporates two major advances over the normal ECE 21 pendulum test in matching more closely the conditions of a real accident:

1) The headform is capable of absorbing energy in rotation as well as translation when a glancing impact is made. A pendulum mounted headform is capable of absorbing energy only in translation.
2) The test is performed on a whole vehicle incorporating the damage resulting from the impact test, whereas the ECE 21 is normally conducted on segments cut from an undamaged car.

The impact speed of the headform was 6.7 m/sec and the impacts were aimed either in a direction originating from the area of the front seat occupants' heads for the header rail and upper facia or in a longitudinal direction for the lower facia tests. The signals were filtered to Channel Class 1000 to SAE J211b.

Headform Impact Test Results

The results of the tests are given as part of Table 3 the severity of the headform acceleration being expressed in terms of the peak magnitude of the Resultant Acceleration vector, the Gadd Severity Index, and the Head Injury Criteria. The points impacted are given in Figure 24 and may be divided into two groups. The first group are contactable in the initial or primary vehicle impact. Examples of this are the upper surface and underside of the facia which generally give rise to impacts of low severity as a result of their energy-absorbing characteristics. The second group are protected by the airbags during the primary impact but then might be contacted in a secondary vehicle impact when the airbag has deflated.

In some cases, the latter produce more severe accel-

Table 3. Headform impact tests—impact speed 6.7 metres/sec (15 mile/h)

Impact Position (Figure 24)	Minicars RSV			Calspan RSV		Chrysler Alpine	
	Peak g	Gadd SI	HIC	Peak g	Gadd SI	Peak g	Gadd SI
A	275	1134	893	47	161	94	—
B	46	178	157	59	206	57	100
C	34	95	87	45	321	47	140
D	33	61	51	40	141	88	292
E	59	111	79	—	—	—	—
F	170	961	820	61	227	61	176
G	112	423	354	79	305	88	239
H	30	83	76	—	—	—	—
I	123	440	369	58	210	58	151
J	24	59	53	—	—	—	—
K	*114/221	467/376	378/339	35	85	69	186
L	89	372	344	—	—	—	—
M	27	48	41	—	—	—	—
N	44	112	103	167	576	63	192
Belt anchorage	—	—	—	235	1621	104	524

* The second figure refers to a secondary impact of the headform on the inside of the windscreen, which it struck in rebounding from the impact point.

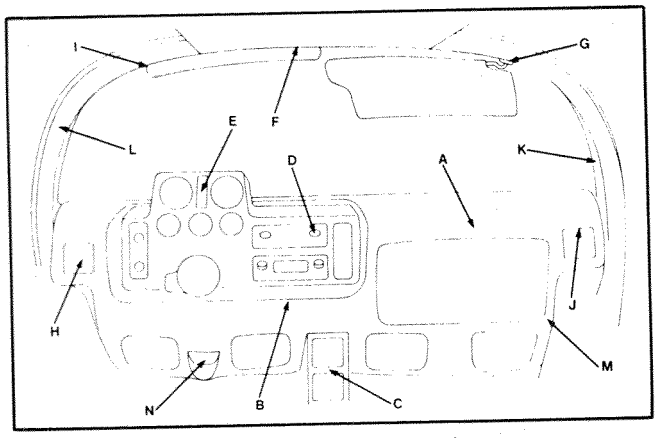


Figure 24. Headform impact position code.

erations of the headform, as for example at point A (see Fig 25), where the edge of the airbag container lies inside the facia covering material, and at point F near the centre of the header rail. Some impact areas resulted in sharp fragments of material being produced which could cause lacerations to an occupant. This occurred at points D and E on the instrument panel and to a limited extent at point C on the centre console.

DISCUSSION

The Minicars RSV Crash Test

The RSV impacted the 30° wood faced angled barrier at a speed of 60.3 km/h. The driver's (port) side of the vehicle made first contact.

The vehicle structure met the intrusion requirements of ECE Regulation 33 with regard to front occupant survival space.

Two Part 572 dummies were positioned in the front seats. Analysis of the signals from the dummy instrumentation showed that they met the requirements of FMVSS 208.

Both the restraint systems functioned; but whereas the passenger's system started to deploy 0.017 after first contact, the driver's system did not start until 0.045 sec.

The 30° angled port side barrier impact requirements of FMVSS 301 were met, there being no fuel leakage during the impact or the 30-min. period following impact. However, when the vehicle was subjected to the static rollover test required in the regulation, a fuel leak that exceeded the limit set in the regulation was observed. After the fuel leak had been stopped by removing a hose from the filler pipe and sealing it off, the test was repeated. This time there was no fuel leakage. Therefore, if a fuel-tight joint had been made to the filler pipe, the vehicle could have met the static rollover test requirements of FMVSS 301.

The peak noise pressure levels were measured to be 159.7 dB for the left side of the driver's head and 160 dB for the right side of the driver's head with all of the windows closed. These exceed the 150 dB level recommended in the Code of Practice for Reducing Exposure of Employed Persons to Noise.

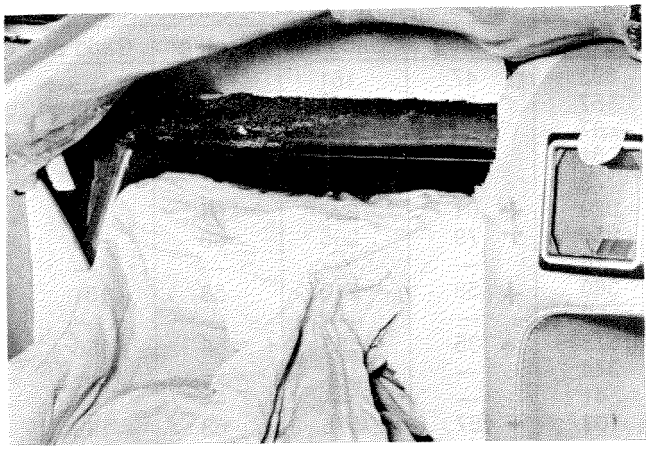


Figure 25. The metal work of the passenger's airbag container.

The Minicars Headform Impact Tests

The results of the headform impact test show that although the areas in the front of the car which might be contacted in the primary impact are well protected, there are points which may be contacted in the secondary impacts which require additional protection. This would be in the form of improved energy-absorbing material on the facia and header rail (at points A and F, Fig 24) and a change to a material that does not produce sharp fragments when impacted on the instrument panel and data console (points C, D, and E, Fig 24).

Comparison of the Minicar's RSV with the Calspan/Chrysler RSV and a Standard Production Chrysler Alpine

The combined results of the three cars are given in Tables 1, 2, and 3. The Chrysler Alpine car was the baseline production car used to develop the Calspan RSV. Although the Minicars RSV had the greatest overall static crush, the survival space as defined by ECE Regulation 33 was greatest for this car with only the Alpine production car being less than is required for different conditions in the regulation. The increased crush in the Minicars RSV is reflected in a lower vehicle deceleration pulse measured at the A-post on the impacted scale, with a corresponding increase in duration.

With a minor design modification to the Minicars fuel filler system, both RSVs would have passed the static rollover test of FMVSS 301. The Chrysler Alpine production car was not tested to the standard.

As the occupant restraint for each car was different, their effectiveness can only be assessed by the dummy performance. The Chrysler Alpine had standard production lap and diagonal belts; the Calspan RSV had a steering wheel airbag and a passenger inflator belt with knee restraints for both; and the Minicars RSV had airbags with knee restraints. Although the noise level in the Minicars RSV was 165 dB, it cannot be directly compared to the Calspan RSV result of 153 dB since the Minicars RSV windows were closed and the Calspan RSV windows were not.

Although a different type of dummy was used in the Chrysler Alpine test and a direct comparison between the tests should not be made, the indications are that there was a marked improvement of the injury criteria for the heads of the RSV passengers and the Calspan driver. The injury criteria for the Minicars driver's head are within FMVSS 208 but, possibly due to the late deployment of the airbag, are no better than a typical standard production car. The chest accelerations for all the cars were similar. The axial femur forces were higher for both RSVs and reflect the use of knee bolsters as part of the restraint design as compared to the production vehicles' use of lap and diagonal belts as the primary restraint. In all cases the femur loads were below the maximum allowed in FMVSS 208. The high lateral acceleration at the pelvis of the Minicars RSV driver does not necessarily imply an injurious loading as it will depend on the position and distribution of the accelerating force.

Because of the different design concept of the Minicars RSV, direct comparisons of headform impact tests between cars at specific points in the passenger compartment were not always possible (e.g., there is no upper anchorage for a seat belt on the B-post in the Minicars RSV). The impact positions given in Table 3 relate directly to the Minicars RSV and, where possible, the results for the equivalent position in the other two cars have been given. The design requirement to provide a rigid door hinge mounting down the centreline of the roof of the Minicars RSV is reflected in the higher figures for the car's header rail and windscreen pillars (points F, G, and I, Fig 24). The need to cover with an energy-absorbing material certain small but critical impact areas that will not necessarily be identified by the barrier test is highlighted by the Calspan RSV figure for the seat belt upper anchorage and the steering column (point N). The attention given in both RSVs to impact protection over the area of the centre console is shown by the higher figure on the standard production car (point D). Comment has already been made on the need to protect against secondary vehicle impacts when airbags may no longer be providing protection (point A).

CONCLUSIONS

The protection provided for occupants of the Minicar RSV in a 60 km/h 30° angled barrier impact appears to be generally of a high order. A few revised details of interior design and functioning of components would further improve the results.

Comparisons with the Calspan RSV and its baseline car, the Chrysler Alpine, show the improvements in protection that can be provided. Most particularly intrusion around occupants has been prevented and a severe impact to the head of the front passenger has been eliminated. The results show both the good protection in a standard production car that can be provided for wearers of seat belts against most injuries and the high level of protection that is demonstrated to be possible by the RSV cars.

REFERENCES

1. Friedman D. The Minicars Research Safety Vehicle. Presented to the Eighth RSV Conference Wolfsburg October 1980.
2. Smith, B F and Petty S P F. The Results of Headform Impact and Angled Barrier Tests on the Calspan RSV. Presented to the Eighth RSV Conference Wolfsburg October 1980.
3. Lowne R W. A Revised Upper Leg Injury Criteria (Unpublished).
4. Code of Practice for Reducing the Exposure of Employed Persons to Noise. Page 6, Section 4.7 HMSO 1972.

Crown copyright 1982: Any views expressed in this paper are not necessarily those of the Department of the Environment Department of Transport. Extracts from the text may be reproduced, except for commercial purposes, provided the source is acknowledged.

Design and Development of Modified Integrated Vehicle for Enhanced Crashworthiness

G. KLAUS, R. SINNHUBER, G. HOFFMANN
Volkswagenwerk AG,
Wolfsburg, W. Germany

ABSTRACT

The report summarizes the work of Volkswagenwerk AG in the MIV (Modified Integrated Vehicle) Research Project of the U.S. Department of Transportation, National Highway Traffic Safety Administration.

Within the framework of the MIV Project Volkswagenwerk was requested by NHTSA to develop concepts and structures which would harmonize contradictory design considerations—the greatest possible reduction in dummy loadings with the lowest possible vehicle weight increase under the precondition that the design be suited to current mass production methods. The 4 door-Volkswagen Rabbit was to serve as the basis of the study.

The NHTSA goals mandated the development of new technology in conjunction with new test configurations and devices for lateral impact at 30 mph and frontal fixed barrier impact at 35 mph.

The realization of NHTSA's project goals necessitated the development of an all-new "Integrated Structure," a concept in which the greatest number of components is effective during the defined frontal and lateral impacts.

The specific goals established by NHTSA were met in the MIV project. The results of Phase 1 demonstrate a potential for promising reductions in dummy loadings. However, because these reductions were observed in only a single test, the results are presently not sufficient to justify the incorporation of MIV components into production vehicles. Further research on a broader scale with a broad range of vehicle types is required. The MIV project is an important step, but only one of many which must be taken in the complex research effort necessary to realize further increases in existing levels of passive safety in real world lateral and frontal collisions.

INTRODUCTION

The objective of the MIV project was to optimize two contradictory design considerations—the greatest possible reduction in dummy loadings at the lowest possible vehicle weight increase (max. increase 20 lb/vehicle) with the precondition that the design be suited to mass production.

The MIV is by definition not a totally integrated concept as discussed and presented by Volkswagenwerk AG during the Eighth ESV Conference or as demonstrated in the form of the Volkswagen Integrated Research Vehicles IRVW I and II. The MIV, in contrast, does not include consideration of special energy saving or special emission reduction engine/transmission concepts.

Because vehicle layout, according to established criteria and subsequent reinforcement for modified design criteria, always leads to substantial weight increases with commensurate limitations upon producibility, it was decided not to use the "add-on" strategy, but to develop an all new "Integrated Structure" for the 4 door MIV. This concept requires that the largest possible number of components be effective during the specified frontal and side impacts.

NHTSA's design goals were the 35 mph frontal fixed barrier impact and the 30 mph side impact with the new 1.565 kg (3,450 lb) deformable 19° Crabbed Barrier and the new HSRI Dummy which were specially developed for the side impact.

STATEMENT OF WORK

Vehicle engineering measures for the increased passive safety requirements specified in the project were to be derived from the results of baseline tests as well as from the know-how gained in the ESVW I, ESVW II, RSVW, IRVW I and II projects. The effects of these measures were to be examined in defined tests:

—19° Crabbed Barrier/4 door MIV-60° side impact at 30 mph impact velocity
—4 door MIV/Fixed Barrier head-on impact at 35 mph impact velocity

The NHTSA goals mandate the development of new technology in conjunction with new test configurations and devices for lateral and frontal impacts.

—for greatest possible reduction in dummy loads
—for lowest possible weight increase
—consistent with current mass production methods.

Initially several baseline side impact tests with unmodified vehicles were to be performed at 30, 35, and 40 mph to assess the dependency of impact velocity upon dummy loadings and vehicle deformation.

The new HSRI Side Impact Dummy and the newly developed Crabbed Barrier (Figures 1, 2, and 3) were used. The deformable moving barrier was crabbed at an angle of 19°. The impact is intended to simulate a 60° car-to-car side impact where the velocity of the striking vehicle is twice that of the struck vehicle.

The initial tests were to constitute the basis for modifications to be derived to meet requirements for increased

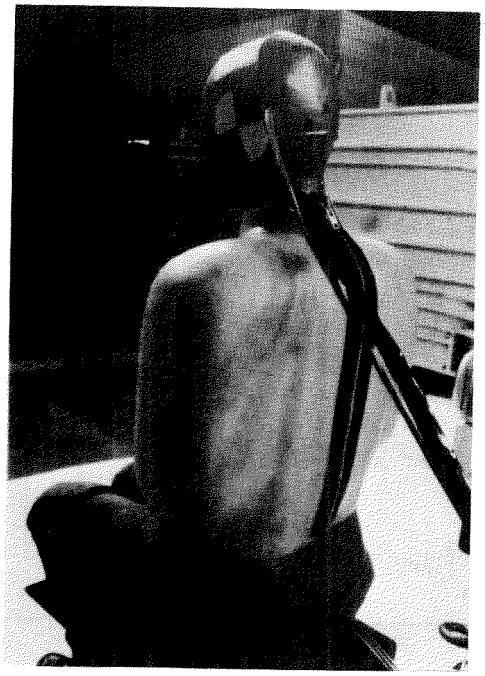
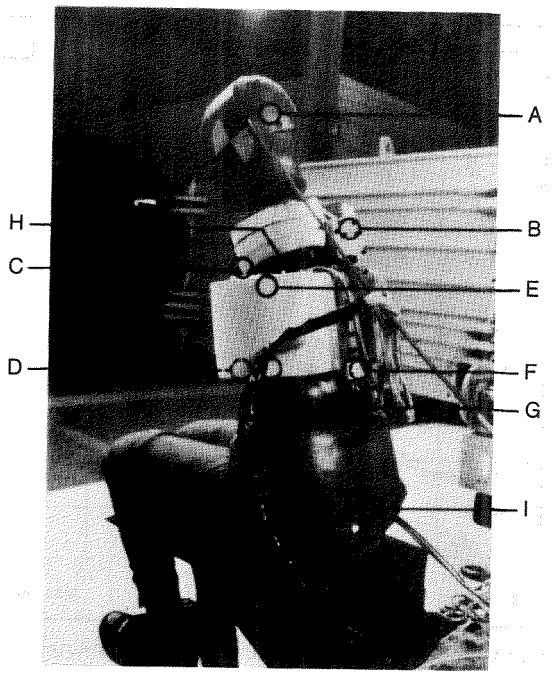


Figure 1. HSRI side impact dummy sid.



A. Head Triaxial
B. Upper Thorax (T1), Triaxial
C. Upper Sternum, Longitudinal
D. Lower Sternum, Longitudinal
E. Left and Right Upper Rib, Lateral
F. Lower Thorax (T12), Triaxial
G. Left and Right Lower Rib, Lateral
H. Displacement Transducer
I. Pelvis, Triaxial

LOCATION OF 18 ACCELEROMETERS

passive safety in the impact configuration defined in the MIV project.

TEST PARAMETERS AND TESTS PERFORMED

Test Parameters

All tests were run under the following conditions as specified by NHTSA:

—Side Impact:

Striking vehicle:	simulated by the deformable Crabbed Barrier
Struck vehicle:	4 door VW Rabbit or MIV
Impact point:	I = (D + 6) / 0.8693 + 1.5 (in)
Impact angle:	60°
Dummies:	two 50% male HSRI at the impacted side, front and rear seating positions, as delivered by NHTSA

Protection criteria for the HSRI Side Impact Dummy were specified by NHTSA as: "Volkswagen shall use measures so that the largest possible reduction in dummy loads is achieved."

—Frontal Impact:

Impact speed:	35 mph
Impact angle:	0°
Dummies:	two 50% male Hybrid II on the front seats
Protection criteria:	FMVSS 208

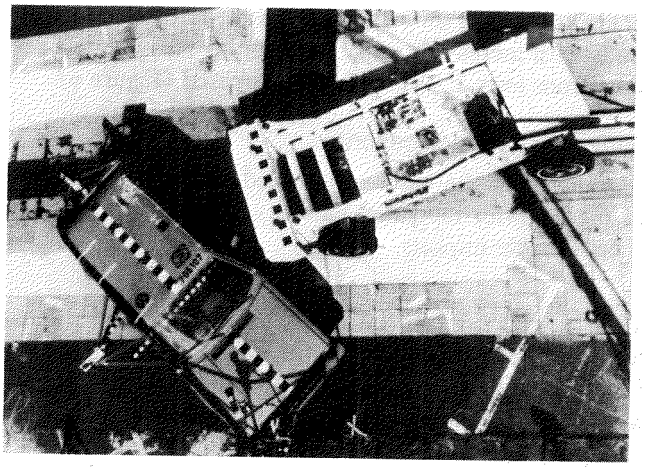
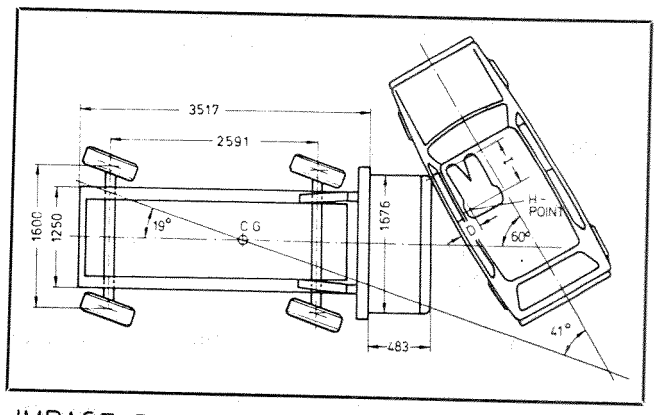


Figure 2. Side impact test configuration.



IMPACT POINT : I=(D+6)/0.8693+1.5 (IN)

Figure 3. Side impact test configuration point of initial contact.

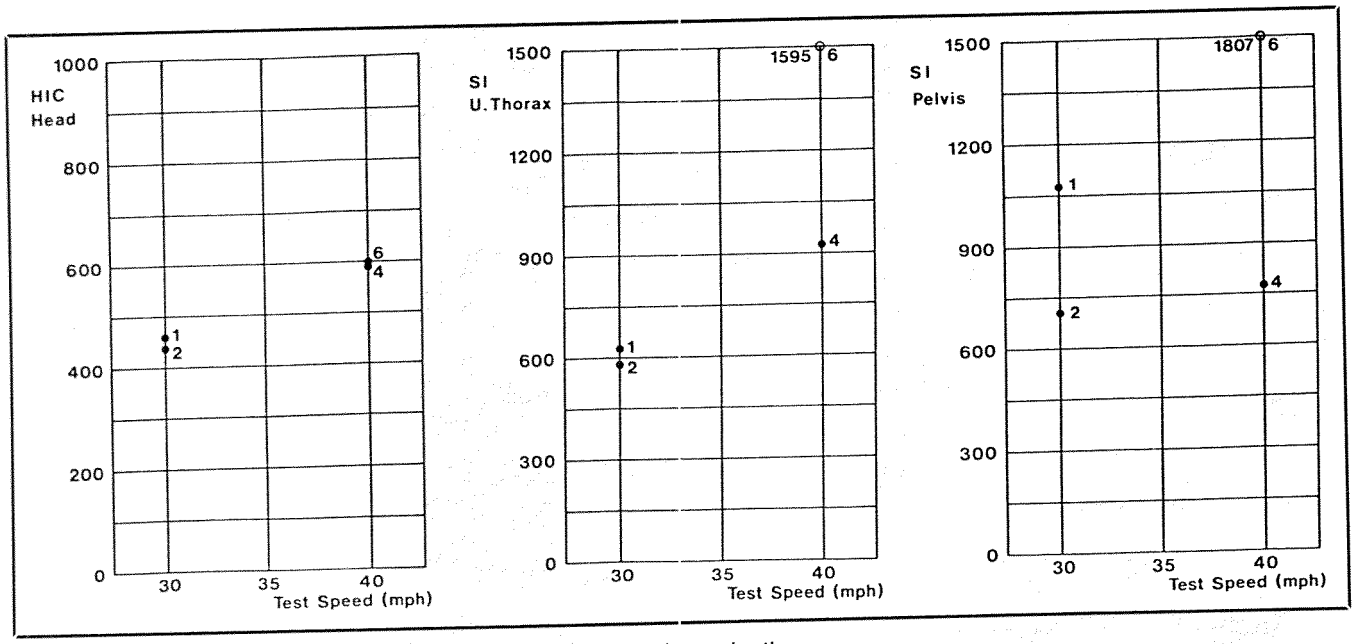


Figure 4. Baseline side impact tests 1, 2, 4 and 6. Scatter determination.

Tests Performed

The following side impact tests were conducted:

—Baseline Side Impact Tests with 4 door VW Rabbits

Test 1	30	
Test 2	30	
Test 3 v =	35	mph
Test 4	40	
Test 6	40	

—Side Impact Tests with 4 door MIV

Test 5	30	
Test 7 v =	30	mph
Test 8	30	

Test 5: Side impact with the new MIV "Integrated Structure" developed in this project and the MIV padding.

Test 7: Side impact with MIV padding only.

Test 8: Side impact with the MIV "Integrated Structure" without MIV padding.

Baseline Tests

Baseline side impact tests were conducted for the following reasons:

a) For determination of the scatter of dummy loadings and vehicle deformation under identical test conditions

b) To evaluate the dependency of dummy loadings and vehicle deformation upon different impact velocities

c) For derivation of modifications for the increased passive safety requirements specified by NHTSA in this project

Scatter Determination

For scatter determination, tests 1 and 2 were performed at 30 mph, and tests 4 and 6 at 40 mph. The scatter for driver dummy loadings is shown in Figures 4 and 5. The transformation of mechanical parameters to medical AIS values (see Figure 5) is described and discussed in the paper of Richard M. Morgan and Hal P. Waters entitled "Comparison of two Promising Side Impact Dummies," presented at the Eighth ESV Conference. The transformation algorithm is still under development. In a comparison of tests 1 and 2, the chest damper, modified by NHTSA, probably caused the greater portion of the scatter. In tests 4 and 6 the scatter was probably caused by the deformation element of the Crabbed Barrier. In test 4 the element had slight exterior cracks.

Dummy Loading as a Function of the Collision Speed

The test results show that there is an increase in dummy loads with increasing impact velocity if only the test results from tests 2, 3, and 6 are compared (Figure 6).

Derivation of Modifications

Analysis of the baseline tests led to the development of the MIV for increased passive safety requirements in specified side impacts.

VW STUDY FOR COMPLIANCE WITH THE MIV REQUIREMENTS IN SPECIFIED LATERAL AND FRONTAL IMPACTS

The NHTSA goal to achieve the greatest possible reduction in dummy loads, in keeping with the objective of

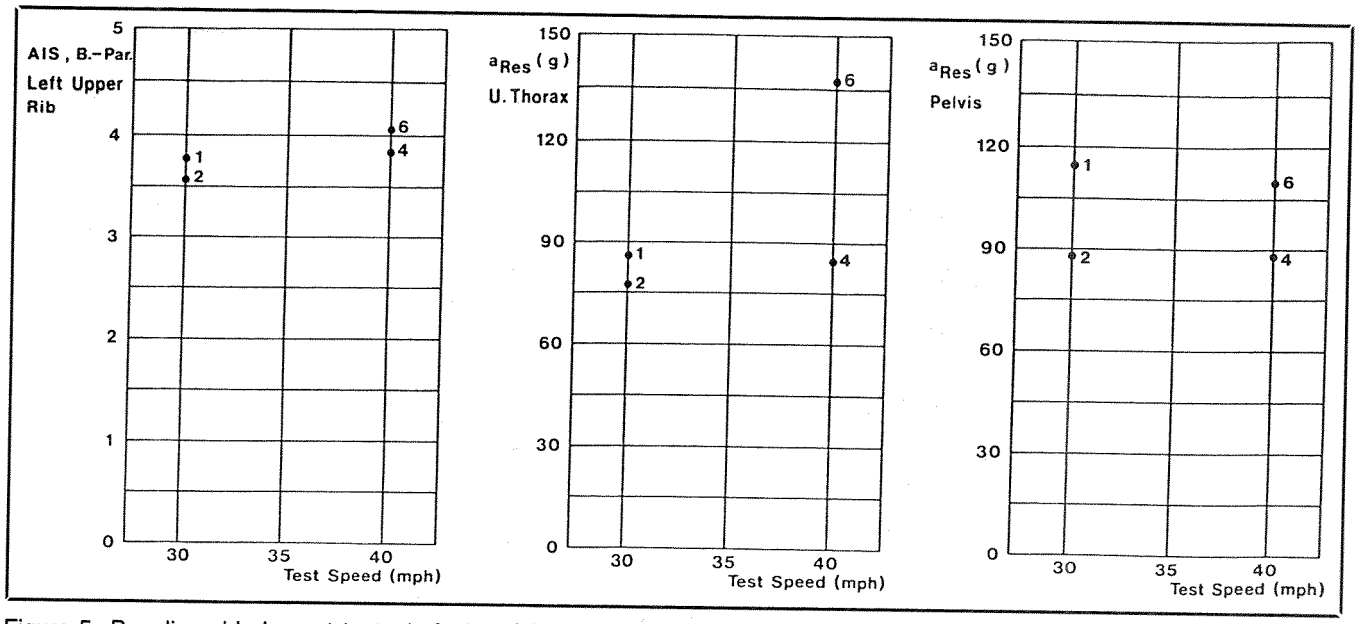


Figure 5. Baseline side impact tests 1, 2, 4 and 6.

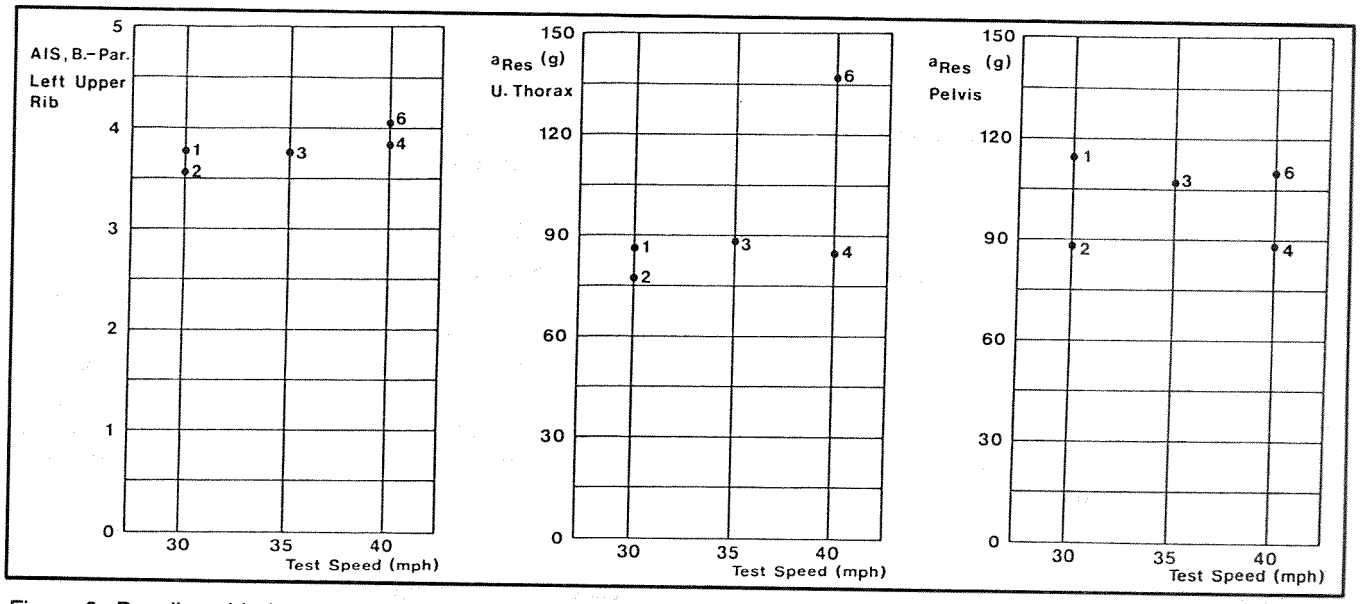


Figure 6. Baseline side impact tests 1, 2, 3, 4 and 6.

lowest possible weight increase together with the prerequisite that the design be suited to mass production, required the development of a new "Integrated Structure" for the MIV. This concept requires that the greatest number of components be effective during frontal and side impacts. The "Integrated Structure" approach involving total redesign, rather than the less effective strategy utilizing add-on parts, is necessary to achieve the goals established by NHTSA.

The MIV Integrated Structure (Figure 7) was developed in conjunction with the unique combination of test configurations and test devices specified by NHTSA in this project.

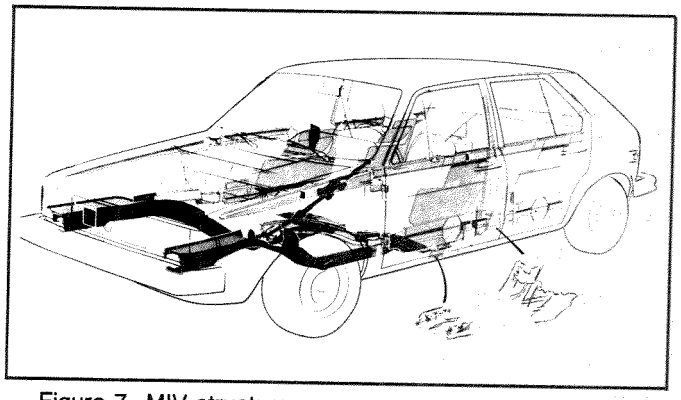
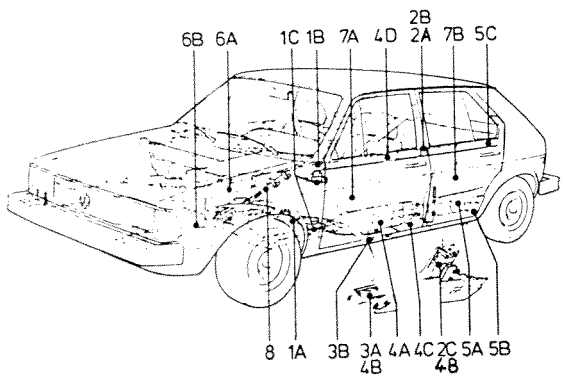


Figure 7. MIV structure.



(1) A – PILLAR
1A WHEELHOUSE BEAM
1B A–PILLAR BRACE
1C HINGE TO A–PILLAR ATTACHMENT PLATE

(2) B – PILLAR
2A WINDOW BEAM SUP.
2B B–PILLAR BRACE
2C DOOR TO B–PILLAR ATTACHMENT

(3) SILL BEAM
3A DOOR BEAM AND SIDE SILL INTERLOCK
3B SIDE SILL BRACING PLATE

(4) FRONT DOOR
4A DOOR BEAM
4B DOOR BEAM INTERLOCK
4C DOOR LOCK MOUNTING
4D SIDE WINDOW BEAM

(5) REAR DOOR
5A DOOR BEAM
5B DOOR LOCK MOUNTING
5C SIDE WINDOW BEAM

(6) FRONT STRUCTURE
6A UPPER BEAM
6B LONGITUDINAL BEAM

(7) DOOR PADDING
7A FRONT DOOR PADDING
7B REAR DOOR PADDING

(8) STEERING SYSTEM

Figure 8. MIV structural components.

The structural components (Figure 8) are:

(1) *A-Pillar*
1A Wheelhouse Beam
1B A-Pillar Brace
1C Hinge to A-Pillar Attachment Plate

(2) *B-Pillar*
2A Side Window Beam Support
2B B-Pillar Brace
2C Door to B-Pillar Attachment

(3) *Sill Beam*
3A Door Beam and Side Sill Interlock
3B Side Sill Bracing Plate

(4) *Front Door*
4A Door Beam
4B Door Beam Interlock
4C Door Lock Mounting
4D Side Window Beam

(5) *Rear Door*
5A Door Beam
5B Door Lock Mounting
5C Side Window Beam

(6) *Front Structure*
6A Upper Beam
6B Longitudinal Beam

(7) *Door Padding*
7A Front Door Padding
7B Rear Door Padding

(8) *Steering System*

TESTS WITH MIV VEHICLES AND COMPONENTS

Side Impact with MIV

The side impact (test 5) with the MIV incorporating the new "Integrated Structure" and MIV side padding demonstrated a promising potential for reductions in dummy loading (Figure 9). Structural deformation was also reduced (Figure 10). The PAP values shown are part of a new algorithm currently under development by NHTSA to transform mechanical parameters into medical AIS values.

The reduction in dummy loadings cannot be reliably attributed or assigned to individual MIV components because dummy loadings are dependent upon test parameters and many other factors including but not limited to:

—force/deflection characteristic of the front structure of the striking car
—force/deflection characteristic of the side structure of the struck car
—force/deflection characteristic and dimensions of the padding, and
—free space between the dummy and the padding.

Comfort is reduced and vehicle operability is impaired by the padding selected and installed primarily under considerations of technical feasibility without emphasis upon comfort or interference with operability.

The demonstrated reduction in dummy loading with the relatively low overall weight increase confirms that

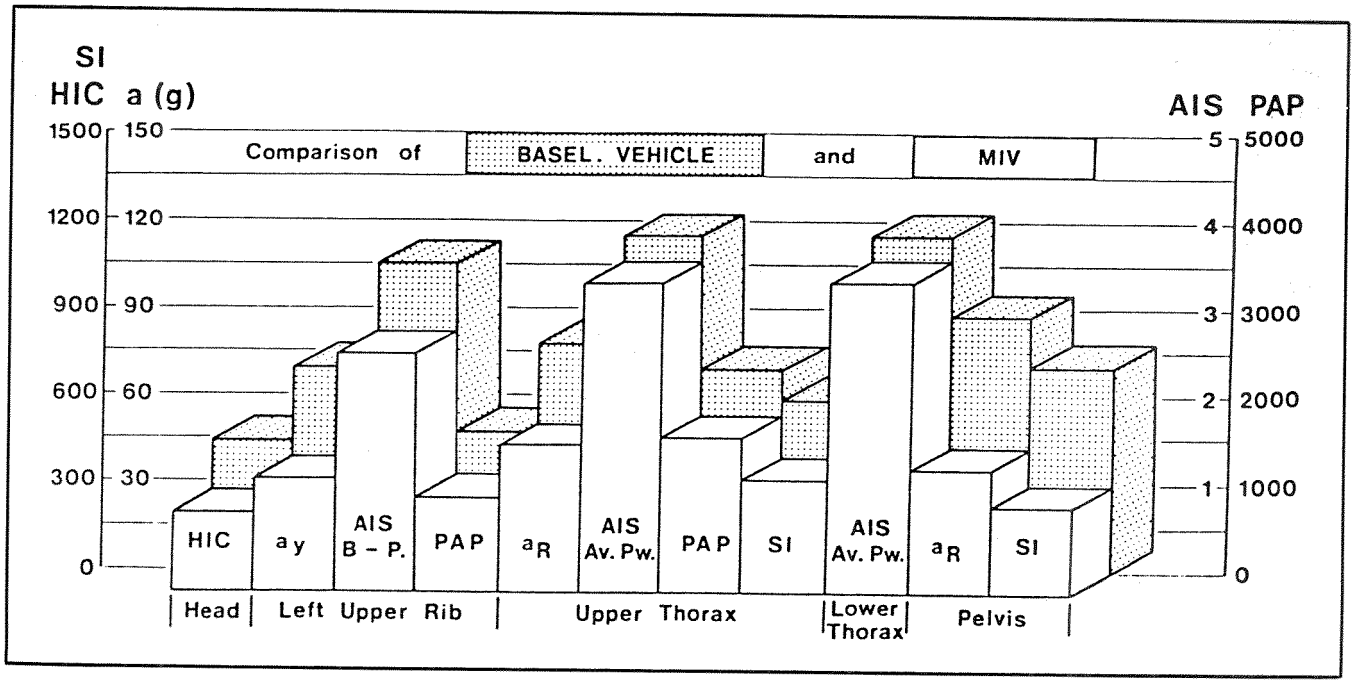


Figure 9. Side impact test 5.

an integrated approach is the only appropriate manner to deal with contradictory considerations of increased levels of passive safety and low weight increase consistent with current mass production methods. The extent to which this potential can actually be realized will depend, in part, upon the performance of MIV structures in defined side impacts when struck by the stiffer MIV frontal structures developed for the 35 mph frontal fixed barrier impact.

Side Impact with MIV Door Padding Only

The objective of test 7 was to evaluate the potential for reduction of dummy loads using only the same door padding as used in test 5 but without MIV structural components. The higher reduction of dummy loads using the "Integrated Structure" and the MIV door padding is evident (Figure 11).

Side Impact with MIV Structure Only

The purpose of test 8 was to determine the effect of the "Integrated Structure" without MIV padding on dummy loads (Figure 12).

A comparison of tests 7 and 8 demonstrates that the left upper rib values in test 7 are lower, some upper thorax and the lower thorax and pelvis values are higher when only the MIV padding is used (Figure 13).

Baseline Vehicle

MIV

Figure 10. Side impact comparison of test 2 and 5.

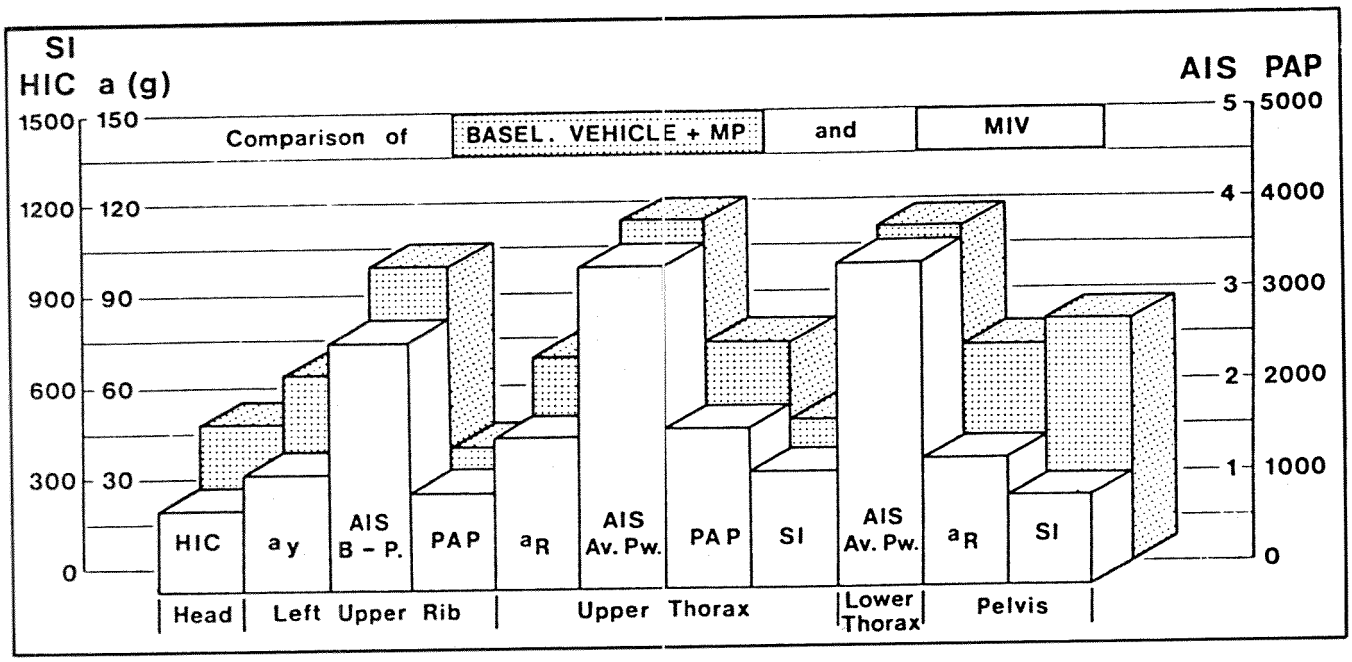


Figure 11. Side impact test 7.

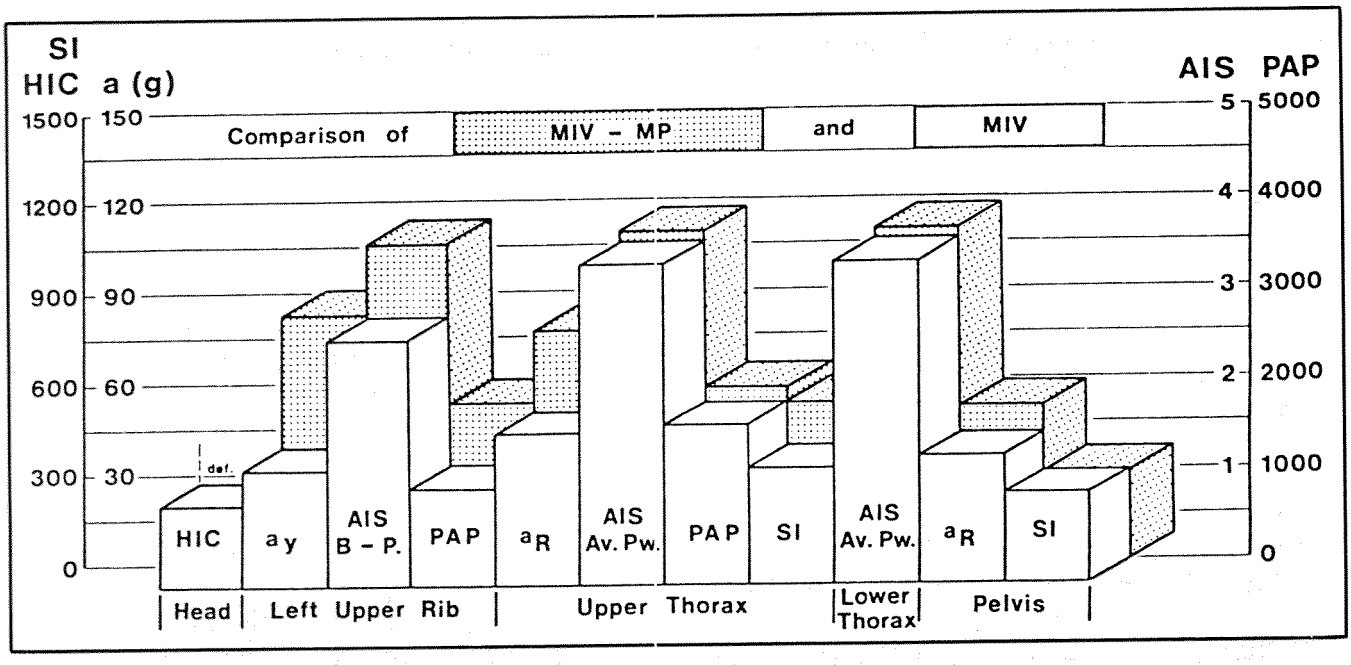


Figure 12. Side impact test 8.

In general, MIV padding will be less effective than the newly developed "Integrated Structure;" it also decreases occupant comfort and interferes with vehicle operability.

Reduction of the thickness of the padding for occupant comfort and non-impairment of vehicle operability will reduce the effectiveness of the "padding only modification."

Frontal Fixed Barrier Impact with MIV

The head-on fixed barrier impact was conducted with the MIV at 35 mph (Figure 14). Working principles of a new passive restraint system and a new steering system were simulated together with the new "Integrated Structure."

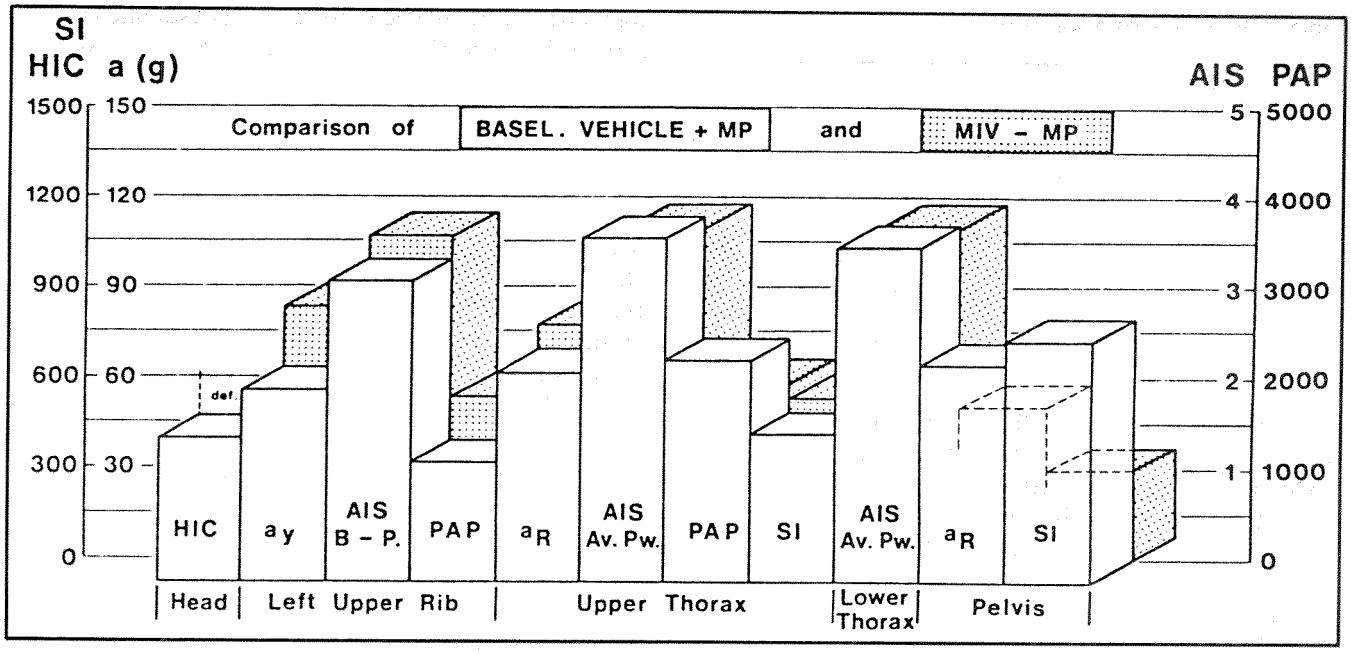


Figure 13. Side impact test 7 and 8.

Figure 14. Frontal impact with MIV.

Impact Speed = 35 mph.

The MIV complied in all respects with impact related FMVSS (Table 1).

SUMMARY

In Phase 1 of the MIV project, VW AG examined approaches which appear technically feasible for the 30 mph side impact with the Crabbed Barrier and the 35 mph frontal fixed barrier impact under the following limiting conditions:

a) Maximum additional weight for the new structure and restraint system modifications: G = 20 lb
b) Maximum padding thickness without widening the vehicle, considering seat positioning and near contact by the 95% male dummy
c) To achieve the greatest possible reduction in dummy loads
d) Maintaining the objective that the design be suited to mass production.

Tests Performed

Five side impact tests were carried out with the 4 door VW Rabbit at 30, 35 and 40 mph to ascertain dummy response at increasing test velocities.

Two of them were conducted with the 4 door Rabbit at 30 and 40 mph in order to evaluate scatter in vehicle deformation and dummy loading.

One side impact was conducted at 30 mph in order to evaluate the effect of the MIV components.

In addition, each side impact test was conducted with

Table 1. Frontal Impact with MIV.

	DRIVER	PASSENGER
HEAD : HIC	554	639
CHEST: A_r (G) (3MS)	38.1	40.3
SI	335	359
PELVIS: A_r (G) (3MS)	46.5	48.2
SI	381	371
FEMUR LOAD L/R (KN)	6.7/6.2	7.2/6.0

only MIV structure and MIV padding to demonstrate the influence of the individual MIV components.

One head-on fixed barrier impact at 35 mph demonstrates the effect of the MIV structure in conjunction with increased frontal impact requirements.

RESULTS

If evaluation is limited to tests 2, 3 and 6, an increase of dummy loads with higher impact velocity can be seen.

Evaluation of all baseline tests (Fig. 6) demonstrates that the scatter of dummy loads is greater than the influence of test velocity. If tests 1 and 4 are excluded because of difficulties with the deformation element (test 4) and the new damper (test 1) modified by NHTSA, repetition of these tests is necessary in order to be able to provide more information about the magnitude of scatter.

Comparison of the side impact tests 2, 5, 7 and 8 at the same test velocity with baseline vehicle, MIV vehicles and components clearly demonstrates that the best overall results in reduction of dummy loads were achieved with the combination of MIV structure and MIV padding. It must be noted, however, that the padding configuration utilized represented a reduction of occupant comfort and impairment of vehicle operability.

Widening the MIV by 140 mm for improved comfort and no impairment of vehicle operability in order to compensate for the 70 mm door padding would, however, probably further increase dummy loadings. In wider vehicles occupant loading may be higher because of the greater distance between dummy and padding. This hypothesis would have to be tested in appropriate vehicular impacts.

The head-on fixed barrier impact was carried out with the MIV at an impact velocity of 35 mph. The working principles of a new passive restraint system and a new steering system were tested in conjunction with the newly developed "Integrated Structure." The test results demonstrated compliance with all Federal Standards associated with the frontal fixed barrier impact.

Considering secondary weight, which is necessarily required in order to correspondingly stiffen load bearing structures and the chassis, the added weight of the MIV components is estimated to be 25 lb. The estimated weight increase is in reference to a specific vehicle with a specific engine/transmission concept from one manufacturer, without considering alternative concepts, or other components such as air conditioner, power steering, etc.

Furthermore the crash test results obtained relate in each case to only one specific test. Even the tests in this project demonstrate that there can be a wide scatter of results under the same test parameters. Statements of general nature or applicability with respect to existing production vehicles can only be derived from this program after tests with additional vehicle types have been completed. Parallel studies should therefore be accomplished on a worldwide scale in order to obtain statements of a general nature. This study should also include further validation of test procedures and devices.

The test devices must be developed and manufactured in accordance with the realities of crash testing practises.

CONCLUSIONS

The MIV demonstrated a promising potential for dummy load reduction in the defined lateral and frontal impacts.

Comfort is reduced and vehicle operability is impaired by the MIV padding utilized in this project.

Further tests with a widened MIV incorporating MIV padding must be conducted to evaluate the effect of increased distance between dummy and side padding, required for comfort and vehicle operability, upon dummy loads and to test the Phase 1 results achieved with closer dummy/padding proximity. It must be emphasized that increase in overall vehicle width will necessarily affect vehicle weight, payload, aerodynamic drag and other coefficients, fuel consumption and possibly consumer acceptance.

The dummy load reductions were achieved with a relatively low overall weight increase and in accordance with current mass production methods. In view of universally accepted considerations of fuel economy and economic use of resources, additional weight should only be incorporated in vehicles where associated advantages clearly outweigh all associated disadvantages and it is assumed that available restraints are used. The use of occupant restraints available today and required to be used in 30 countries, is a prerequisite for the achievement of increased passive safety through the incorporation of MIV structures and components. The frontal fixed barrier impact at an increased velocity of 35 mph can otherwise lead to an overall decrease in passive safety levels if available restraints are not employed because frontal structures will necessarily be stiffer and produce correspondingly higher loadings in other impact types.

The correlation between dummy loading and occupant injury must be established in order to permit statements applicable to real world accidents to be made and to justify

incorporation of the MIV components tested into production vehicles.

Further research on a broader scale with a broad range of vehicle types is required to verify and correlate dummy loads and occupant injury with proposed test configurations and real world accident experience. Important considerations of vehicle compatibility cannot be ignored. Furthermore the influence that MIV components will have upon fuel consumption and the economic use of other resources, vehicle operability, comfort and purchase price must be studied in detail before statements of general applicability can be made.

No single isolated measure but rather only Integrated Concepts considering all previously described limiting conditions can be the proper means to achieve further increases in overall vehicle safety. The Integrated Structure with MIV padding of the Research MIV where the greatest number of components is effective during frontal and lateral impacts is the only aspect considered in this project.

The MIV project is an important step, but only one of many which must be taken in the complex research effort necessary to realize further increases in existing levels of passive safety in real world lateral and frontal collisions.

SVAR Alfa Romeo Synthesis Vehicle Alfa Romeo

THEME OF THE SVAR PROJECT

In the early 70s, projects were initiated on an international scale to improve the passive safety of vehicles. At first it was important to find a solution to set objectives, overlooking the effect of weights, costs, and/or results of production problems.

The sudden deterioration in world energy emphasized the consumption reduction issue alongside the passive safety of passengers—protection of drivers and pedestrians, pollution limits, etc.

The contemporary solution to these problems was not easy since most engine and structural projects are by nature in direct opposition to the demands of energy saving.

To this end, new research vehicles were sought to integrate the various concepts.

Under the ever-present pressure for fuel savings there are prototypes which address only this objective. Recently we have seen aerodynamic research vehicles with some exceptional Cx numbers between 0.20 and 0.30. Engines with extremely low specific fuel consumption are seen, such as the small turbo-diesels with direct injection. Ultralight prototype vehicles utilizing high-cost advanced techniques are another approach to reduce consumption and retain performance.

Finally it should be remembered that the car user, while he instinctively considers the passive safety of his vehicles important, remains very sensitive to the cost of fuel which represents a large percentage of the overall cost of the car's operation.

Alfa Romeo, in order to further its contributions to the research conducted so far, is using a base vehicle and placing large demands for a series of improvements with the simultaneous objectives of reduction in fuel consumption and increasing the levels of passive safety.

An Alfasud has been used to meet these objectives:

- determine fuel economy benefits utilizing today's technology, which could allow for fast adaptation to large production.
- the performance and handling characteristics must remain unchanged.
- obtain results to optimize the characteristics of passive safety.

BASE OBJECTIVES

PERFORMANCE

Maximum Speed	not below the standard base vehicle
Acceleration	
0 → 100 km/h from stop	
0 →1000 m from stop	
0 →1000 m in 5th gear starting from 40 Km/h	not below the standard base vehicle
Fuel Consumption (ECE A70)	
90 km/h	20% reductions as compared to base vehicle
120 km/h	20% reductions as compared to base vehicle
Urban	25% reduction as compared to base vehicle

PASSIVE SAFETY

Forecast verification tests

- 30° frontal impact at 65 km/h against barrier
- lateral car-to-car collision at 50 km/h
- impact at 50 km/h by 1800 Kg by moving barrier
- rollover at 50 km/h (control of fuel losses and dummy retention)
- pedestrian impact (adult or child) at 24 km/h

The dummies used for the tests were the Hybrid II type conforming to Part 572.

Injury criteria for occupant protection and pedestrians in impact tests:

- Head : HIC < 1000
- Chest : max acc. < 60 g/3 ms
- Femur : max axial force < 1000 dN

Performance required according to the following table:

	Frontal Impact	Lateral Impact	Roll Over	Rear Impact
Injury level	○	○		○
Doors must remain closed during impact	○	○	○	○
One door must be operative following impact	○	○	○	○
Possibility to remove dummies by hand following impact	○	○	○	○
No fuel leakage	○	○	○	○
Absence of fire	○	○	○	○
Total containment of occupants during impact	○	○	○	○
No failure of seat anchorages	○	○	○	○

RESEARCH PATHS

The basic objectives or goals of the research have been addressed according to the following groupings:

- *To lower fuel consumption*
  - Adoption of a high efficiency engine
  - Optimization of gearbox and final drive ratios
  - Lowering the aerodynamic drag-coefficient
  - Weight reduction
  - Reduction of rolling resistance
- *To increase safety*
  - Reinforcement of the front structure for improved frontal oblique impact resistance
  - Reinforcement of the rear structure to provide improved energy absorption during rear impact
  - Reinforcement of doors to reduce intrusion during car-to-car impact
  - Reinforcement of the windshield header area and addition of a roll bar in the central roof zone
  - Spoiler installation on engine compartment hood to protect pedestrians

MODIFIED VEHICLES

In order to carry out the required analysis, a vehicle was built which only included those features which tended to reduce fuel consumption (as indicated by the ESVAR-Energy Savings Vehicle Alfa Romeo), and another vehicle was developed to offer higher levels of people protection (SVAR-Synthesis Vehicle Alfa Romeo).

The ESVAR vehicle is to be considered a transitory effort to reduce fuel consumption, while leaving the handling qualities and occupant protection levels the same as those of production Alfasud vehicle.

The SVAR instead is the final product combining benefits of the ESVAR with those of improved passive safety by means of select reinforcement of the structures.

REFERENCE VEHICLES

One must take into consideration that a production Alfasud vehicle offers these principal characteristics:

Vehicle Body

- Front wheel drive. 4 cylinder opposed engine positioned longitudinally
  - Overall length 3995 mm
  - Overall width 1590 mm
  - Wheelbase 2455 mm
  - Track, front 1390 mm
  - Track, rear 1360 mm
  - Empty weight (DIN) 905 kg

Engine

- Flat four
- Bore 84 mm
- Stroke 67.2 mm
- Displacement 1490 cm^3
- Compression Ratio 9.5 : 1
- 2 carburetors, each with twin throats
- Maximum power DIN 70 KW (95 Cv) (6000 rpm/1')

- Maximum torque DIN 130 Nm (13.3 kgm) (3500 rpm/1')

Driveline

- Single dry disch clutch
- 5 speed transaxle

Ratios

1st	1 : 3.75
2nd	1 : 2.05
3rd	1 : 1.38
4th	1 : 1.02
5th	1 : 0.82

- Final drive ratio 3.54 : 1 (11/39)

Performance

- Maximum speed 174 km/h
- Acceleration

0 → 100 km/h from stop	10.70 s
0 → 1000 m from stop	32.40 s
0 → 1000 m in V from 40 km/h	40.65 s

Suspension and Tires

- Front suspension is McPherson struts and stabilizer bar
- Rear suspension is a solid axle located by a Watt link and Panhard rod
- Tires are 165/70 SR 13, wheel 5J

Fuel Tank

- Beneath rear seat, forward of rear axle

Vehicle Fuel Consumption

- Consumption ECE
  90 km/h 6.2
  L/100 km (37.9 mi/U.S. gal)
  120 km/h 8.1
  L/100 km (29.0 mi/U.S. gal)
  Urban 10.6
  L/100 km (22.2 mi/U.S. gal)

Compliance with European Standards for Passive Safety

The vehicle satisfies all European Standards in effect, including these:

- Steering system
  Reg. ECE 12
  Directive 74-297/EEC
- Seat belt anchors
  Reg. ECE 14.01
  Directive 81/575/EEC
- Seat anchors
  Reg. ECE 17.01
  Directive 81/577/EEC
- Visibility
  Reg. ECE 46
  Directive 79/795/EEC

Conformity with Emission Standard

- ECE 15.03-78/655/EEC

Conformity with External Noise

- ECE 51-81/334/EEC

FUEL CONSUMPTION REDUCTION

HIGHER EFFICIENCY ENGINE

After recent successful experiences by Alfa Romeo, it was decided to prepare a small number of Alfasud boxer engines with a microprocessor controlled electronic fuel injection and ignition system (C.E.M.) developed by Alfa Romeo.

Air fuel ratio and spark advance optimization in the whole engine operating range, correction for coolant and air temperatures, and fuel cut off during coast down ensure overall enhancement of engine efficiency and improved fuel economy. High accuracy of the microprocessor controlled ignition system made possible a compression ratio of 10.2 : 1. Work in process with knock sensors will hopefully bring this ratio to a higher value. The Complete Electronic Management System is programmed to permit a "modular" mode of operation: that is to say, the engine operates on 4 or 2 active cylinders according to the load conditions required by the driver.

2 cylinder operation is achieved simply by shutting off fuel injection in 2 of the 4 cylinders. In this way, the overall efficiency of the engine operating at varying low loads and at idle increases considerably. As low load operation and idling are very frequent in city driving, the final result is better fuel economy in these conditions.

Going on with the engine description and the schematic on the following page, we see (Fig. 1) injectors, and major engine components.

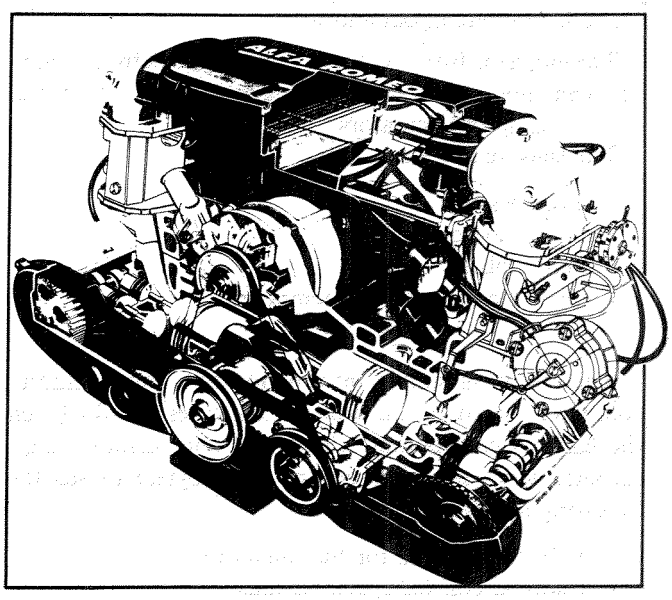


Figure 1. CEM engine.

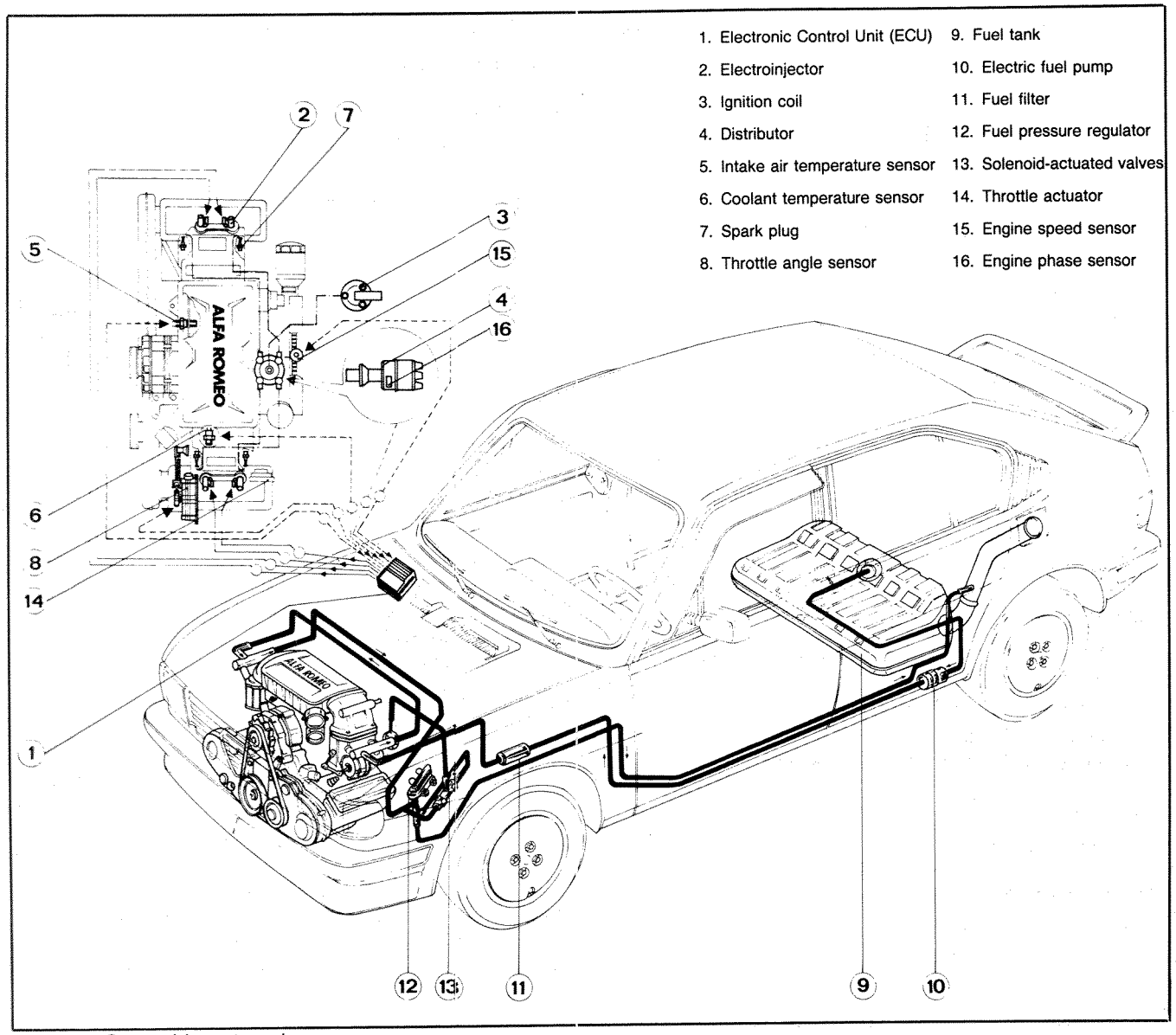


Figure 2. General layout engine.

The engine is fitted with the Complete Electronic Management, and can be seen in Figure 2 with its control box, sensors, and actuators.

The sensors are for:

- throttle angle
- engine speed
- engine phase
- coolant and intake air temperature

These sensors supply information to a digital microcomputer, based on an 8-bit microprocessor which, on the basis of calculations, algorithms and memory maps (program and mapping occupy 6 K bytes) drives the following actuators:

- 4 electroinjectors for fuel metering
- 1 special coil for spark advance
- throttle actuator to control engine idling speed

The idle actuator is useful on the 4 active cylinder CEM to secure constant idling speed under all conditions, but is essential for the "modular" mode of operation because maintaining idling speed with only 2 active cylinders requires wider throttle angles than would be with 4 cylinders in operation.

Flexibility of the system is such, that it was possible to develop the "modular engine" algorithm to achieve these interesting features:

- the passage from 2 to 4 cylinders and back to 2 is quick and smooth.
- 4 cylinder operation continues until the engine is warmed up.
- when the engine is running on 2 cylinders the two pairs change after a certain time and the accelerator is released in order to provide even temperatures in the engine and its combustion chambers. The driver is not aware of this pair switching.

- to ensure good driveability when starting from stop, a program provides 4 cylinder operation. For fast acceleration 4 cylinder operation continues until the change from 1st to 2nd gear is made.

This electronic controlled flat 4 Alfasud engine has the following specification:

displacement 1490 cc

max power (5400 rpm)
70 KW (95 Cv)

max torque (3500 rpm)
133 Nm (13.5 kgm)

In Figure 3 the B.S.F.C. map of this engine is shown as it relates to 4 cylinder operation.

Figure 4 demonstrates the difference in B.S.F.C. while operating in the modular mode. Notable is the benefit of reduced consumption during low speed operation typical of city use, as well as suburban trips at moderate speeds ($\leq$ Km/h).

OPTIMIZATION OF FINAL DRIVE RATIO

With the intent to operate the engine in conditions more favorable for lower fuel consumption, a more direct (longer) ratio was selected (3.15 compared to 3.54).

Below is a comparison of the overall drive ratios:

Ratio	Km/h/1000 rpm	
	3.15	3.54
4th Gear	32.39	28.29
5th Gear	40.29	35.23

A performance comparison between the base vehicle and the modified vehicle can be seen in the test results.

DRAG REDUCTION

Aerodynamic research has been carried out in the Pininfarina Wind Tunnel facility.

The steps from the original configuration to that of the final are these:

baseline vehicle

$S = 1.714\ m^2$
$Cx = 0.423$
$Scx = 0.725\ m^2$

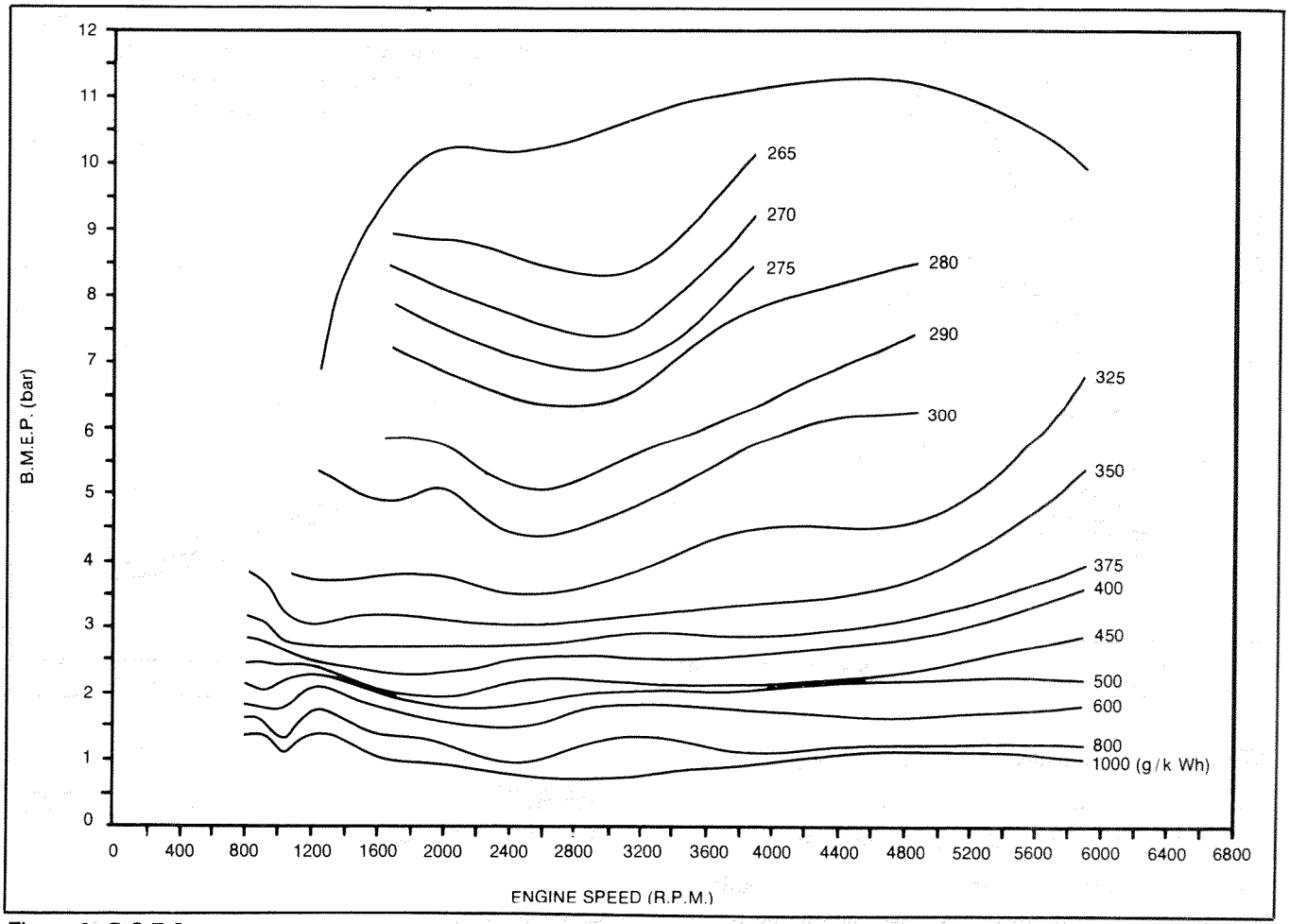


Figure 3. B.S.F.C. map 4 cylinder operation.

	Cx benefit
• Front air dam optimization	0.014
• Spoiler	0.037
• Wheel housings	0.006
• Nose and cooling air inlet	0.012
• Platform underside modifications	0.005
• Front door deflectors	0.021
Total gain	0.095

Final values of aerodynamically improved vehicle

$S = 1.714\ m^2$

$Cx = 0.328$

$Scx = 0.562\ m^2$

Drag reduction 22.5%

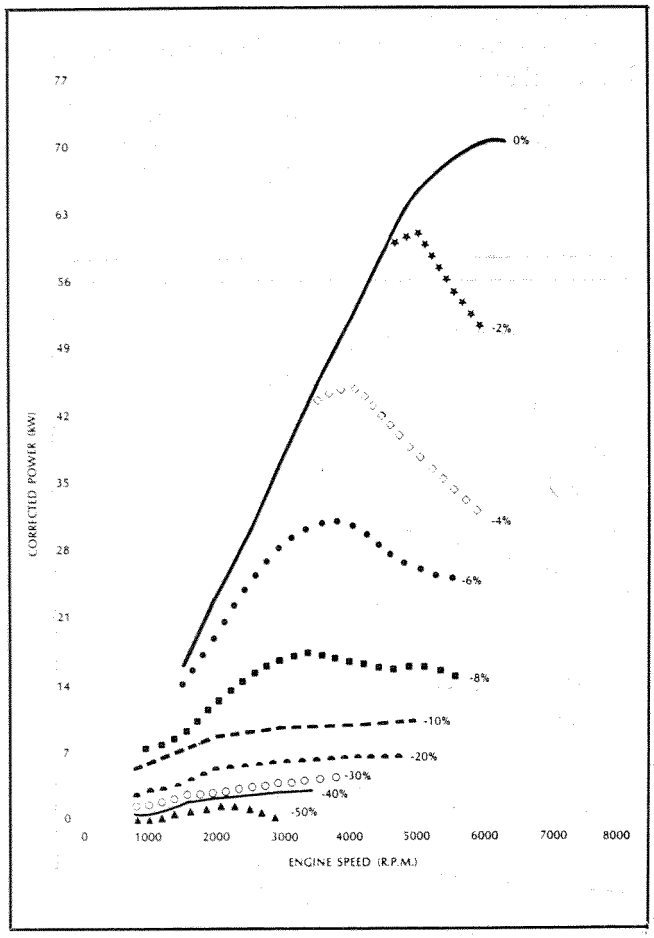


Figure 4. Map of final B.S.F.C. reduction achieved with C.E.M. modular Engine.

WEIGHT REDUCTION

Efforts at lightening have been made generally throughout the body, with the following limitations:

- weight reduction could not cause a compromise in complying with European safety standards for the ESVAR vehicle.
- structural resistance of the body/chassis could not be changed in any way that would cause a compromise to the basic objective of improving occupant protection.

The final results are shown here:

* Body Reduction	kg. 27,500
* Engine Reduction	kg. 6,000
* Mechanical components Reduction	kg. 35,500
* Interior & trim Reduction	kg. 12,000
* Spoiler, air dam, deflectors, etc. Increase	kg. 4,000
Total weight saved	kg. 77,000
Weight saving as compared to baseline vehicle	8.4%

REDUCTION OF ROLLING RESISTANCE

Figure 5 shows a typical curve for tire rolling resistance on an average vehicle, where 30% of the total resistance still remains at 80 km/h.

The ESVAR and SVAR vehicles are equipped with Pirelli P8 tires 165/65 R 14 on 5½ J × 14 wheels which permit high levels of active safety, durability, comfort, and which reduce the power lost to rolling resistance.

The characteristics of these tires are a lower section, use of newly formulated materials both in the carcass and tread. A particular tread design is employed.

Figure 6 shows the reduction of rolling resistance between traditional cross-ply, radial steel belted, and the new P8 tires.

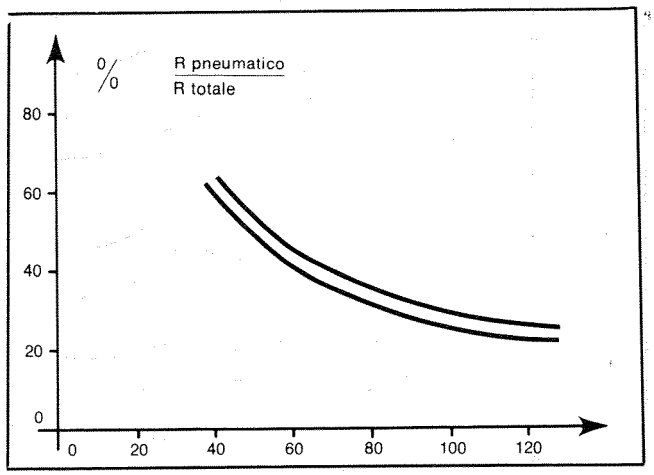


Figure 5. Rolling resistance.

IMPROVEMENT OF PASSIVE SAFETY CHARACTERISTICS

The new objectives created a need to improve passive safety performance by strengthening body structures, which normally result in weight increases.

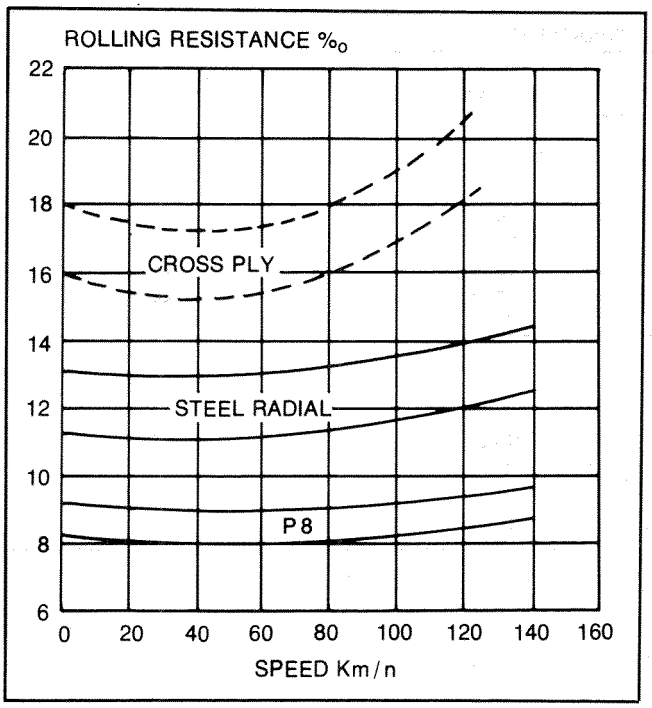


Figure 6. Rolling resistance for various types of tires (source Pirelli).

This weight increase was clearly in contrast with fuel saving efforts and therefore much effort was spent to maintain any weight gain within small limits by the use of aluminium alloy in some components.

The weight gain limits were developed as follows:

- *Oblique frontal impact at 65 km/h*
  platform modifications consisting of reinforcing longerons in the forward portion with stiffening webs beneath the pedal zone
  Weight penalty + *6.3 kg*

- *Car-to-car-lateral collision*
  reinforcing door beams and strengthened "A" pillars
  Weight penalty + *25.0 kg*

- *Rear impact at 50 km/h*
  rear reinforcement of the platform by longerons
  Weight penalty + *8.7 kg*

- *Rollover at 50 km/h*
  addition of header zone reinforcement and roll bar in center zone
  Weight penalty + *2.0 kg*

- *Weight increase due to aerodynamic modifications* + *12.0 kg*

Total weight gain **54 kg**

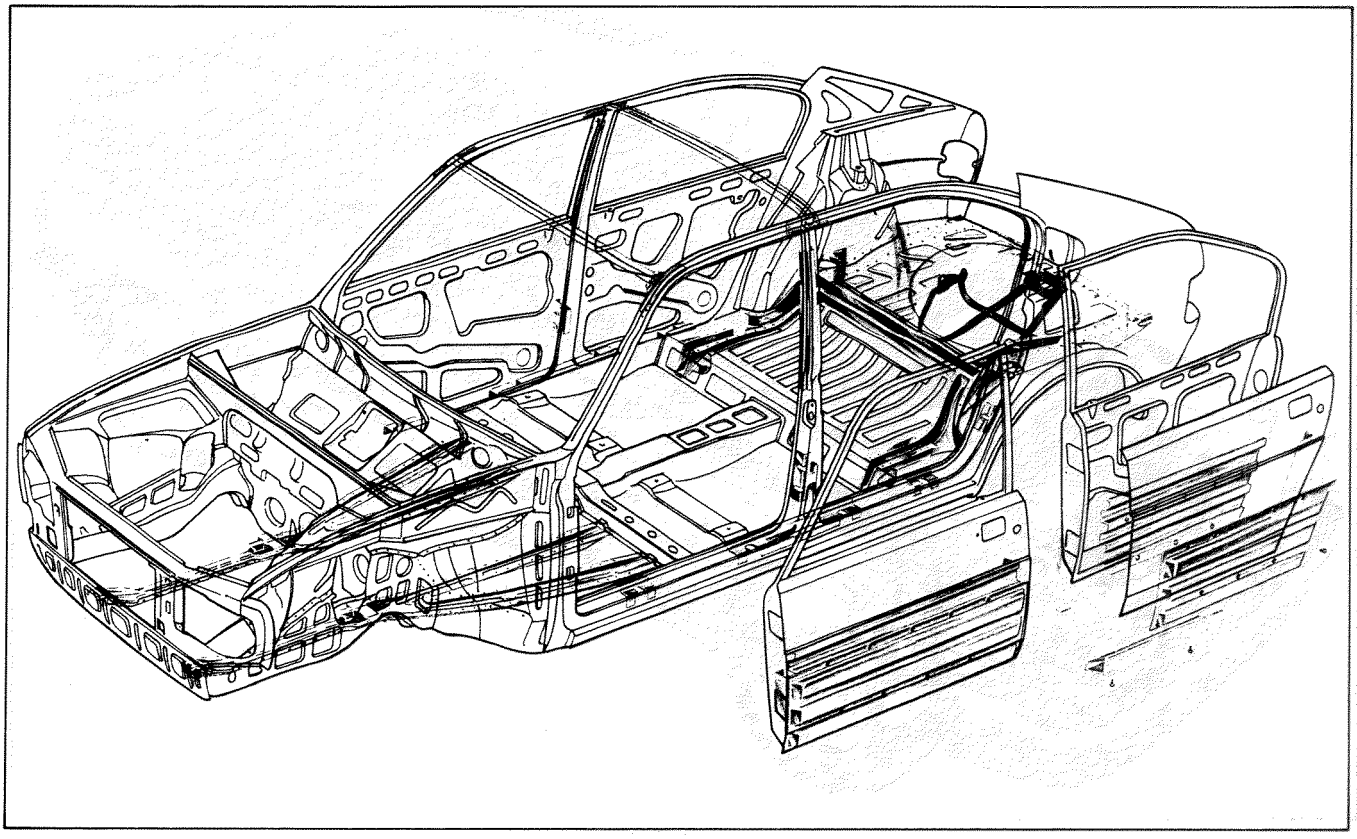


Figure 7. Shows the additional reinforcement required.

Modified vehicles characteristics			
	Baseline Vehicle	ESVAR	SVAR
Engine 1490 cm^3	Carburetors	Complete Electronic management	Complete electronic management
Final drive ratio	3.54	3.1	3.1
Weight DIN (Kg)	905	828	882
Coeffic. Cx	0.423	0.328	0.328
Tires	Standard production	Low rolling resistence	Low rolling resistence

MAIN FEATURES OF THE ESVAR AND SVAR VEHICLES

On the table we have summarized the modified characteristics as compared to the base vehicle. We remember that the lightening of the body/chassis has been voluntarily limited, in order not to jeopardize the safety tests to which the vehicle would have undergone after the addition of the reinforcements.

Figure 8 depicts the General Layout of the SVAR as defined. In evidence are the details of the aerodynamic improvements such as air dam, spoiler, and door window deflectors.

PERFORMANCE AND FUEL CONSUMPTION

ESVAR VEHICLE

Performance		
	Baseline Vehicle	ESVAR
—Top speed, 4th gear Km/h	174	> 185
—Acceleration from stop from 0 to 100 Km/h-sec	10.70	9.80
—from 0 to 1000 m - sec	32.40	31.12
—Acceleration in 5th gear from 40 Km/h-sec	40.65	41.60

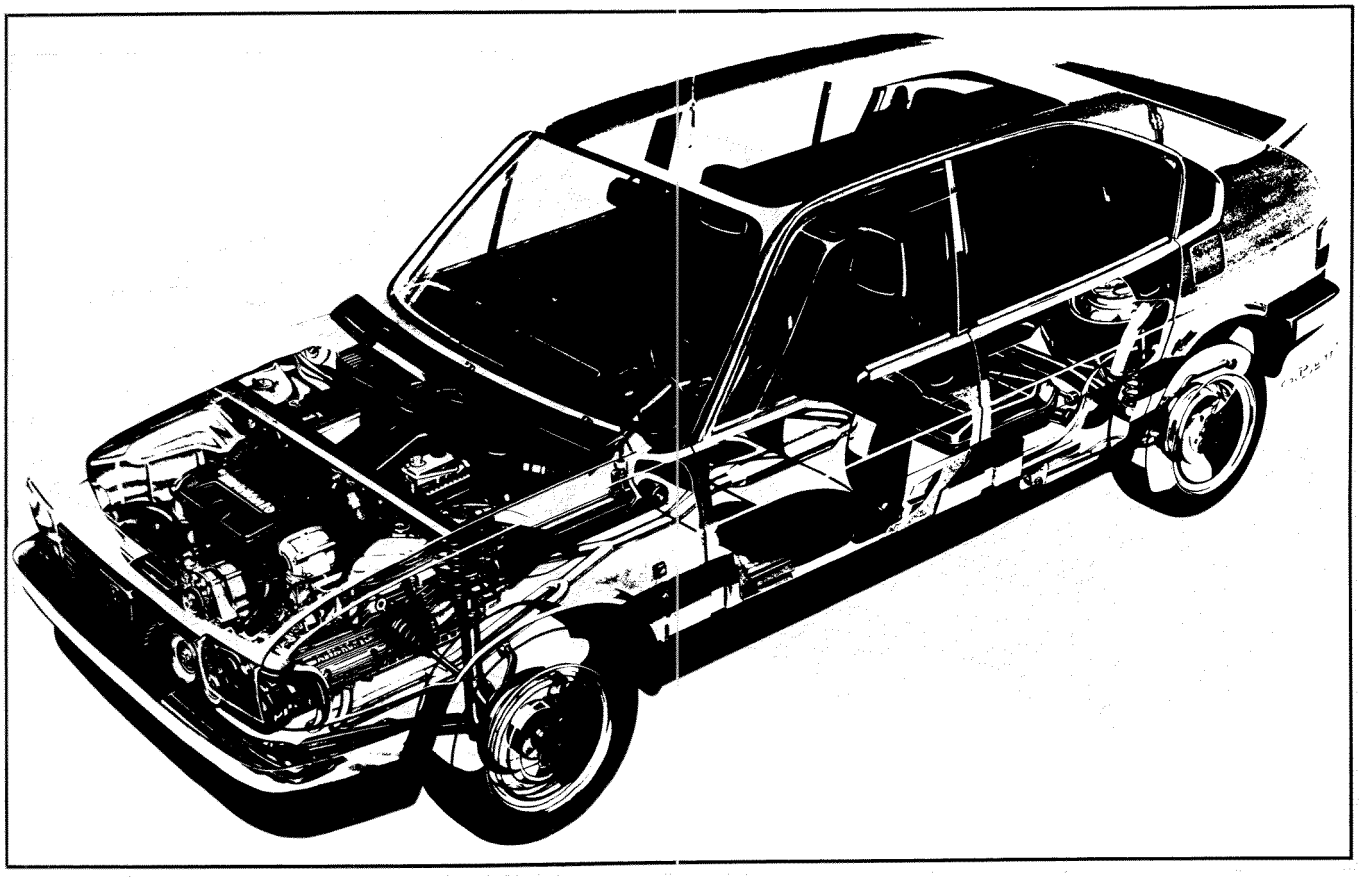


Figure 8.

Weight saving and aerodynamic advantages can be seen in the acceleration times and maximum speed.

Acceleration from 40 km/h in fifth gear, due to the longer final drive ratio, now requires 41.60 seconds, or 0.95 seconds longer than the base vehicle. This performance is still considered acceptable.

Fuel consumption - l/100 Km		
	Base vehicle	ESVAR vehicle
90 Km/h constant	6.2	4.9
120 Km/h constant	8.1	6.3
Urban cycle	10.6	7.8

- Fuel consumption

Here the fuel saving feature of the modular mode, when operating on 2 cylinders, can be seen as a considerable reduction in the 70 km/h range.

At 90 km/h the fuel saving advantage is about 20%, increasing with speed up to 22% at 140 km/h.

- Fuel consumption during the ECE urban cycle

Below are the results obtained with engines in 4 cylinder and modular modes. According to the ECE standard, the inertia weight used on the base vehicle and the ESVAR are equal, since the weight reduction has not been sufficient to permit the use of a lower inertia weight class. Therefore the benefits are derived from the engine and the longer final drive ratio.

Fuel consumption - ECE Urban cycle - l/100 Km		
Base vehicle	Vehicle ESVAR	
	Mode 4 cylinder	Mode modular
10,6	9,2	7,8
The saving has been 13,2% between the base vehicle and the ESVAR 4 cylinder. Accounting for a 5% longer final drive and complete electronic management of the engine	(injection + ignition) a saving of about 8% can be seen in a simulated ECE cycle. In the modular mode, the data shows a reduction down to 7,8 litri/100 Km which yields an overall fuel saving of 26,4% as compared to the base vehicle. If the ≪ effect of the longer final drive ≫ is dropped out, then the modular mode itself will yield a saving of about 21,4%. Overall, it is interesting to note that the difference between the constant 4 cylinder mode and the modular mode is 15,2% (from 9.2 to 7.8 l/100 Km).	

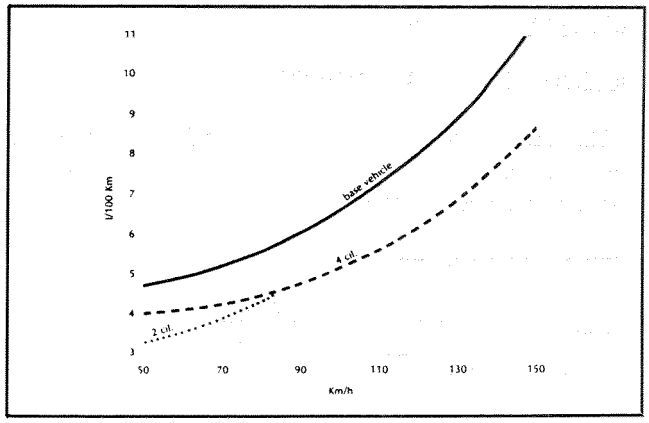


Figure 9.

The saving has been 13.2% between the base vehicle and the ESVAR 4 cylinder. Accounting for a 5% longer final drive and complete electronic management of the engine (injection + ignition) a saving of about 8% can be seen in a simulated ECE cycle.

In the modular mode, the data shows a reduction down to 7.8 liter/100 km which yields an overall fuel saving of 26.4% as compared to the base vehicle.

If the "effect of the longer final drive" is dropped out, then the modular mode itself will yield a saving of about 21.4%.

Overall, it is interesting to note that the difference between the constant 4 cylinder mode and the modular mode is 15.2% (from 9.2 to 7.8 l/100 km).

SVAR VEHICLE

Performance			
	ESVAR vehicle	SVAR vehicle	
—Top speed, 4th gear	>185	>185	
—Acceleration from stop from 0 to 100 Km/h-sec	9.80	10.10	
from 0 to 1000 m - sec	31.12	31.50	(1)
—Acceleration in 5th gear from 40 Km/h -sec	41.60	42.65	(2)

1) The higher time of the SVAR is attributed to higher weight.
2) The fifth gear acceleration time of 42.65 sec as compared to 40.65 sec of the base vehicle is due to the final drive ratio.

Consumption - l/100 Km		
	ESVAR vehicle	SVAR vehicle
90 Km/h	4,9	5,1
120 Km/h	6,3	6,4
ECE Urban cycle	7,8	7,8

During constant speeds the difference is due to the heavier weight of the SVAR, while in the urban cycle no difference is seen due to the same inertia weight class.

SAFETY TESTS

OBLIQUE FRONTAL IMPACT

The results obtained during frontal impact at 65 km/h against a fixed barrier at an angle of 30 degrees to the trajectory of the vehicle are:

	Driver dummy	Passenger dummy
HIC	360	384
Dummy head max acc. g/3ms	49	61
Dummy chest max acc. g/3ms	43	30
Dummy femur max load left, right dN	308/455	168/60

Verified the required performances during the impact: i.e., doors remains closed, no fuel leakage, no fire, etc.

REAR IMPACT

1800 kg moving barrier rear impact at 50 km/h two dummies, left front and left rear, retained by active belts.

Results injury levels:

	Driver dummy front	Passenger dummy rear
HIC	51	26
Dummy head max acc. g/3ms	30	14
Dummy chest max acc. g/3ms	51	13

Performances required positively verified: non-opening doors, fuel leakage, rear car deformation (changement point H versus front 7 mm).

LATERAL IMPACT CAR TO CAR

Target SVAR impact velocity 50 km/h. Collision angle 90 degrees; SVAR car equipped with three dummies Hybrid II, two in the front, the third in the rear, with active belts.

Results:

	Driver dummy	Front dummy	Rear dummy
HIC	47	98	261
Dummy max acc. g/3ms	30	35	67
Dummy chest max acc. g/3ms	45	54	19

Verified all performances: doors were kept closed upon collision, unable to close or open left front and rear doors, no leakage in the fuel system, etc.

ROLLOVER

SVAR vehicle, two dummies Hybrid II retained by active belts. Rollover at 50 km/h.

—no opening of doors
—possibility to open doors after impact
—no dummy ejection
—no fuel leakage
—no fire

PEDESTRIAN IMPACT

The SVAR has impacted at 25 km/h a Part 572 Hybrid II adult dummy and 6-year-old dummy.

Injury levels:

	Adult	Child
HIC	290	78
Max head acc. g/3ms	58	36
Max chest acc. g/3ms	29	22
Max pelvis acc. g/3ms	20	35

ACTIVE SAFETY

The optimal characteristics of stability, handling, and braking of the vehicle have been checked by usual Alfa Romeo standards and based on the subjective evaluation of expert staff test drivers, as well as by specific instrumentation tests.

The dynamic behaviour of the SVAR has proven proficient, as expected, and therefore acceptable. In our opinion the vehicle can be easily controlled by drivers of different abilities and experience.

Though the complete RSV program could not be completed due to reasons of time, space, proving grounds, and/or equipment availability (i.e., simulated lateral wind), "open loop" tests were nevertheless conducted to show:

—lateral adhesion
—handling
—braking

Active safety testing is done by expert staff test drivers at Alfa Romeo's Proving Grounds in Balocco, where the ASTM skid number ranges from 70 to 80.

For the tests the vehicles are instrumented with:

Hardware	Measured Parameters
stabilized inertial platform	lateral acceleration
rate gyro	angular velocity yaw angle
electrical transducer	steering wheel angle
electrical transducer	drift angles
optical sensor	vehicle velocity and stopping distance
pressure transducer	brake pedal force

Handling and lateral adhesion tests are performed with the vehicle loaded to 60% of its max gross weight.

For braking tests, vehicle loads are 60% and 100% M.G.W.

LATERAL ADHESION

- *Response rate*

For checking the behavior rates of the vehicle, tests are done on circular pads at the speeds and lateral adhesion (g) required.

Figure 10 shows the yaw response at lateral acceleration rates of 0.4 g for steering angle of the wheels; the ratio between the steering wheel angle and steering gear ratio is used.

Values measured are within prescribed limits.

The test results permit an interpretation in terms of a "stability factor" K.

The figure resulting from the SVAR characterizes a "stability factor" between 2 and 3.10^{-3} sec^2/m^2.

These values are indicative for an average vehicle in terms of understeer. (Fig. 11).

- *Steering pad*

Data are taken from the vehicle as to its behavior rates on a radius of 37.5 m up to the point of where front end loses adhesion.

Figure 12 illustrates the relation of the steering angle to the lateral acceleration.

This is indicative of the high acceleration level to the progressive behavior of the vehicle.

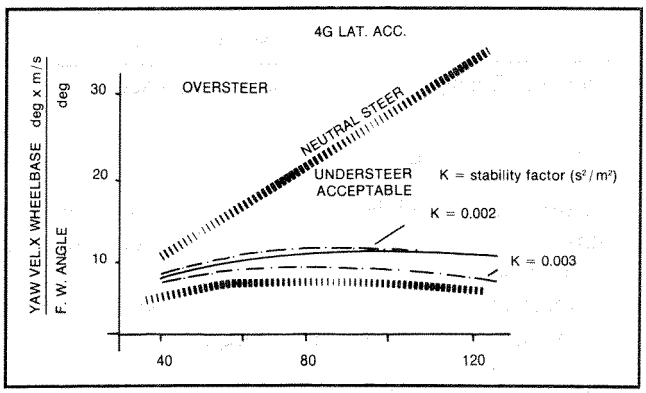


Figure 10. Yaw response rate.

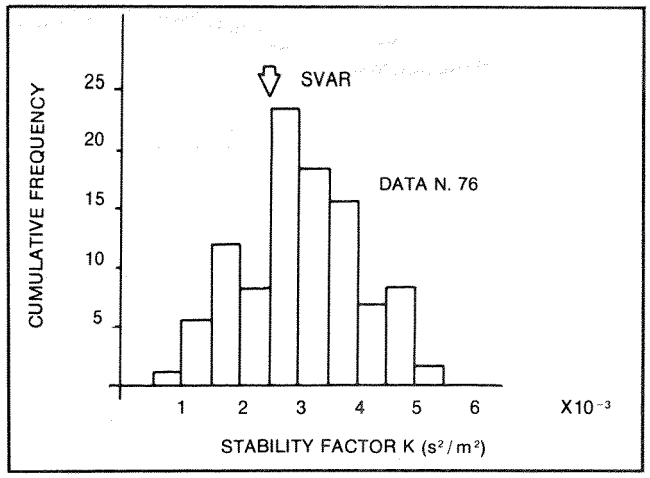


Figure 11. Stability factor histogram, k at 0.4 g lateral acceleration.

HANDLING

- *Maximum lateral acceleration*

The scope of this test is to measure the highest lateral acceleration with various tire inflation pressures.

The lateral acceleration values measured are not necessarily the highest achievable, but are above those required anyway.

Surface	Tire Pressure	Lateral Acc. Required	Lateral Acc. Measured
Dry	Design value	0.60	>0.75
	120%	0.60	>0.75
	80%	0.55	>0.7
	120% front 80% rear	0.63	>0.7
	80% front 120% rear	0.59	>0.7

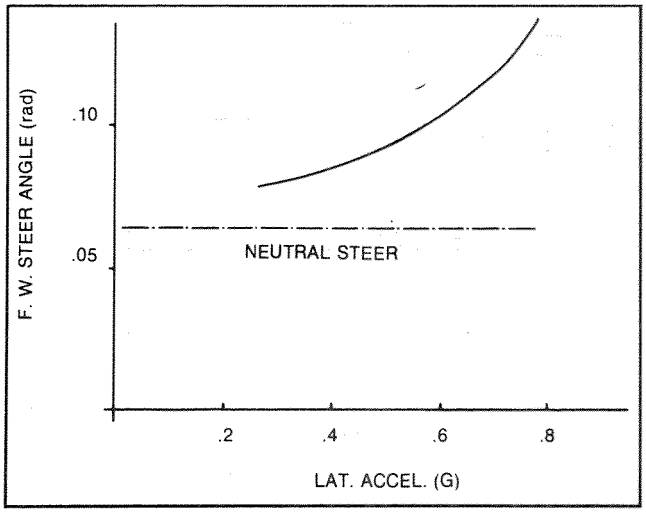
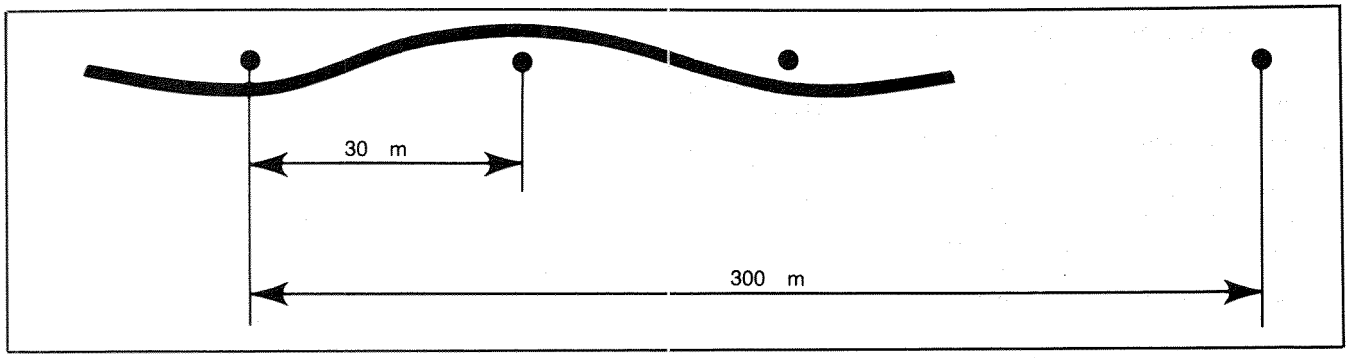


Figure 12. Steering angle response rate (radius 37.5 m).



- *Slalom*

This test is performed over a course of 300 m with 10 pylons spaced 30 m apart.

The slalom average speed is above the minimum required, during tests "overturn" was never verified.

Minimum average velocity	
Required	Measured
80 Km/h	90 Km/h

BRAKING

- *Braking straight-line*

Straight-line braking distances are measured three times for each test condition:

- complete baseline braking system
- system without servo
- system without front circuit
- system without rear circuit

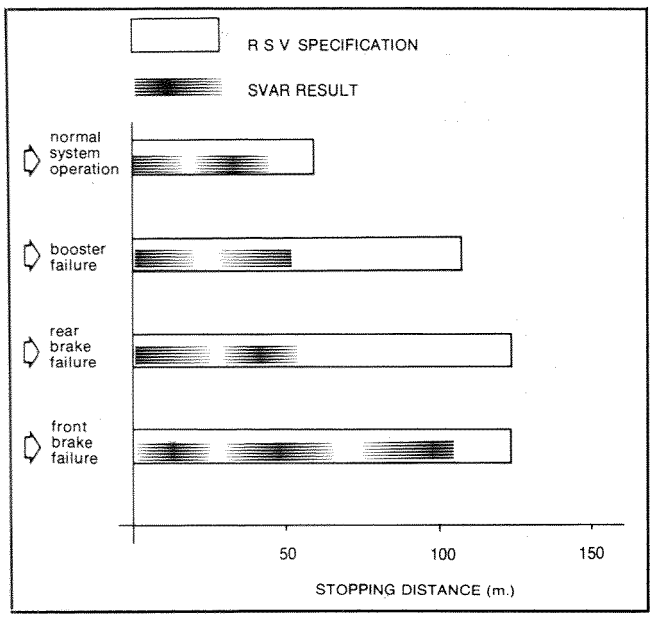


Figure 13. Stopping distance—straight line.

Initial velocity is 96 km/h on a braking lane 3.7 m wide.

As demonstrated in Figure 13, the vehicle is characterized by a braking distance much lower than that required.

As well, the vehicle did not deviate from its path, stopping in a straight line without wheel lock-up.

- *Braking in curves*

This test is carried out only using the complete baseline system.

The vehicle, while travelling at 64 km/h on a 108 m circular track (0.3 g lateral acceleration) is stopped in a distance much shorter than that required (Fig. 14).

The vehicle is characterized by a minor deviation from its circular path, which is easily corrected by a slight steering correction.

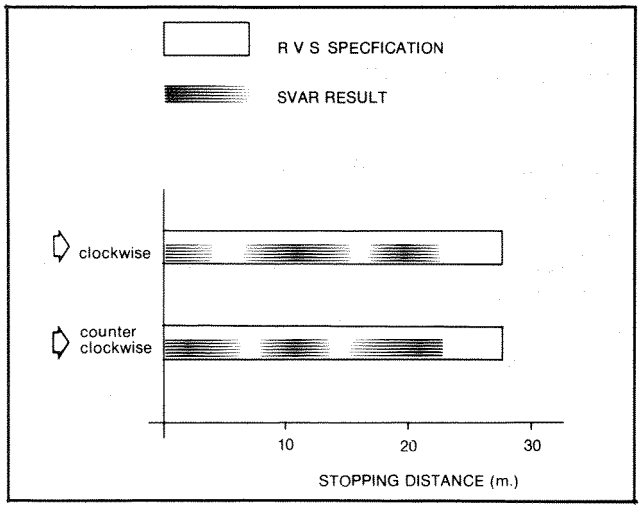


Figure 14. Braking in curve—stopping distance.

CONCLUSIONS

A production vehicle can show reductions in fuel consumption while not altering the philosophy or criteria for occupant protection.

Almost all for the modifications done on the ESVAR are possible using today's technology.

There is evidence of rather important cost/investment problems. Some solutions of "controlled economy" could

permit introduction to production in short or medium terms. Other solutions require consideration of cost/benefit. Certain applications may be valuable as "image" for the manufacturer and therefore beneficial. Much depends, in the end, on the eventual cost increase of petroleum and on technological developments which today are very costly.

The SVAR was constructed to obtain indications of solutions which could be further studied in order to optimize occupant protection.

It is worthwhile to underline the fact that the ESVAR vehicle is, in the end, slightly lighter than the base vehicle. It is equipped with all of its devices and inherits as well the advantages of low fuel consumption.

The results obtained are significant for future designs that have requirements for improved protection with a minimum increase in weight and cost.

From these lessons, it is seen that about 30% of the weight gain could be eliminated by rationalizing the structure.

Overall results of the safety tests indicate that it is necessary to continue the research, obtaining more data for future rational projects.

With this last note we conclude the Alfa Romeo report on the studies of today's need to reduce fuel consumption and occupant protection, concluding that it is possible to achieve progress in a light compact vehicle, while retaining the performance objectives—which in the original vehicle were quite high.

The research continues.

ESVAR

SVAR

APPENDIX

MAIN TECHNICAL DATA

		Base vehicle	ESVAR	SVAR
Overall length	mm		3995	
Overall width	mm		1590	
Wheelbase	mm		2455	
Front track	mm		1390	
Rear track	mm		1360	
Empty weight (DIN)	Kg	905	828	882
Engine: flat 4				
Bore	mm		84	
Stroke	mm		67,2	
Displacement	cm^3		1490	
Compression ratio		9,5:1	10,2:1	10,2:1
Max power DIN - KW/rpm/1'		70/6000	70/5400	70/5400
Max torque DIN Nm/rpm/1'		130/3500	134/3500	134/3500
Clutch			single dry disc	
Transaxle			5 speed I : 3,75 I : 2,05 III : 1,38 IV : 1,02 V : 0,82	
Axle ratio		3,54: 1	3,1 : 1	3,1 : 1

The German Research Car Project

KLAUS H. BUROW
TÜV Rheinland, Köln

JÜRGEN BANDEL
Federal Ministry for Research and Technology, Bonn

ABSTRACT

The paper presents results of the German research car project. Four prototype cars were built by Audi NSU, Daimler-Benz, Volkswagen and a group of high school institutes. Technical details of the prototypes are described which were chosen to meet the project goal of an integral improvement in safety, energy and resource conservation, environmental compatibility, economy and utility.

INTRODUCTION

In 1978 the German Ministry for Research and Technology started the research car project (Fig. 1) in order to determine the technological potential of a combination of the most promising individual solutions, thus devising an integral concept of a passenger car of the future.

The fundamental ideas of this project and some technical details were reported on the 8th ESV Conference in Wolfsburg, 1980. The project ended September 1982; most results of the demonstration and evaluation phase are to be reported in a short time.

In this paper, some results from a more generalizing point of view will be presented, whereas in the following three papers of this Conference, emphasis is laid on passive safety features of the research cars.

In contrast to other projects which aimed at only one field of automotive technology this project (Fig. 2) was set up to cover the full range of development needs.

It was mainly to demonstrate future technology with the potential to meet the whole range of conflicting demands on future vehicles. The presented technologies should have the potential for large series production.

Beside the mandated average 30% improvements and the general requirements (Fig. 3), it was open to the companies to compensate a smaller improvement in one field by a higher efficiency in another field. Thus the competitors were enabled to concentrate more on one special field of their interest, or to set priorities particular to the company's production politics.

Audi NSU (Fig. 4) tried to meet the goal with technologies of the next 10 years. Focal points of interest were vehicle body structures and use of alternative materials.

—Daimler-Benz emphasised the development of a ceramic gas turbine for a large size limousine and the implementation of features for driver's aid and comfort.

—The university group focussed on exterior effects of automobiles, i.e., emission of noise and exhaust gas as well as safety-measures for pedestrians and cycle riders.

—Volkswagen ranked economy and utility highest; another focal point was use of alternative materials.

In the following some general trends and results are shown.

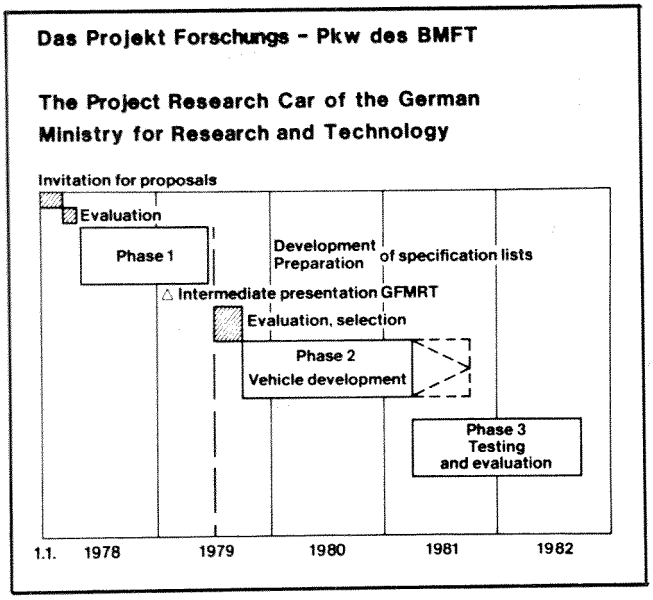


Figure 1. Time schedule for the research car project.

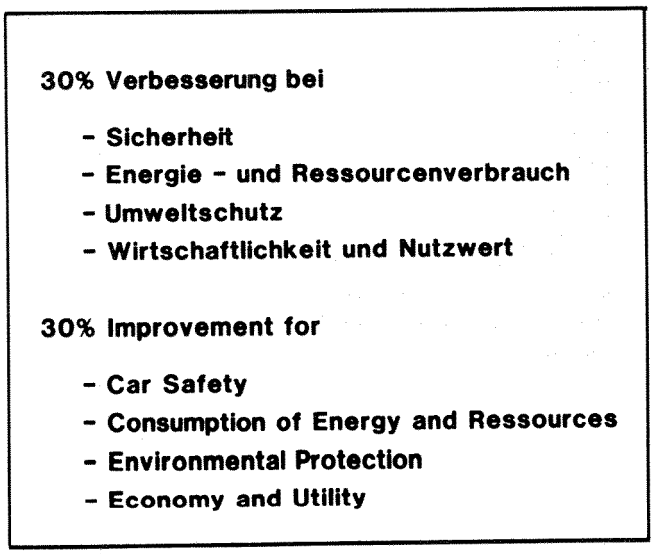


Figure 2. Basic goals in the project.

- 4 Sitzplätze, Seats
- > 400 kg Zuladung, Payload
- KomfortmaBe mindestens heutiger Standard, at least present standard of driving comfort
- Fahrleistungen, Driving Performance
  - 0 - 100 km/h ≤ 13 s
  - V_{max} ≥ 140 km/h
  - Reichweite > 400 km, cruising range
- Erfüllung gültiger Gesetze in der BR Deutschland und EG, compliance with regulations and standards in the FR of Germany and European Community

Allgemeine Richtwerte zum Lastenheft des Forschungs-Pkw

Figure 3. General requirements.

SAFETY

The 30% improvement for vehicle safety was defined for summing up measures for accident avoidance and mitigation of injuries.

Although a number of new techniques were presented in the prototypes, it can be stated that safety was not of highest priority. Despite that the goals seem to be met. As measures for improved passive safety will be reported in the following three papers, only some remarks on accident avoidance features will follow here.

Generally seen emphasis was laid on driver information systems. Principally such systems give support to the driver in his complex task of driving his car within the traffic flow as well as it controls reliability and safety related features of the vehicle itself. By this the driver's need for memorizing and simple or complex thinking operations are reduced.

One major point is the reduction of permanently displayed information on operational status to an absolute minimum, e.g., driving speed, fuel reserve and daytime; further information is available on request only. (Fig. 5).

Figure 4. The Audi research car.

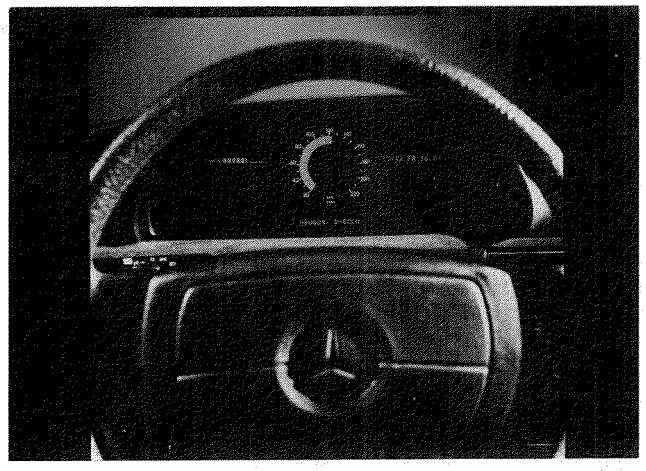


Figure 5. Daimler-Benz, minimal permanent display.

Vehicle operational reliability control works automatically and generates warning information according to safety priority. Warnings of high priority because of dangerous operation status which call for immediate stop are displayed in the primary field of view.

One example for an in-vehicle route guidance and driver's information systems is called ALI (*A*utofahrer *L*eit- und *I*nformationssystem), the display of which is shown in the mid section of Figure 6.

An ALI-equipped vehicle reports its presence and destination when entering the area covered by the system. The information is transmitted via induction loop to a roadside unit. Recommended direction for the particular destination of the vehicle is taken from microcomputer in the roadside unit, and is then transmitted back to vehicle via the same induction loop, which also detects speeds and types of all other vehicles passing by. Roadside unit data of a cross-section are preprocessed and transmitted to the control centre. There further evaluations are carried out with particular emphasis on the optimum routes for the desired destinations of all vehicles in the

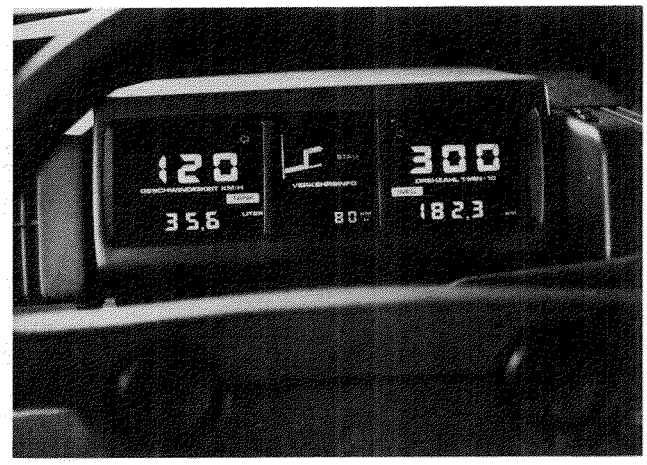


Figure 6. ALI, driver's route guidance and information system; Volkswagen research car.

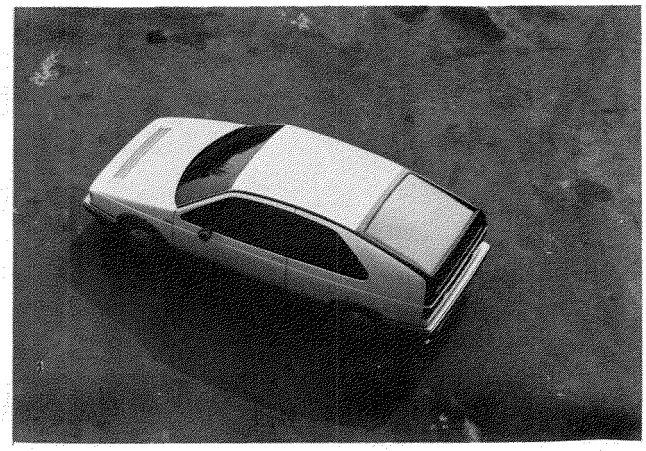


Figure 7. Volkswagen research car; view from the top.

control area. Alternative routes are assessed with reference to the overall objective of

—reduction of travelling time
—reduction of vehicle operating costs
—reduction of number of accidents.

This system was successfully tested with promotion of the Federal Ministry for Research and Technology with participation of more than 400 vehicles in the Ruhrgebiet Autobahn area.

Improvement of *conditional safety* played quite an important role in all research cars. Climatization of the compartment will be of greater importance with larger and more sloped windows (Fig. 7). Ventilation, temperature and moisture will be controlled electronically.

A future solution could be utilization of heat-pipe techniques. Heat exchangers for air conditioning systems will transmit heat from exhaust gas or motor cooling fluid to the heating air as well as it will transmit heat from the compartment air to the cooling fluid of the air conditioner.

Panel shape of the heat exchanger can be used for door inside panel installation for example (Fig. 8).

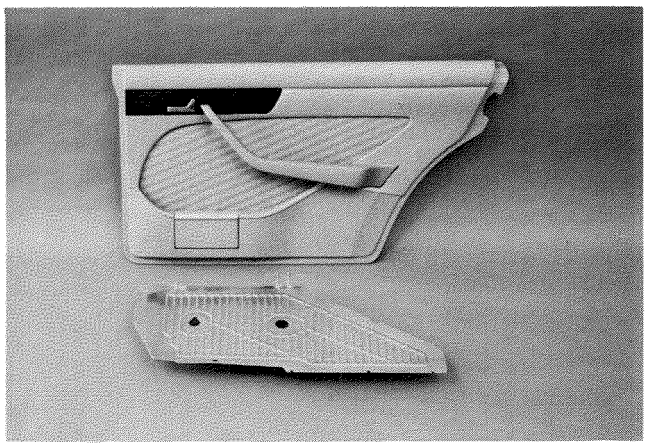


Figure 8. Panel shaped heat pipe for indoor installation; Daimler-Benz.

With respect to *driving behaviour* if can be said that vehicle layout can be varied to a great extent to control dynamic behaviour. However, criteria for what the ideal vehicle behaviour for the "normal driver" really is, do not sufficiently exist, neither with respect to comfort nor to safety. So it can be stated that wheel-suspensions of the research cars more or less are state-of-the-art layouts.

By summarizing, it can be said that safety was not of highest priority although a series of new technologies was presented. Nevertheless, the goal of 30% improvement in this field seems to be reached.

ENERGY CONSUMPTION AND ENVIRONMENTAL PROTECTION

The goals for fuel consumption and the results of the different motor types are given in Figure 9.

The demand for a fuel consumption reduction of at least 30% compared to 1978/79 model cars is surpassed.

At the beginning of the project this claim had been criticized as too hard to reach because of the pretended conflict to the claim for 30% exhaust emission reduction.The energy shortage of the years after as well as the given results lead us to the opinion, that the demands were well founded. Each of the four competitors in the project ranked energy consumption being of the highest priority.

The piston engine of today is predicted being the vehicle engine of the future, too. Consequent use of some fundamental principles gives an astonishing potential for improved efficiency.

Not referring to details, some of the principles used in the project will be reported here:

1. Choice of thermodynamically most favourite combustion process: It was not surprising that each of the participants made use of at least the Diesel engine in one of these prototypes. Consequently they made use of the direct injection Diesel engine for a passenger vehicle.

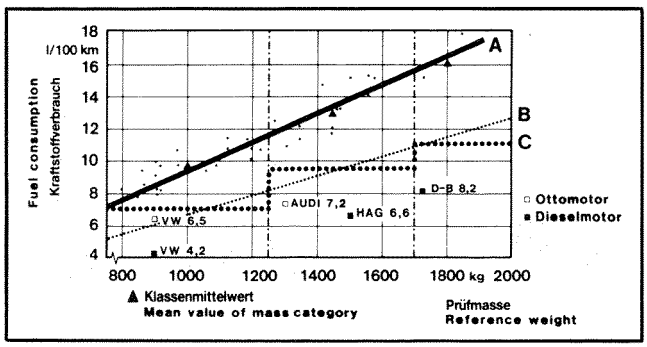


Figure 9. Fuel consumption of 1978/79 model cars and research cars; goals and results.

Kenndaten Diesel - Motoren			
	HAG	VW	D-B
Hubraum cm^3	2500	1191	3308
Leistung kW (PS)	72(98)	33(45)	110(150)
Einspritzung	direkt	direkt	indirekt
$b_{e\ min}$ g/kWh	237	218	255
Verbrauch l/100 km			
90km/h Konstant	4,6	3,3	5,7
120km/h Konstant	6,0	4,9	7,5
Stadtverkehr / City	7,8	4,2	9,8
Durchschnitt 25/25/50	6,55	4,2	8,2

Figure 10. Data of the diesel engines in the research cars.

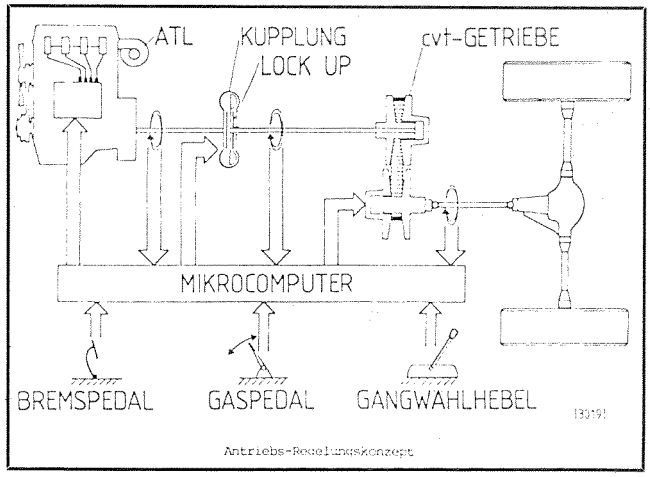


Figure 11. Scheme for motor-transmission control (University Group).

Some basic data from the three finished Diesel engines (Fig. 10) show that this engine type shows outstanding fuel consumption in combination with exhaust gas and noise emissions below the limits given for the project.

2. All of the piston engines, and this is the second principle, are supercharged. This is for Diesel engines as well as for spark ignition engines (Otto-engines).
3. The third principle is to eliminate idling and thrust mode engine operation totally. This has been realized in the Diesel-version of the VW-car. Power is to be generated only then when it is needed to cover driving resistance or when it is demanded for acceleration by the driver via driving pedal. More information is given in the paper by Volkswagen.
4. The fourth possibility is to operate the engine only in the near of its point of optimum fuel consumption and to shift control-function to the gear. Theoretically of best advantage are continuous variable transmissions with sufficiently spread converting ratio combined with electronically controlled engine-power transmission-management.
   With an ideal (100% mechanical efficiency) CVT, fuel consumption can be reduced by 30% compared to mechanical 4-speed gear box by running the engine just along minimum fuel consumption control characteristic.

Engine and gear box performance maps are laid down in a microprocessor (Fig. 11), the control strategy being that for every single point in the power map the product of engine and gear box efficiency gets a maximum.

First results with UNI CAR show that the used CVT "Transmatic" is an interesting alternative with respect to mechanical efficiency, speed of ratio change, spread of ratio, specific power and costs.

The only alternative engine in the project is the gas-turbine-version (Fig. 12) in one of the Daimler-Benz cars, developed parallel to the Diesel version. This gas-turbine is dual shaft with rotating heat exchanger disk, single stage centrifugal compressor with backward curved rotor blade tips, ceramic combustion chamber, single stage axial gas generator turbine, single stage axial power turbine, adjustable inlet guide vanes, electronic control of fuel-supply. All internal hot sections are made of ceramics.

Test bench work has been successful; first in-vehicle tests have been carried out in September.

With respect to fuel consumption the goals set in the project were reached. With regard to exhaust gas emission it must be said that the given limits ($CH + NO_x = 10$ g/test and $CO = 36$ g/test; European Test Cycle acc. to ECE R 15) could not be achieved reliably in all cases. In those spark ignition engines it could only be achieved by giving up the achieved optimum fuel consumption values; but even then the given fuel consumption limits were sufficiently reached.

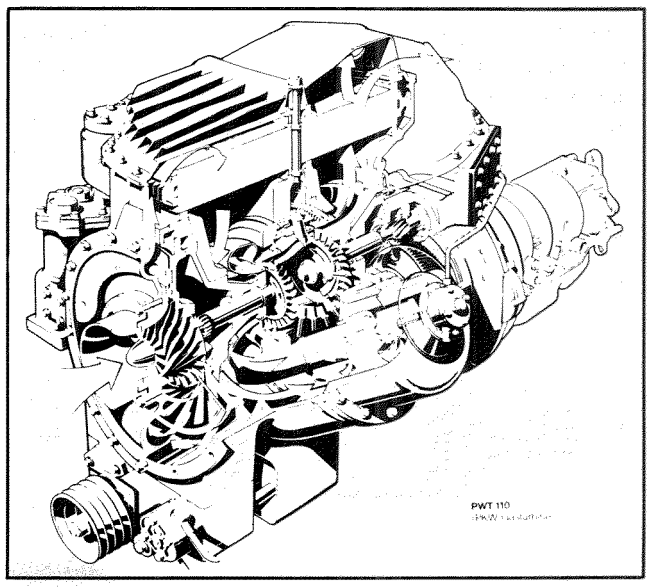


Figure 12. Schematic representation of the Mercedes-Benz research turbine.

We think that some more detail work which could not be done due to the short project duration could result in better emission results.

For the Diesel engines all limits for exhaust gas emission, particulates included, could be achieved, the latter even without filtering.

Related to noise emission the set limit of 73 dB(A) according to ISO 362 was regarded as difficult to fulfill because of the levelsetting tire noise. The results, however, show that with the help of acoustical capsules for the engines a noise level of 72 dB(A) could be measured even for direct injecting diesels.

BODY DESIGN CONCEPTS

Guide lines for body design in the research cars can be described as follows:

—principally retaining today's production procedures, modifications with respect to use of alternative materials, subsystem production and assembly as well as to final assembly should be investigated
—the whole body design ought to play an important role in vehicle economy improvement by reduced weight and favourable air drag
—expenditure on energy during manufacture and recycling were to be considered in design.

The principle way for improvements in this respect seems to be the consequent separation of body functions into the supporting structures and the outer cover giving vehicle shape.

The supporting framework (Fig. 13) consists of a 3-dimensional framework of thin surface elements and high-strength rigid beams—in all four prototypes these structures are made out of steel sheets.

On one side an optimal ratio between vehicle outer dimensions and passenger compartment space demands for minimal beam measures. On the other side survival space in accidents demands for an extremely rigid compartment, up to this both can only be done by steel obviously.

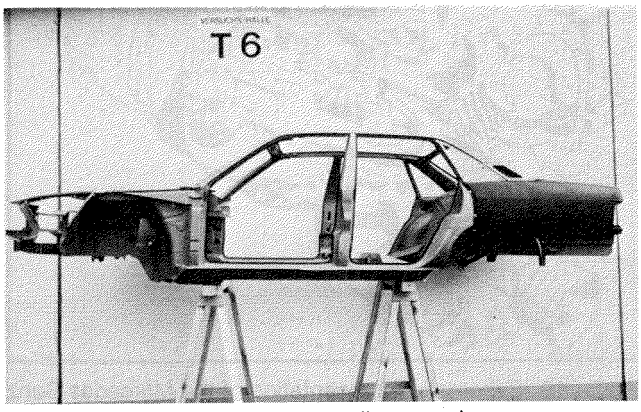


Figure 13. Body structure of Audi research car.

Other results were obtained with regard to the outer cover included the roof and the lower floor panel. Here the use of new materials will increase in the near future (Fig. 14).

All four prototypes show plastic front sections with integrated bumpers. Mostly they consist of an GFRP- or aluminium cross member and a PUR body and skin. Main advantages are the drastically reduced number of parts in connection with greater freedom for design.

Side doors unanimously were made of aluminium. Audi here also realized the functional separation of door structures. First into an aluminium structure carrying the lock, window lifting mechanism and door hinges as well as incorporating the side intrusion guard; second into the inner door cover and the outer door cover (aluminium).

As to side panels and mud guards lightweight materials will be used; both aluminium and plastics are considered; a distinct trend to one of these materials cannot be seen yet.

The most extensive structural modification can be seen for the Audi car. Normal as well as steer forces acting on roof and floor ask for extensive reinforcements for the steel panels.

For this purpose the roof as a sandwich construction out of a honeycombed aluminium core and GFRP-shells could be advantageous.

The floor unit (Fig. 15) consists of a GFRP-construction with directed fibers from high-temperature-resistant resins. Reinforcements for panels and supporting beams are made of PU-hardfoam cores. For anticorrosion purposes the floor asembly covers the side fenders up to the doors.

The problems for this structural layout are the assembly between steel frame and plastic subassemblies by gap-filling adhesives. Another problem is that roof and floor can only be mounted after completion of supporting framework including total surface treatment.

On the other side this assembly sequence offers big advantages for mounting the equipment of the passenger compartment. Additionally roof and floor can totally be preassembled away from the main assembly line on special work benches with all equipment including mechanical devices, electric wiring, carpets, seats etc.

Beside the just mentioned structural design works, an important contribution to energy saving was given through a drastical reduction of air drag. With realistic chassis design the air drag coefficients for the four research cars were between 0.24 to 0.29.

ECONOMY AND UTILITY

Utility of a vehicle is ruled by its

—transport capacity
—reliability
—safety

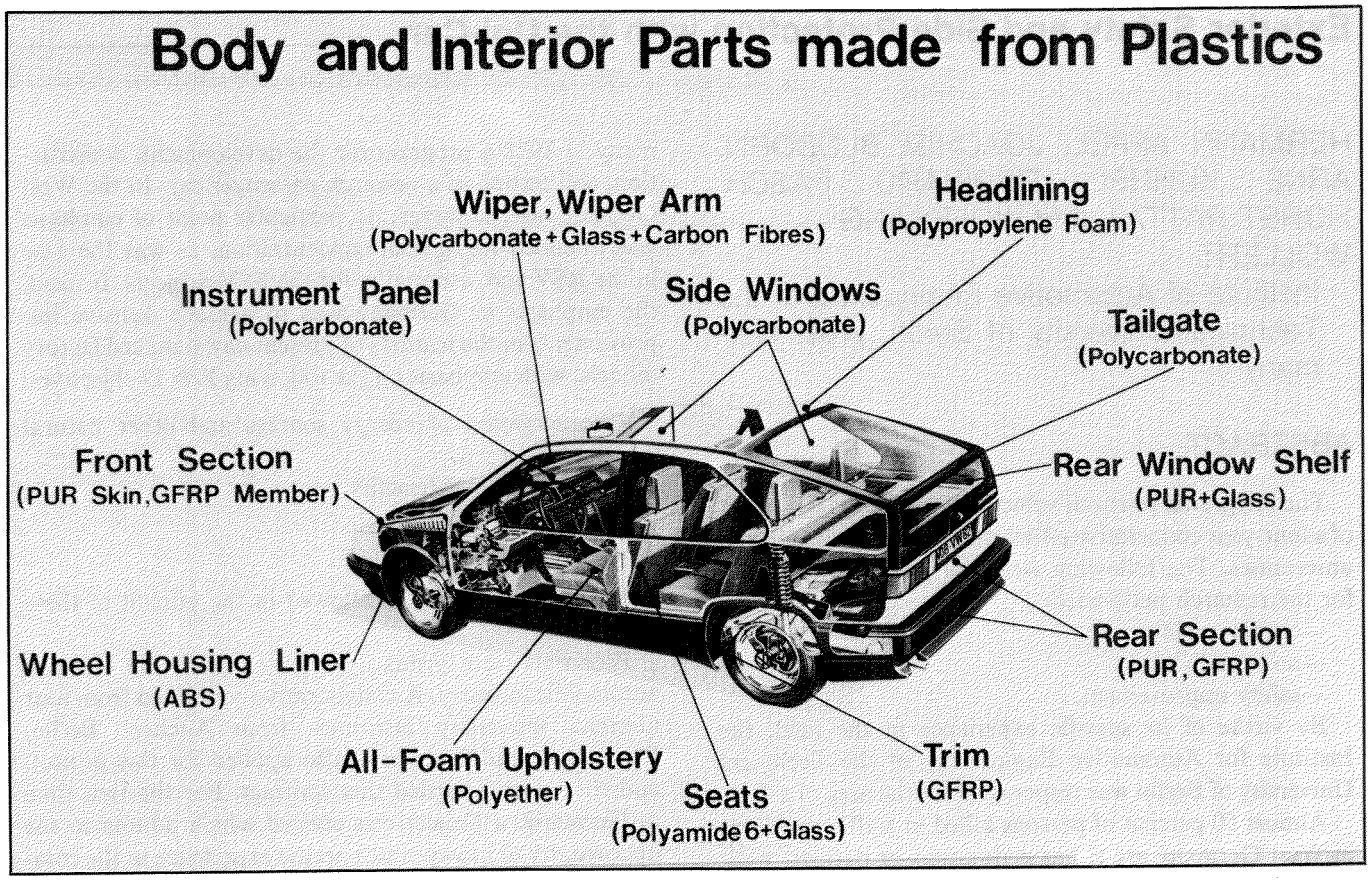


Figure 14. Body and interior parts made from plastic (Volkswagen).

—environmental compatibility
—life expectancy and depreciation

Regardless to economy, utility can be improved by high sophisticated technology—their interrelation is governed by costs. The optimal ratio between them depends much on the expectational attitude of the buyer of a specific vehicle class.

So a concluding valuation of the four vehicles with respect to 30% improvement in economy and utility is hard to give. A purely subjective remark at this time can be given yet:

—Even the few examples in this paper show that for the above mentioned factors governing utility a remarkable improvement can be stated
—An improved utility can be proposed because most of the presented technologies in one field of demands did not affect negatively other fields of activity—that was just the aim of the project
—The competitors in the project ranked economy very high for their work. These decisions made in 1978/79 have been verified by the international economical developments
—The demand of the project for technical solutions with the potential for large series production as well as the short project duration excluded realization of long-term technologies but did also avoid exotic, unrealistic solutions.

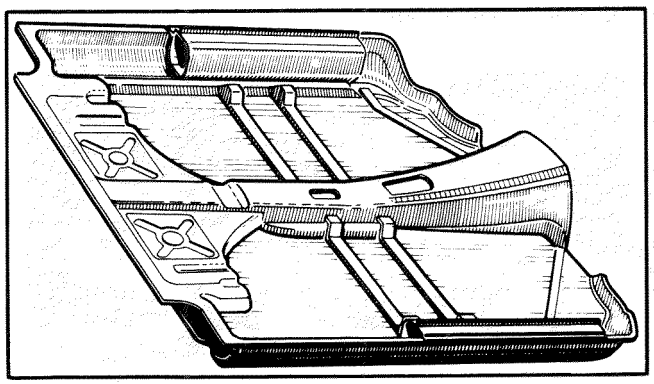


Figure 15. GFRP construction of floor panel (Audi).

The four prototypes indeed demonstrate effective and economical solutions for an improved automotive technologies for the last 20 years of this century. For this reason the German Federal Ministry of Technology regards the project as being successful.

Exterior Safety and Side Protection with the Uni-Car

HERMANN APPEL, JOACHIM BLÖDORN, ARNE KÜHNEL, REINHARD PASCH, HORST RATTAJ, and WOLFGANG WOLLERT

Institute of Automotive Engineering at the Technical University of Berlin, West Germany

ABSTRACT

The integrated research vehicle UNI-CAR is the result of a four-year cooperative effort among four West German universities. The following were the points of emphasis for the research performed:

—energy savings
—noise reduction
—safety improvement.

By virtue of its specific experience in the field, the Institute for Automotive Engineering of the Technical University of Berlin was responsible for the area of safety.

Almost 50 percent of persons killed in traffic accidents in West Germany are either pedestrians or cyclists: what we call "the outside victims." This situation has been fully taken into account by the safety concept of the UNI-CAR. Extensive protection has been provided for pedestrians and cyclists by the geometrical design and the use of soft materials (foam) for the front end of the car. Aerodynamic requirements were also able to be taken into account in this concept. The configuration was provided in such a manner that protective criteria were observed up to 50 percent in cases of collision speeds of 45 km/h (28 mph).

A second focal point in the safety concept of the UNI-CAR was side protection: the side impact is one of the dominant collision types, especially in city traffic. Approximately 20 percent of all deaths among car passengers result from cars struck from the side; their number amounts to approximately 10 percent of all traffic deaths. The test velocity for the car-to-car side collision was set at 50 km/h (31 mph). This speed would include 75 percent of all side crashes resulting in injuries.

Verified measures were employed to prove that the officially stipulated safety gain of approximately 30 percent was achieved. We must point out, however, that some of the solutions as chosen are not yet ready for mass production.

INTRODUCTION

Similar to the United States in 1974 with its Research Safety Vehicle Program (RSV), the West German Federal Minister for Research and Technology initiated in Germany in 1978 a program for the development, construction, and testing of a research passenger car. In the West German case, however, no particular point of emphasis was intended for special concentration, as was the case in the RSV and, especially, for the ESV projects. Instead, the emphasis in Germany was to achieve decisive improvements in the features of present day standard factory models, with emphasis on the following R & D objectives:

—conservation of energy sources and other natural resources
—environmental benefits
—safety (30 percent)
—economy and efficiency

Compensation was to be allowed in the pursuit of these goals.

Proposals were primarily solicited from the German automobile industry. A collaborative composed from four German university institutes—from Aachen, Berlin, Darmstadt, and Stuttgart—also applied for this project, and they were awarded this contract. For the first time in Germany, a project was started which admits to the opportunity to incorporate specific experience in the complete development of a passenger car. Structural and construction work assumed the Karmann company. The first prototype was introduced after the extremely short period of 23 months (Fig. 1). Testing of the total of 4 prototypes will be completed by the end of 1982.

As part of the scope of responsibilities of the Technical University of Berlin, this presentation is intended to describe which safety concept was chosen for the UNI-CAR, and under what prescribed constraints this selection was made. Measures implemented for increasing the exterior safety (for pedestrians and cyclists) and side-crash protection will be described; with the aim of test results, estimates will be made with regard to the increase in safety which can be expected.

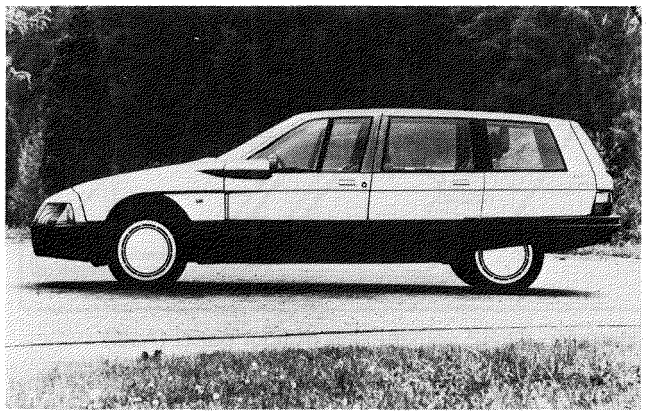


Figure 1. Prototype 1 of the UNI-car.

SAFETY CONCEPT OF THE UNI-CAR

The collaborative of the universities selected a total of three emphases for development for the UNI-CAR:

—reduction in fuel consumption by the following features: use of a diesel engine with direct injection, utilization of an electronically controlled CVT gear system, and drastic reduction of the air resistance
—reduction in noise emission by means of encapsulation of the engine and the exhaust pipe
—increase in passive safety, especially toward the outside.

The first two developmental goals—better aerodynamics and less noise emission—have resulted in form-determining and structural measures. These measures, in turn, act as constraints for the vehicle body and, therefore, for the safety concept and the design of the car interior. These restriction conditions include the following:

—a front end with a smooth surface, rounded off in all directions
—a low, long, and gently inclined front end
—a marked withdrawal of the roof edges at the sides
—a sharply inclined windshield
—a spacious middle tunnel running throughout the interior.

The following safety concept was chosen under the prescribed constraints and objectives for protective measures:

—a medium-large and medium-heavy vehicle as a compromise among self protection, partner protection, and compatibility
—slight increase in the structural and interior safety in the event of a head-on crash
—improvement in the restraint system for the front-seat passengers
—marked improvements in structural and passenger-compartment safety in the event of a side crash (test conditions: 90 degree car-car collision with an impact velocity of 50 km/h (31 mph) against the target vehicle at rest)
—considerable improvement of the exterior safety with regard to pedestrians and cyclists (test condition: collision velocity of 45 km/h (28 mph)).

EXTERIOR SAFETY, MEASURES TAKEN, AND TEST RESULTS

Design of the Front End

As a compromise between the requirements placed by the aerodynamic principles involved (a low, gently inclined front end) and by the pedestrian safety considerations (moderately developed, rounded-off leading edge of the hood, with sufficient overall height for deformation paths), the form shown in Figure 1 was selected. The aggressiveness represented by the form is mitigated by sufficient coil distance (distance between the street surface and the head dent in the hood: 1.95 m for the UNI-CAR and 1.75 m, for comparison, for the VW Golf), and by integrated bumpers, headlights, and exterior mirrors.

Impact-Energy Absorption at the Front End

The following safety measures and structural design features were chosen to be provided in the form of polyurethane foam to ensure sufficient deformation paths:

—a soft face with a deformation path of approximately 150 mm (Fig. 2)
—an impact-energy-absorbing hood, with a deformation path of approximately 70 mm (Fig. 3)
—an energy-absorbing windshield frame, with a deformation path up to approximately 45 mm (Fig. 4)
—a peripheral, energy-absorbing roof edge, with a deformation path of approximately 15 mm (Fig. 5).

The safety measures employed are summarized by perspective views in Figures 6 and 7.

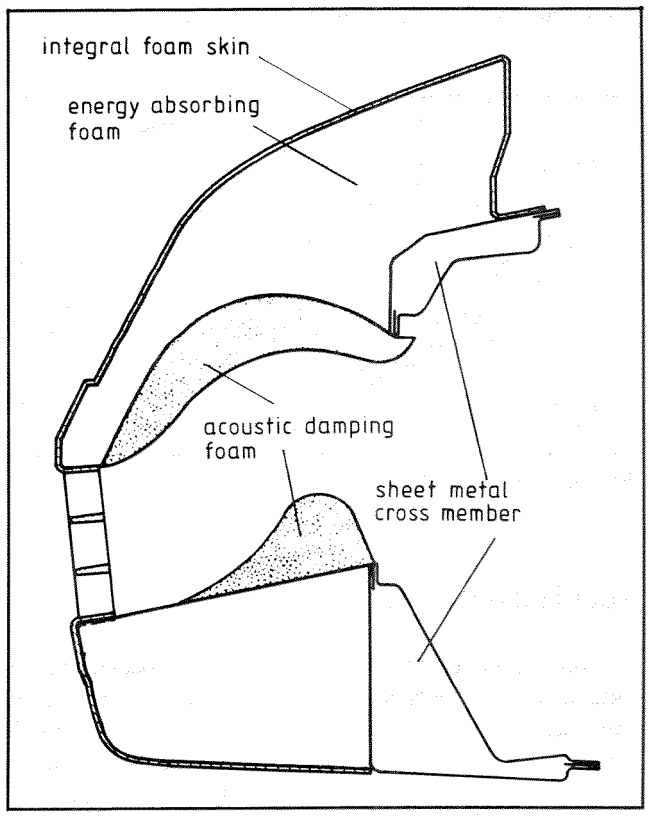


Figure 2. Soft face.

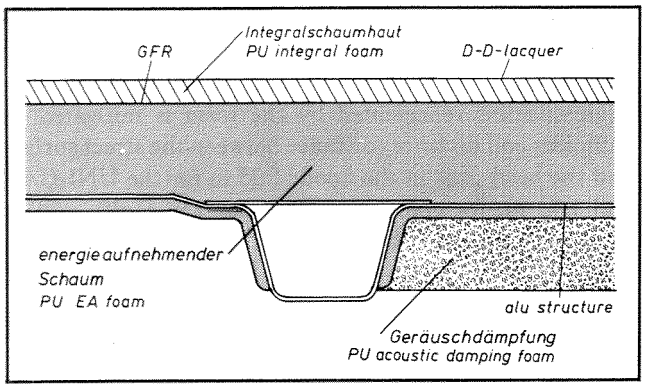


Figure 3. Hood.

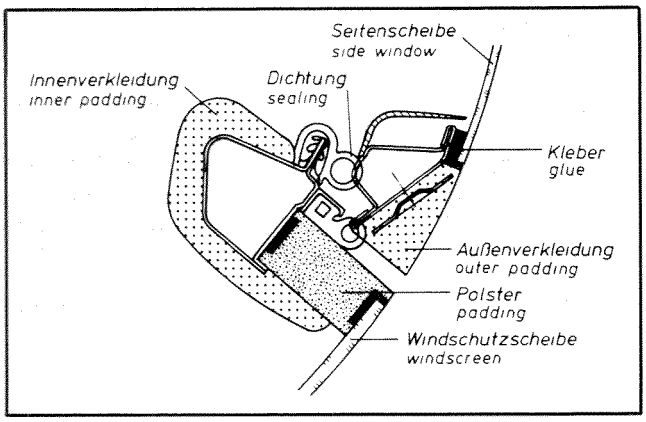


Figure 4. Padding of the windshield frame.

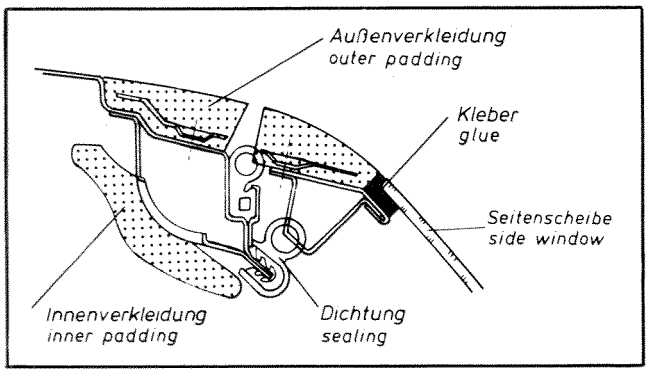


Figure 5. Padding of the roof edge.

Test Results

Approximately 90 percent of all vehicle-pedestrian accidents in West Germany take place within built-up communities, i.e., on streets in which a speed limit of 50 km/h (31 mph) is prescribed. Consequently, collision speeds for the tests were set at 25 km/h (16 mph) and 45 km/h (28 mph) in an attempt to correspond to realistic conditions; furthermore, the test pedestrian was struck

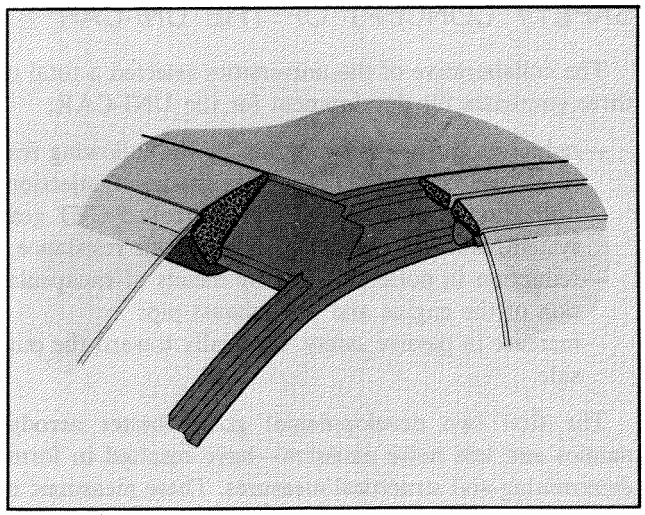


Figure 6. Section through the roof frame.

from the side by a braking car: all of which conditions serve to cover approximately 85 percent of all car-pedestrian accidents.

Since the UNI-CAR was intended to be designed to take into account the body sizes of a medium-sized child (1.25 m tall) and of the "50-percent male" (1.74 m tall), dummies were selected in accordance with the respective data for six-year-old children and for the 50-percent man.

Several versions of the UNI-CAR, each with variations in material characteristics, were available for the tests: three different front faces and hoods, each with various degrees of foam rigidity, were tested. For comparison purposes, a car with a similar outer contour—a Citroen CX—was also incorporated into the test program. This was to enable estimates to be made concerning form-related influences with respect to earlier tests with pontoon-shaped test cars.

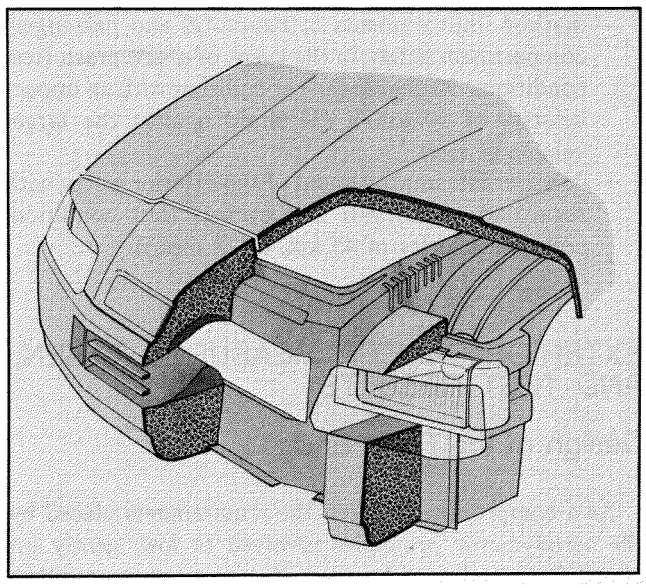


Figure 7. Section through the front end.

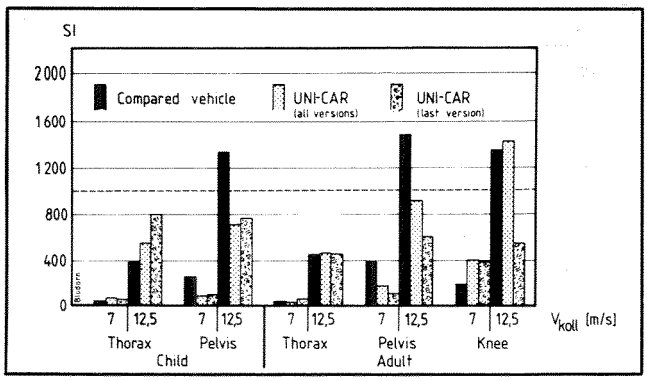


Figure 11. SI as a function of the collision velocity in pedestrian tests.

points, with a minimum of 70 mm intervening room), and if large, nonsupported surfaces which could be deformed in their entirety were kept within certain limits, then tolerable HIC figures up to velocities of 45 km/h (28 mph), with very high energy absorption, are indeed possible. See Figure 10.

Figure 11 shows the influence of the soft face, for which the SI (severity index) calculated for pelvis and thorax is compared for the various test vehicles. The advantages of the UNI-CAR are more apparent here than for the tests for the hood, primarily responsible as it is for head injuries.

The reason for this phenomenon is the known fact that favorably designed sheet-metal hoods can also result in low loading figures—if the victim does not happen to strike any bracing elements. In the case of a front end made of sheet metal, however, the presence of bracing, edges, and corners can hardly be avoided; in any case, the intention is to pass the 5 mph test as stipulated in FMVSS 215, without harm to the pedestrian—and this would not be possible with a metal front end.

As with the hood, the version of the soft face with the greatest yielding characteristics proved to be most superior here as well. One of the results from a soft face made entirely of integral polyurethane foam, which was also included in the testing, showed that forces applied to the pedestrian could indeed be reduced: here, the beneficial effect was achieved by elimination of the bracing and reinforcement normally featured locally at the cooling-air intake, at the headlights, and at the body seams. The addition of foam to these points resulted in more than doubling the weight here, however.

The acceleration-time sequence plots alone, however, do not suffice to explain all the differences observed in collision sequences with respect to all accident evidence and traces and damage done to the dummies and the test vehicles. With tests conducted using the conventional comparison car, it was observed that the following types of injuries were suffered in almost every second test: dummy legs and knee joints were damaged by the pronounced bumper edges, and collarbones were broken by impact of the elbow on the hood in the vicinity of the engine. Furthermore, splinters from headlight covers and

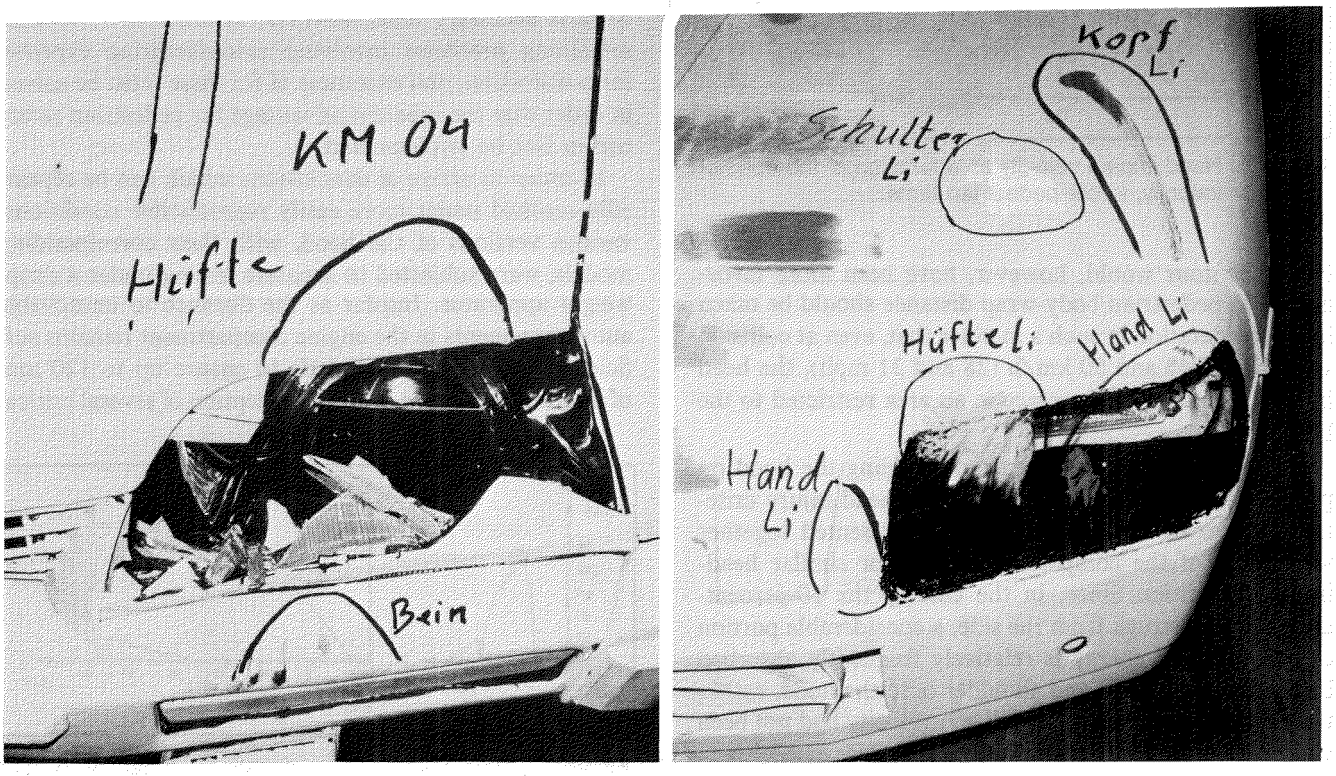


Figure 12. Damages to the comparison vehicles from pedestrian tests (right side UNI-Car; impact locations marked with different colours).

Comparisons of test results with pontoon-shaped vehicles and wedge-formed ones such as the UNI-CAR will always demonstrate different motions sequences and loading conditions, as a result of geometric factors. We must point out that hoods with front edges at the normal limousine height are associated with extremely high thorax loads and very long trajectory lengths for children; extremely low design forms, on the other hand, present the danger of increased head-impact velocities of adults on the hood.

The UNI-CAR compromise reached among aerodynamics, constructed size, design, visibility conditions, and deformation paths represents an acceptable mean in the configuration of the car body contour with regard to safety provided for child and adult pedestrians. In this regard, Figure 8 shows a plot of the head-impact velocity perpendicular to the hood surface, as a function of the car-pedestrian impact velocity. The test values are therefore similar to well-known results from other investigations, despite the flat form involved here. A somewhat

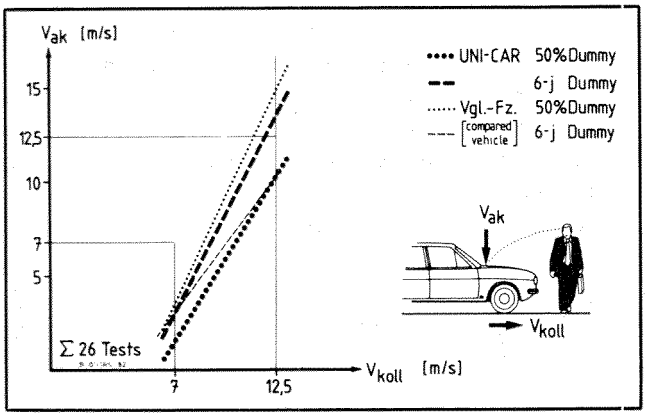


Figure 8. Head impact velocity as a function of the collision velocity, in car-pedestrian tests.

higher contour would, however, have been more favorable. The pedestrian body-wrap distance should be taken into consideration in such a manner that, even at collision velocities of 45 and 50 km/h (28 and 31 mph), the head impact will always take place in an area restricted to the hood.

Figure 9 shows the influence of padding the hood on pedestrian head loads. Here the HIC (head injury criterion) values of the UNI-CAR are represented together with those of the comparison vehicle for similar head-impact velocities. Since, in the case of the 50-percent-male dummy struck from the side, a considerable portion of its rotational energy is relatively frequently absorbed by the impact of arm and shoulder onto the hood, rather than by the head itself, the collision velocity had not been chosen as a criterion of comparison.

These tests show quite clearly that the versions of the UNI-CAR favorable for production purposes were, un-

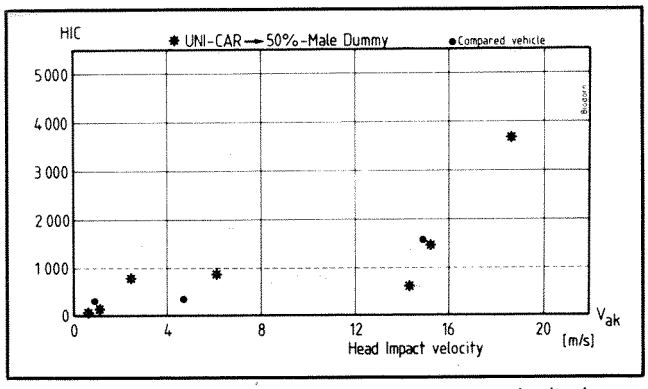


Figure 9. HIC as a function of head-impact velocity in pedestrian tests.

fortunately, relatively rigid and did not therefore result in the improvements which had been expected. Those features which were primarily unfavorable were the aluminum supporting frames for the heavier hood versions which had been padded with energy-absorbing polyurethane foam that proved to be too dense. Also problematical was the excessively strong car body shell at the soft face, in the vicinity of the headlights in their wells, as well as the seam along the hood. The last point here was especially disadvantageous in the case of the child dummy.

Good results, however, were achieved through use of a sandwich hood made of a layer of polyurethane between two layers of glass-fiber-reinforced plastic; test measured values are shown here in Figure 10. Further development work is necessary here, however, in order to solve still-remaining problems involving manufacturing expense, form distortion, and exactness of fit: these must be solved in order that the inherent advantage for pedestrian safety can in fact be implemented.

In order to arrive at conclusions which can be repeatedly reached under more easily reproducible conditions, various versions of the hood, with their corresponding models, were subjected to separate testing under a drop-weight apparatus. Insofar as the distance to immovable auto components in the engine compartment remains sufficient (the attempt was made to ensure up to 120 mm of intermediate space, with the exception of several critical

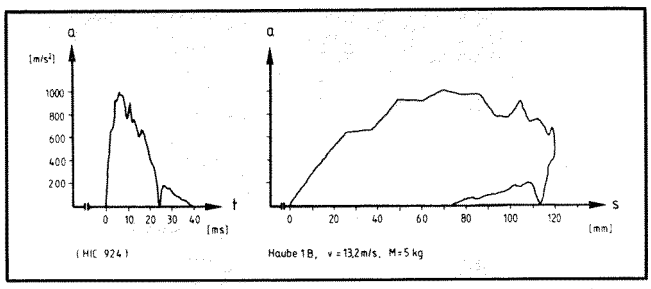


Figure 10. Path-of-force characteristic for a sandwich hood of polyurethane between glass-fiber-reinforced plastic.

hood latches protruding partially through the hood metal to the outside would also have given real cause for critical injuries in the case of an actual accident. The dangers here are not correspondingly recorded in the acceleration-time printouts, however. Figure 12 shows the two cars compared in testing in the headlight area after a collision with a 50-percent dummy at 45 km/h (28 mph). The UNI-CAR has remained for the most part undamaged, and will therefore be significantly less aggressive in respect to the types of injuries which could be expected from these damaged vehicle parts.

SIDE CRASH PROTECTION, MEASUREMENTS, AND TEST RESULTS

Side Protection Measures

The side protection system consists of a transverse bracing which is rigid in compression: two transverse beams behind the front seats, between the "B" pillars. The bracings are provided with additional rigidity by the seat pans. See Figure 13. The door braces and latches ensure that, in case of a side crash, an interlocked bracing system will function to withstand initial forces applied in bending and, for greater deformations, in tension. To guarantee direct transmission of tension forces (i.e., without first having to overcome play), careful design of the connection points was necessary (e.g., pillars, hinges, door, lock, etc.). See Figure 14.

By virtue of seats which cannot be adjusted in the longitudinal direction, it was possible to provide uniform optimal side padding for all sizes of passengers. The seats have been moved a relatively great distance toward the middle of the car, thereby allowing for considerable side intrusion before the occupants are struck by the penetrating parts of the car.

Finally, interaction (collision) between the left and the right passengers is extensively avoided by virtue of the high transmission tunnel and shoulder padding. See Figure 15. An additional advantage is provided by anchoring the top of the three-point safety belt system on the *inside* rather than at the outside.

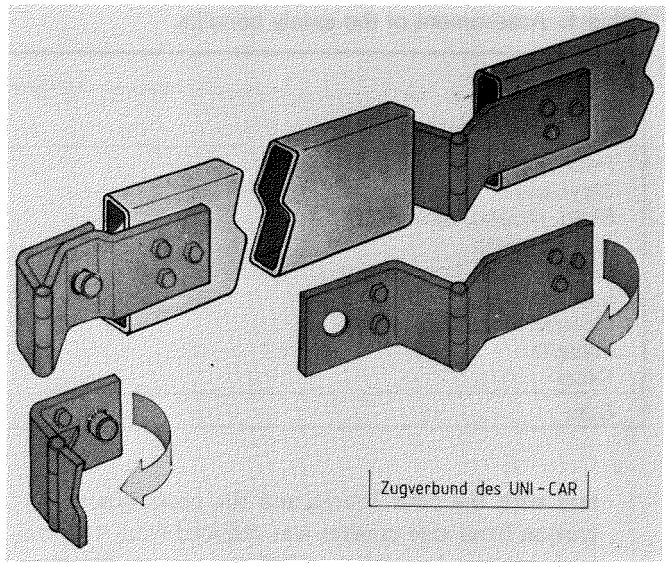


Figure 14. Hinges and locks on the UNI-Car.

Test Results

Investigation was made of the effectiveness of the various cross-bracing elements, individually and in interaction. For reasons of cost, the tests were conducted with standard factory car models which had been modified in accordance with the improvements made with the UNI-CAR. The following results were determined:

—By virtue of the bracing, considerably more seating room remains available.

—Best effectiveness was achieved by an integrated sys-

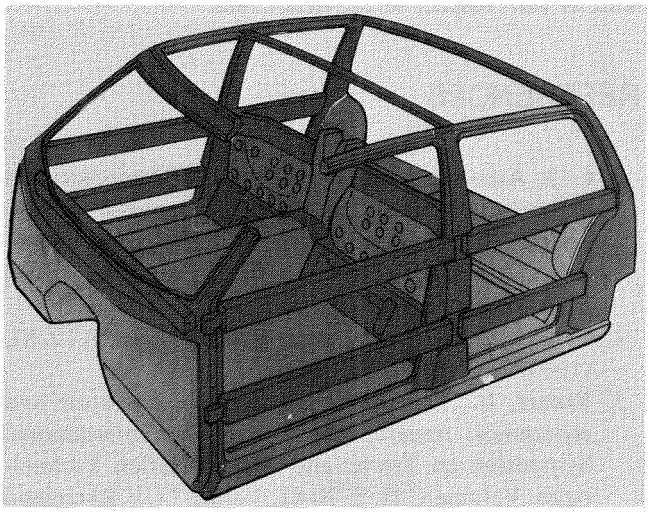


Figure 13. Passenger compartment of the UNI-CAR.

Figure 15. Interior padding in the UNI-CAR.

Table 1. Assessment of the safety benefits.

Traffic Participants	Fatality rate absolutely (FRG 1980)	Fatality rate (coll. with car) (%)	Reduction of fatality rate (%)	Safety benefit (%)
Pedestrians	3095	23	40	9.2
Bicyclists	1142	9	40	3.6
Mofa, Moped, Mokick	765	5	40	2.0
Motorcyclists	1232	9	20	1.8
Occupants in frontal impacts	3912	37	20	7.4
Occupants in side impacts	1825	17	25	4.3
Other	1070	—	0	0
Sum	13041	100	—	28.3

tem with the door braces and the cross braces. Intrusion from side crashes was reduced from 465 mm with unbraced vehicles, to 225 mm, i.e., to less than half.

—The free space remaining as a result of the above phenomenon can be utilized for minimization of forces acting on passengers by means of providing suitable padding of the side doors. This is achieved by ensuring as great a padding deformation path as possible for acceleration of passengers up to the lateral vehicle velocity after a crash from the side.

—In the striking car, the passengers and vehicle will be subjected to slightly higher collision forces as a result of the bracing reinforcement provided in the struck vehicle. The safety advantage gained on the other hand by the maintenance of more survival space in the target vehicle passenger compartment more than compensate for the insignificant worsening of conditions for the striking car, with the result that this slight disadvantage is acceptable.

ASSESSMENT OF THE SAFETY BENEFITS

Calculation of the safety benefits gained in the area of passive safety is performed in accordance with a new prognosis method. The individual steps are as follows:

—probability of injury as a function of the collison velocity, with the present state of vehicle design
—gain in speed which results experimentally after introduction of the safety measures, with equal loading
—injury probability as a function of the collision speed, with UNI-CAR conditions
—distribution of speeds in actual accidents
—breakdown of participants into AIS (abbreviated injury scale) classes by means of collision speed, with present state of automotive design
—shifted breakdown of participants into AIS classes using the collision speed, with UNI-CAR conditions
—distribution of pedestrian injuries in West Germany
—reduction in the proportion of those injured in West Germany
—reduction in the number of deaths and severe injuries.

If the above procedure is applied to all relevant collision types for which the UNI-CAR could bring improvements, a safety gain of approximately 30 percent could be achieved with respect to the number of traffic deaths. See Table 1. This figure results from inclusion of estimates made in the comparison of data from:

—actual traffic accidents
—test results with present conditions of automotive design (standard factory models)
—test results with the UNI-CAR.

This safety benefit results from the following breakdown:
13% for pedestrians and bicyclists
4% for motorcyclists
7% for car passengers in a head-on crash
4% for car passengers in a side crash.

As a result, the stipulations set in the relevant Loading Specifications for a safety gain of 28 percent in the area of passive safety were in fact satisfied by the cumulative effects of advantages from the various accident types, as well as with respect to the death rate.

REFERENCES

1. (—): Ausschreibung zum Projekt "Demonstration automobiltechnischer Forschungsergebnisse in integrierten Gesamtkonzepten von PKW-Versuchsmodellen," Bundesminister für Forschung und Technologie (BMFT), Bonn (1978).
2. Bandel, J.: Der Forschungspersonenwagen, ATZ 82, (1980) 2, S. 59-62.
3. Breuer, B.: The pedestrian-oriented, low-noise and economical research car Proceedings International Symposiun on Traffic and Transportation Technologies, Volume C II, S. 70-88, Verlag TÜV Rheinland GmbH, Köln 1979.

4. Appel, H., Blödorn, J., Kühnel, A., Pasch, R., Rattaj, H., Willumeit, H. P., Wollert, W.: Das Sicherheitskonzept des Forschungs-PKW UNI-CAR. VDI-Bericht Nr. 418, 1981, S. 123-130.
5. Potthoff, J.: Zur aerodynamischen Formgebung des Forschungs-PKW UNI-CAR. VDI-Bericht Nr. 418, 1981, S. 219-230.
6. Liedl, W., Schwarz, R.: Noise reduction concept for UNI-CAR research passenger car. Internoise 1981, Amsterdam.
7. Kühnel, A., Blödorn, J., Appel, H., Pasch, R., Rattaj, H., Wollert, W.: Realisierung und Wirksamkeitsnachweis von Sicherheitsanforderungen am Beispiel des Forschungs-PKW. Unfall- und Sicherheitsforschung Straßenverkehr, Heft 36, 1982, S. 152-157.
8. Kühnel, A.: Der Fahrzeug-Fußgänger-Unfall und seine Rekonstruktion, Dissertation 83, 1980, Berlin.
9. Pasch, R., Kühnel, A., Wollert, W., Blödorn, J., Rattaj, H., Appel, H.: Structural rigidity and occupant loading in the case of the side collision. VII. International IRCOBI Conference on the Biomechanics of Impact, 1982, Cologne.
10. Blödorn, J., Wollert, W., Kühnel, A., Pasch, R., Rattaj, H., Appel, H.: Anwendung von Polyurethan-Schaumstoffen zur Verbesserung der Äußeren Sicherheit beim PKW. Kunststoffe 72 (1982) 4, S. 217-221.
11. Appel, H., Breuer, B., Essers, U., Helling, J., Willumeit, H. P.: UNI-CAR—Der Forschungs-Personenwagen der Hochschularbeitsgemeinschaft. ATZ 84 (1982) 3, S. 107-115.
12. Kühnel, A., Appel, H., Blödorn, J., Pasch, R., Rattaj, H., Wollert, W., Willumeit, H. P.: Sicherheitsgewinn und Innenraum des UNI-CAR. XIX. Intern. FISITA-Congress, 1982, Melbourne, Australia.
13. Breuer, B.: Der Forschungs-Personenwagen UNI-CAR. XIX. International FISITA-Congress, 1982, Melbourne, Australia.

The Safety Aspects of the VW Auto 2000

ULRICH W. SEIFFERT and
HANS-WILHELM GROVE
Research Division
Volkswagenwerk AG
Wolfsburg, Germany

INTRODUCTION

The tasks which research and development work is called upon to fulfill have become increasingly more critical. This does not, however, alter the fact that the motor car has to satisfy a large number of various, conflicting requirements. For the research division of the Volkswagenwerk, this means representing the integral demands made on the motor car of tomorrow. As long ago as 1973, the concept of the IRVW was born and represented in hardware. As far as this concept is concerned, nothing has changed up to this conference. Contrary to the well-known demands, a whole series of additional demands now have to be fulfilled. Figure 1 shows these conflicting demands. Because of the causal relations, vehicle safety must not, in our opinion, be seen in isolation, also with regard to the further development of vehicles. In this respect, the "Auto 2000" research project is a logical continuation of our research work up to now. The VW Auto 2000 project is demonstrated in the following along with the results achieved to date.

DESCRIPTION OF THE VW AUTO 2000 CONCEPT

General

The VW 2000 research vehicle has already been described in detail in several articles (1) (2). For this reason, the general description can be limited to the aims and a few highlights together with the results. The aim of the project was to represent the future of motor car engineering up to the year 2000. Given this aim, the vehicle concept was to be optimized along with a significant improvement of vehicle safety, a reduction of exhaust gas and noise emission and increased fuel economy. Along with alternative materials for all areas of the vehicle, the use of electronic aids for the three electronic centres in the vehicle was to be investigated in particular. As a result, the 2-door saloon shown in Fig. 2 was displased at the IAA (International Automobile Exhibition) in Autumn 1981 in Frankfurt with the 3-cylinder Diesel engine and at the 1982 Hannover Trade Fair with the spark-ignition engine. In 1982, selective follow-up work was carried out, the results of which are given in the following.

The 4-seater vehicle permits a payload of 400 kg. The luggage compartment at the rear has numerous possible variations and means that the vehicle can be used to perform a whole range of transport tasks. The two research prototypes are fitted with two different engines—a 4-cylinder spark-ignition engine and a 3-cylinder direct-

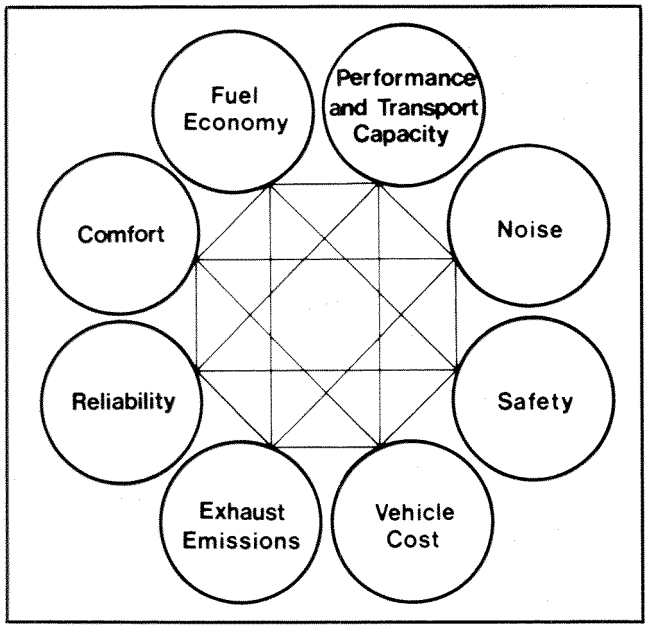


Figure 1. Conflicting demands in car development.

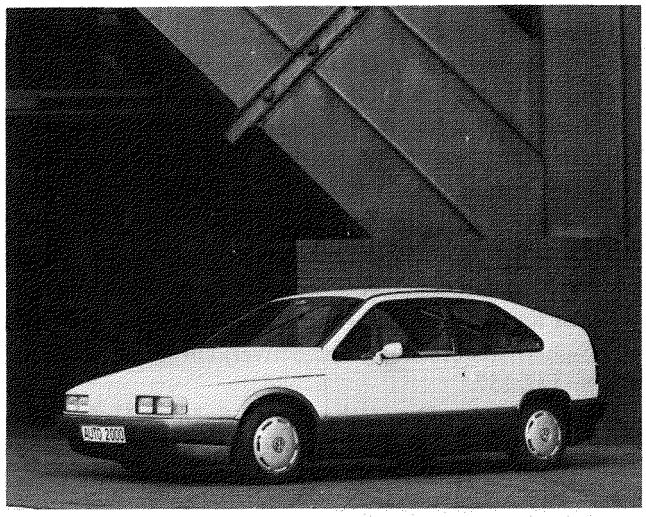


Figure 2. Volkswagen car 2000.

injection Diesel engine. Together with the transmissions selected for each engine, the vehicle consumption and performance values shown in the tables resulted.

The fact that these values were achieved with comparatively high performance should be particularly emphasized. However, in the course of the work the conflict between a further reduction of exhaust gas emission and an increase in fuel economy became apparent. It was only possible to achieve these consumption figures by means of the low drag coefficient of $c_D \times F = 0.25 \times 1.86 = 0.47$, i.e., substantially lower than the mean value of new vehicles sold in Germany in 1981 of $c_D \times F = 0.81$ (Fig. 3). Despite the use of a great number of alternative materials, it was not possible to lower the vehicle weight

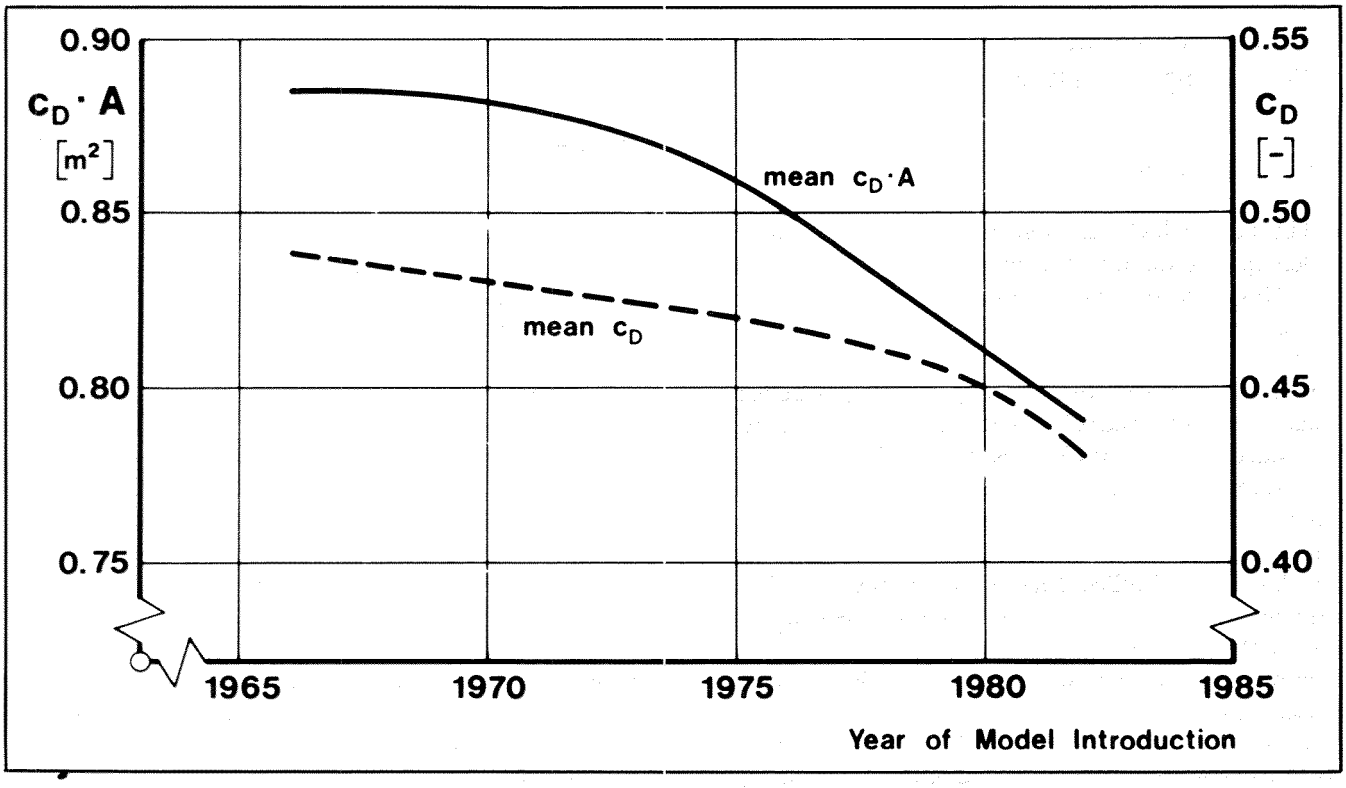


Figure 3. Evolution of c_D and $c_D \times A$ worldwide.

much below the mean value of present-day production vehicles. One reason for this is the large number of additional items of equipment, the weight of which must be compensated for by reducing weight elsewhere.

Diesel Engine and Stop/Start System

The Diesel engine was designed as a 3-cylinder direct-injection engine with electronically governed Diesel injection pump. Of the possible supercharging devices, an exhaust turbocharger was selected. The consumption and performance of the Auto 2000 achieved with this combination are shown in Figures 4a-4c. The engine/clutch management system is worthy of particular mention here. The clutch system was designed as shown in Figure 5. The controlled clutches K1 and K2 cause the engine to be switched off when the vehicle is stationary or when decelerating. If this system had not been integrated in the vehicle concept, fuel consumption would have been approximately 17% higher in the ECE urban cycle and approximately 4% higher in the US 75 test. Exhaust gas emissions were also reduced by switching off the engine. The measured values for the different test methods were:

ECE exhaust gas test:
CO = 3 g/test HC + NOx = 6 g/test
US exhaust gas test:
CO = 0.92/mile HC = 0.3 g/mile NOx = 1.2 g/mile

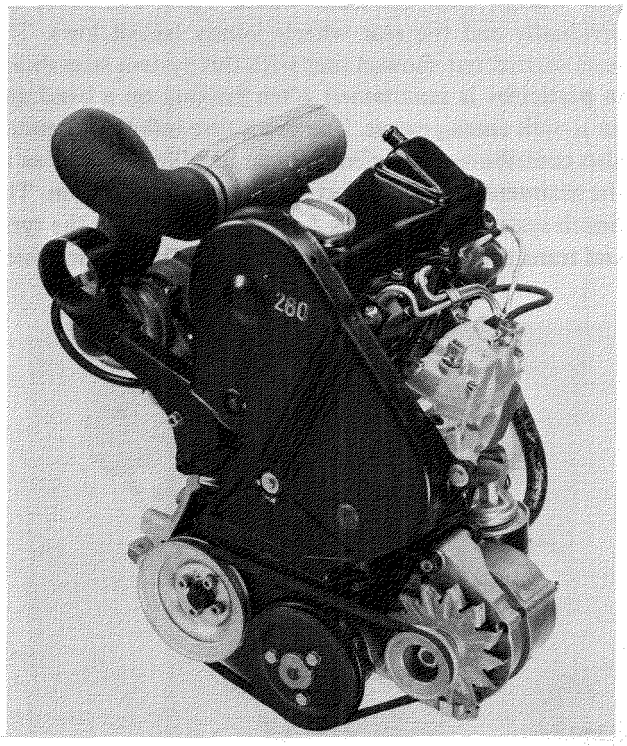


Figure 4a. 3-cylinder diesel engine (direct injection with turbocharging).

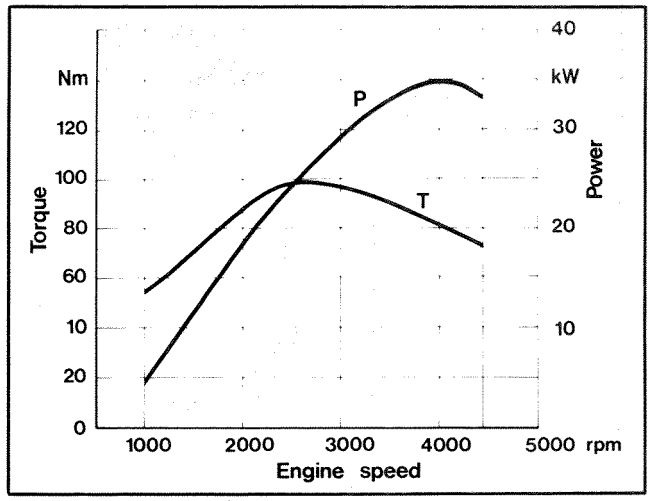


Figure 4b. Full throttle characteristics of turbocharged direct injection diesel.

		Diesel Engine
Top Speed	km/h	150
Acceleration 0-100 km/h 40-100 km/h in 4.th.Gear	s	20
Fuel Consumption (DIN 70 030) ECE-Test constant 90 km/h constant 120 km/h 1/3 Mix	l/100 km	 4.2 3.3 4.9 4.1
Pollutant Emissions CO/HC/NO_x		Within Present European Limits
Noise Emission	dB (A)	73

Figure 4c. Operational data (diesel-version).

Spark-Ignition Engine with Automatic Transmission

The spark-ignition engine used was a 1.06 litre engine with mechanical supercharging, petrol injection, knock limit control and map-controlled high-power transistorized ignition system. Figure 6a shows this engine with the mechanical supercharger controlled via a variable drive. The results achieved are shown in Figures 6b and 6c. Related to the limited pollutants, there is a clear conflict between a further reduction of pollutant components and of fuel consumption.

Acoustic Capsule

To reduce exterior noise, a vehicle acoustic capsule as shown in Figure 7 was designed for both engines. The

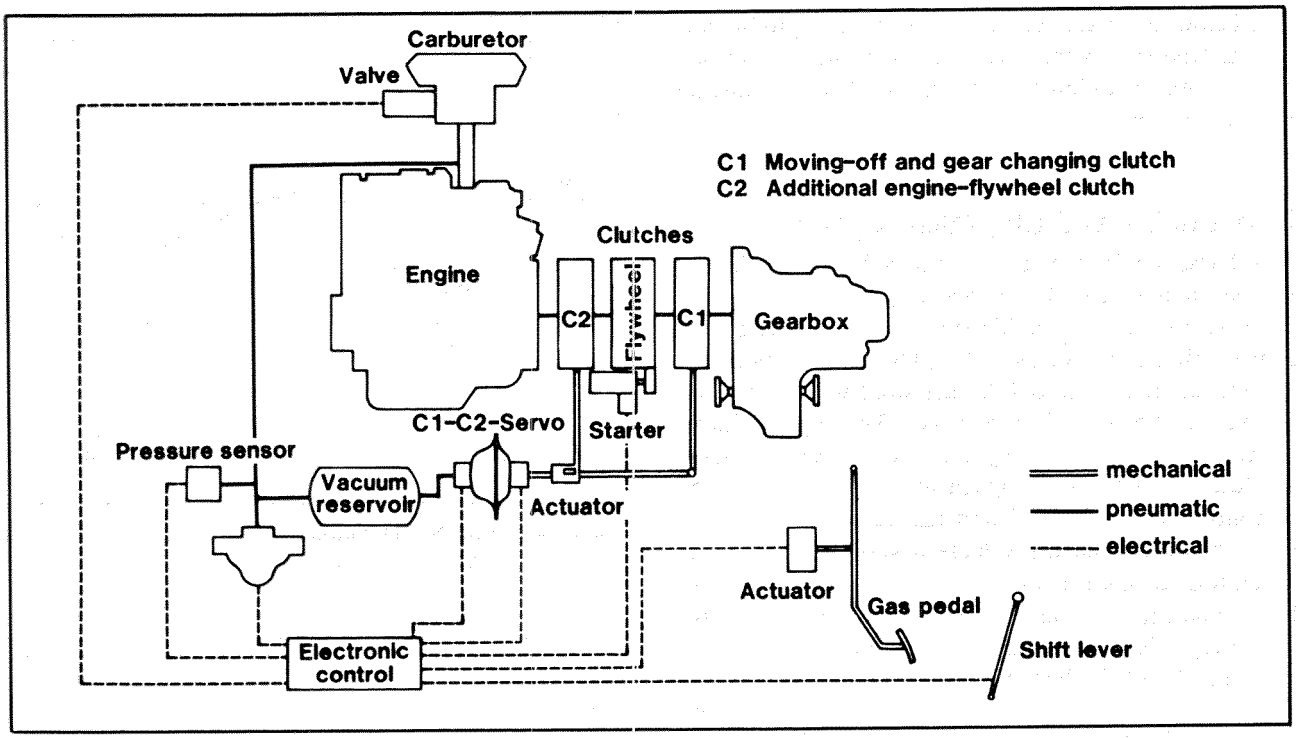


Figure 5. Start-stop system with flywheel inertia usage.

installation of this capsule has reduced exterior noise in the ISO pass-by test by 6-7 dB (A) in comparison with the legal type approval test value of 80 dB (A). On the vehicle with the spark-ignition engine, installation of the capsule components highlighted the problems concerned with the rise in temperature in the engine compartment. For a solution appropriate for series production, the capsule cannot for this reason be used to the same extent as in the Auto 2000, with the result that the reduction in noise would not be as great.

SAFETY ASPECTS

Accident Avoidance

In the field of accident avoidance a number of additional components were tested which have not yet been installed in this form as standard in vehicles. Here, we are dealing with the following features:

driver information centre with the ALI system
tyre pressure indicator
synthetic voice indicating warnings
antiskid device

A sub-frame with wishbones was selected for the front axle and a plastic design with countersteering rubber bearings for the rear axle. These bearings, which are also installed in the VW Passat, contribute to directional control, particularly in the event of side forces. The built-in antiskid device was developed together with the Teves company for the Auto 2000. Figure 8 shows the system selected. The hydraulic unit combines in a compact design the master cylinder, brake servo, accumulator, electric motor, pump and antiskid pressure modulator. The system is based on a three-circuit brake system (front wheel, rear wheel), with the front wheels being controlled individually and the rear wheels jointly (select low). The tests carried out showed that with this system steerability in particular is maintained when braking on a bend and on μ-split carriageways. The exact tyre inflation pressure also contributes to perfect vehicle handling as well as to the maintenance of comfort and low rolling friction. The Bosch system installed has 4 pressure sensors in the tyres and transmissions from tyres to chassis. The sensor, which

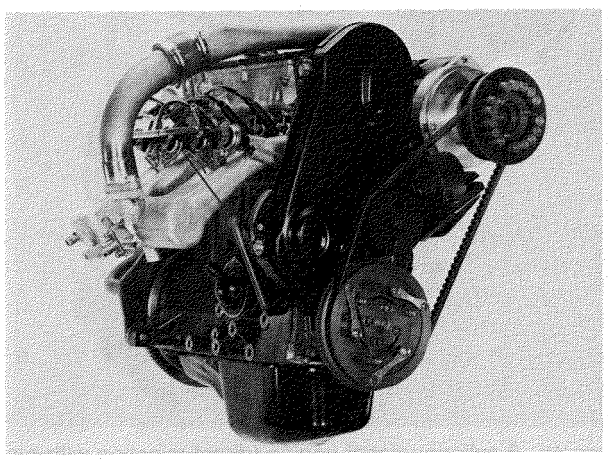


Figure 6a. 4-cylinder SI-engine (Comprex-Supercharging).

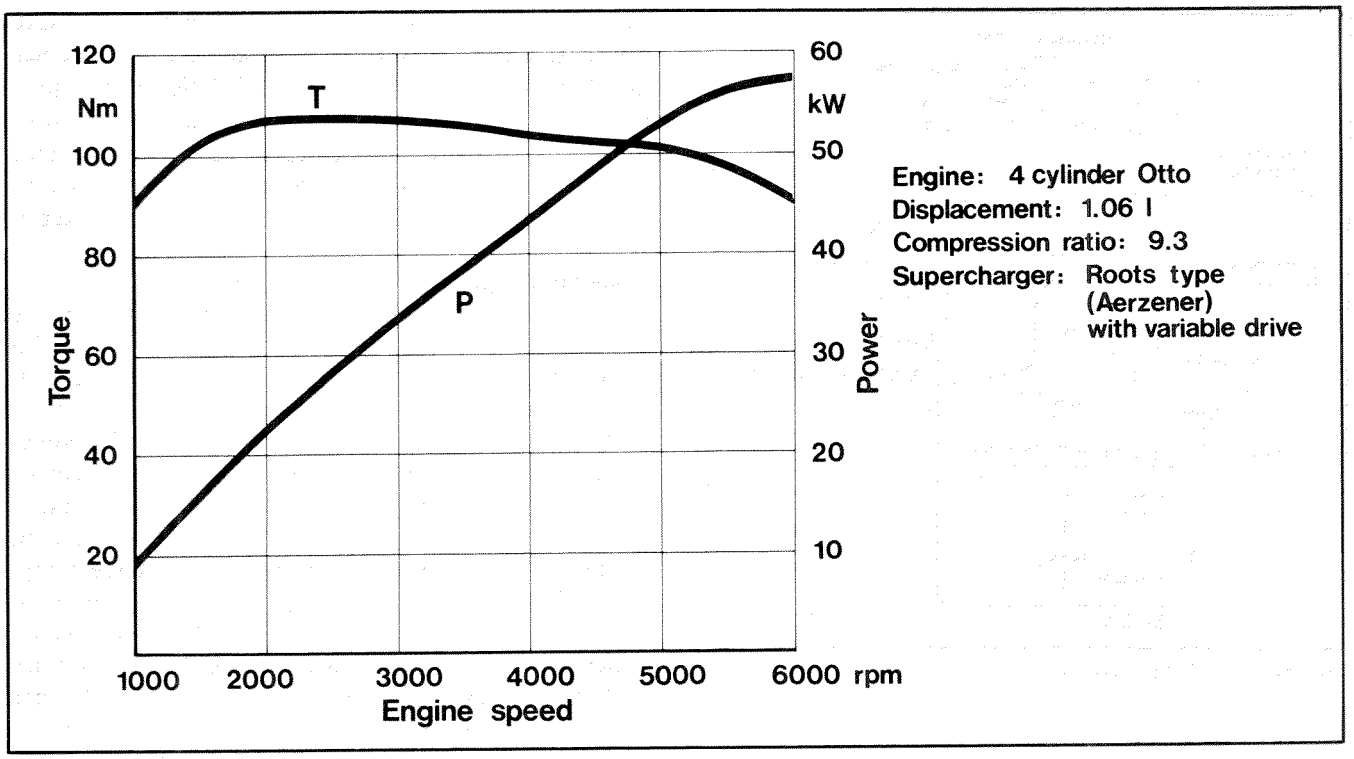


Figure 6b. Full throttle characteristics of supercharged Otto engine.

		Spark-Ignition Engine
Top Speed	km/h	180
Acceleration 0-100 km/h 40-100 km/h in 4.th.Gear	s	12
Fuel Consumption (DIN 70 030) ECE-Test constant 90 km/h constant 120 km/h 1/3 Mix	l/100 km	 7.9 4.3 5.6 5.9
Fuel Economy US-Test City Highway Combined	mpg	 32 50 38
Pollutant Emissions CO/HC/NO_x (ECE)		Within Present European Limits
Noise Emission (ISO DP 362)	dB (A)	73

Figure 6c. Operational data (SI-version).

is screwed into the rim, consists of a reference pressure chamber and a metal diaphragm which, when bent, actuates a contact so that if the pressure is too low a DC voltage signal is transmitted to the driver information centre where the synthetic voice utters the phrase "tyre inflation pressure too low." The ALI system should be seen as a further element towards accident prevention. This system gives the driver information on the flow of traffic. There is still a great safety potential in a continuous flow of traffic with regard to reducing the number of accidents.

Mitigation of Injuries

Particular attention was paid to mitigating injuries in the event of an accident. The measures taken can be divided into two areas:

Protection of pedestrians: rounded body, no sharp-edged body parts, windscreen made of Sekuriflex (special tempered safety glass), deformable bonnet.

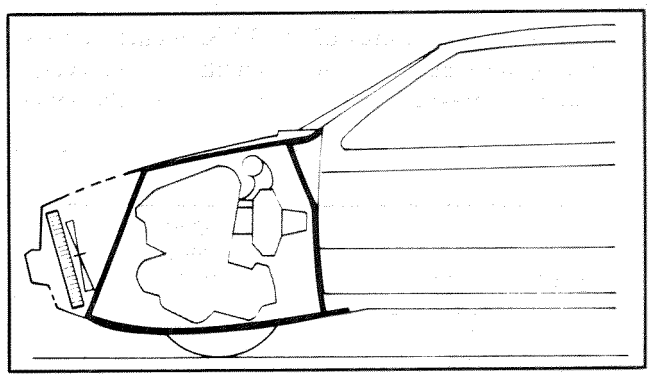


Figure 7. Capsule concept.

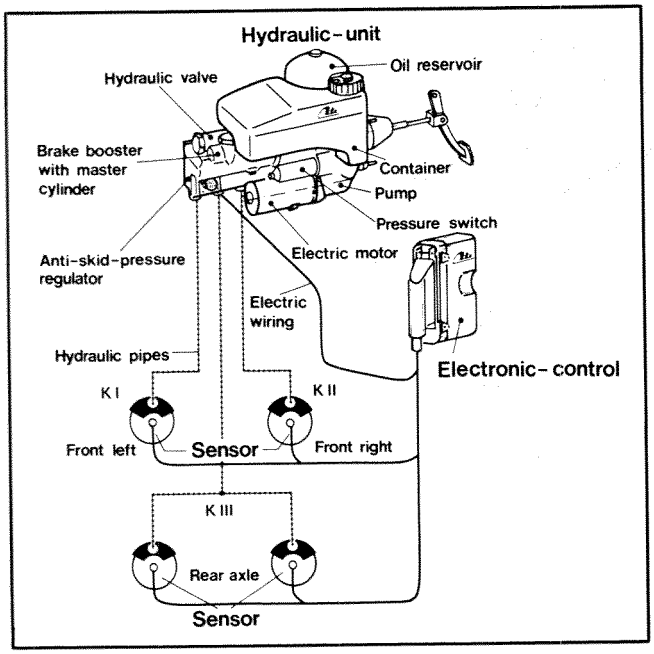


Figure 8. Anti-skid device.

Protection of occupants: energy-absorbing body, special safety steering column, passive seat belt system.

An optimum design of the body was aimed for taking into account legal requirements, the constraints imposed by aerodynamics, the vehicle curb weight of approximately 800 kg together with the engines and transmissions selected.

The wheelbase is 2450 mm, the front track width 1410 mm and rear track width 1358 mm. The passenger compartment dimensions are: front/rear headroom 956/923 mm; front/rear elbow width 1455/1426 mm and the so-called comfort dimension (distance from pedals at front to front edge of rear seat bench) 1825 mm. To achieve a design satisfying this range of requirements, the latest findings of the Finite Element Method were used. Figure 9 shows the FEM mesh of the research vehicle with the appurtenant comparative results with regard to calculation and testing. The comparison shows that along with the optimization measures of the FEM model, the test conditions must also be exactly simulated. For energy absorption in crashes, optimization runs for the longitudinal members were carried out, likewise with FEM methods. Figure 10 shows the mesh of a longitudinal member with the results of the quasi-static pressure test. On the basis of the theoretical investigations, the structure for the body in white was designed as shown in Figure 11. For head-on collisions, a design with straight longitudinal members was elaborated which absorbs the energy on two planes. The contact surfaces on the pillars were made larger specially for the door arch.

The new developed special Sekuriflex windscreen was bonded to the body frame, as shown in Figure 12. The structure of the windscreen also means an increase in safety for occupants not wearing a seat belt. This windscreen has an additional plastic foil on the innerside which helps to avoid lacerations of the face and the sometimes occurring penetration through the windscreen during crash. The Sekuriflex windshield is now under testing related to the other performance criteria in Germany. Figure 13 shows a section through the side door. Because of the relatively large door opening of the 2-door body, it was necessary to design the arch accordingly. Together with the energy-absorbing inner door parts, a further improvement is to reduce the danger of injury in the event of collision from the side. For the front seats, the passive seat belt system of VW, body belt with knee bolster, was fitted (Fig. 14). The system of VW body belt together with the special breakaway steering column (Fig. 15) gives protection up to 30 mph or more in accordance with the requirements of US-FMVSS 208. The following results are those of sled impact tests carried out with Golf bodies, equipped with the passive restraint system:

Δv = 37 mph		Driver	Passenger
HIC	(-)	789,0	739,0
a res chest	(g)	47,6	39,6
F femur left	(kN)	5,09	4,45
F femur right	(kN)	4,25	5,67

As is generally known, the head impact in particular is higher in the event of a real crash than in the impact test due to the different way in which vehicle and dummy behave. Nevertheless, it can be assumed that FMVSS 208 is met up to 30 mph or more.

Initial tests with a modified Hybrid II-dummy were also carried out to check the protection of pedestrians. The results are listed in the following:

Position of dummy	Impact speed (mph)	Dummy data ($t \geq 3$ ms)			
		Head		Chest ares (g)	Pelvis ares (g)
		HIC(-)	ares (g)		
Mid front of vehicle perpendicular to the car	15,6 22,3	161 191	54,7 48,0	24,9 36,5	31,0 40,8

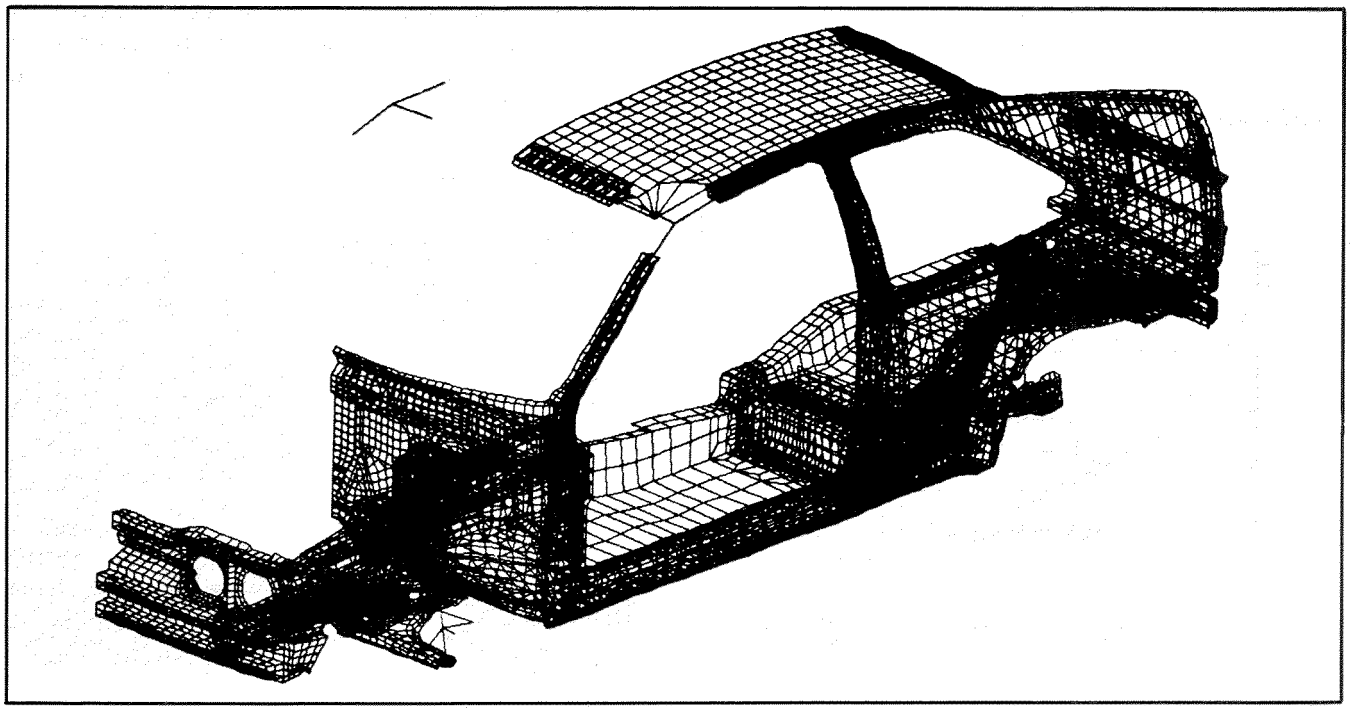


Figure 9a. Finite element analysis.

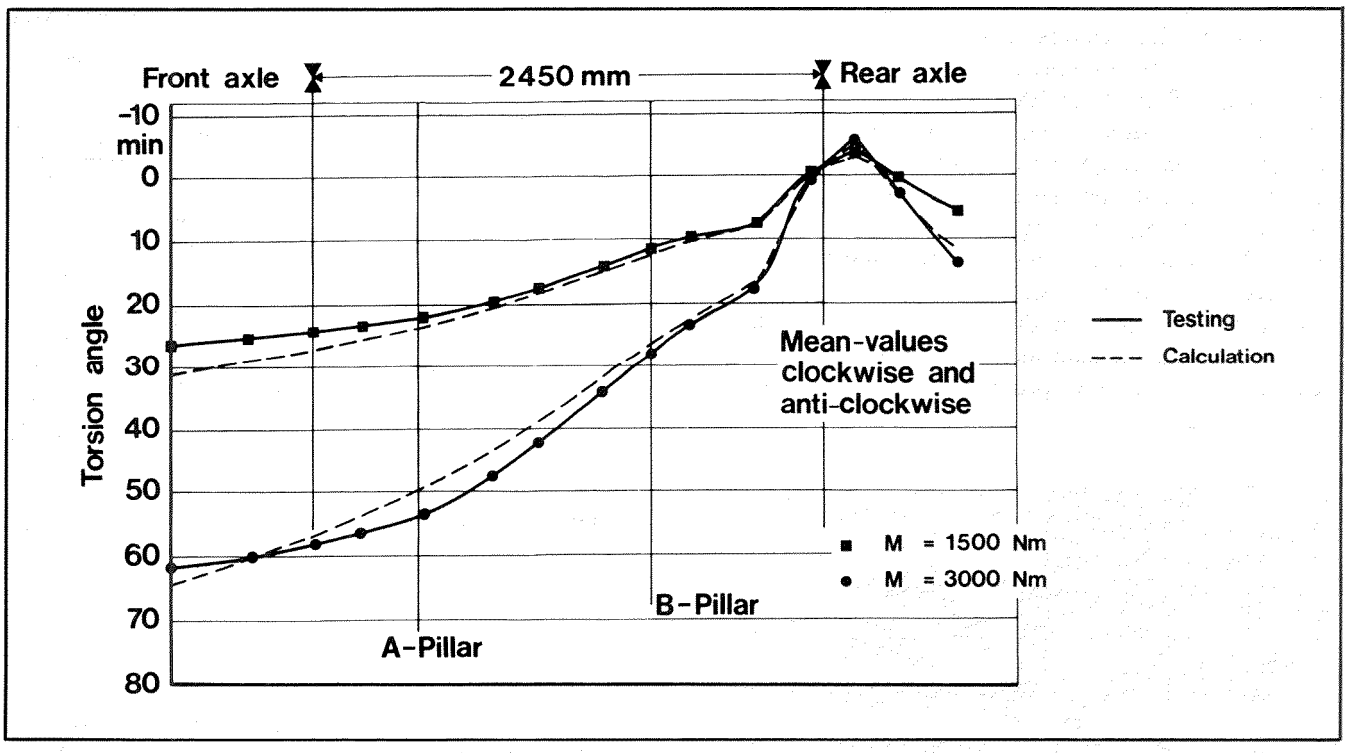


Figure 9b. Finite element analysis.

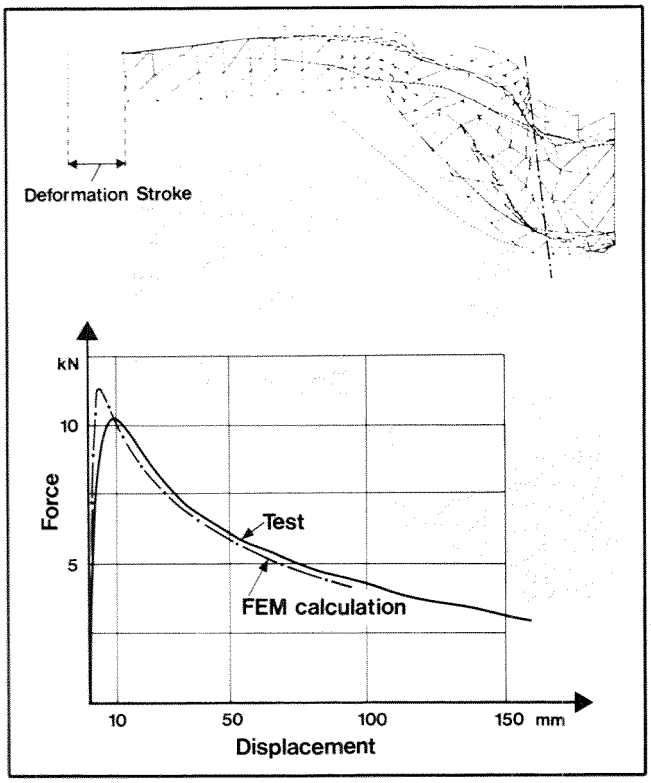


Figure 10. Finite element analysis for the front-beam.

Compared with vehicles with a high front end, the "flight path" of the dummy is different with the aerodynamic shape of the Auto 2000. This applies both to the kinematics of the dummy motion as well as to the contact time of the dummy on the front of the car. The initial impact is taken up by the front end which in case of pendulum test absorbs energy up to 2.5 mph. At higher speeds, the dummy comes into contact with the Sekuriflex windscreen. Figure 16 shows the contact between the car 2000 and the pedestrian dummy during the collision phase. Although the data measured at the dummies are well below the criteria specified for restrained vehicle occupants, a judgment about the performance in real world pedestrian accidents cannot be made at this time.

The tests and analyses of vehicle safety show that for a future vehicle concept designed along the lines of economy it is also possible to provide a reasonable degree of vehicle safety.

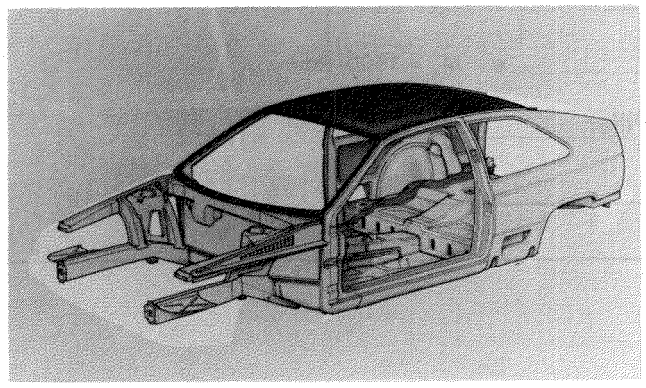


Figure 11. Body in white.

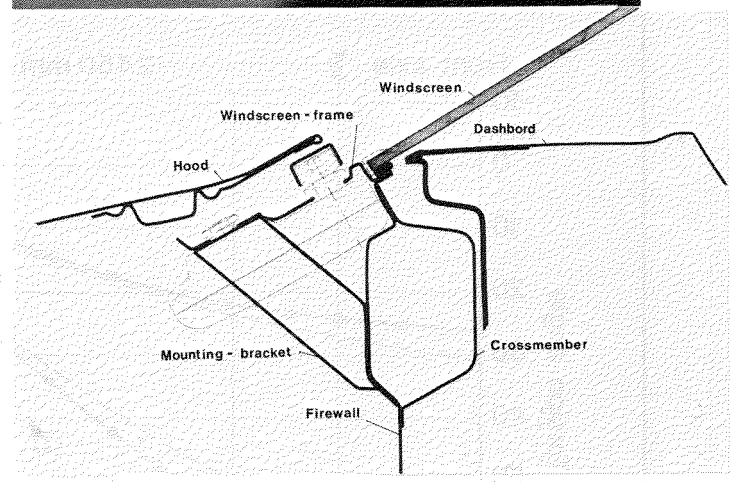


Figure 12. Hood/windscreen-design.

SUMMARY

The obligations incumbent on vehicle development should not just be seen in the field of vehicle safety. Along with the further increase in vehicle safety in the field of accident avoidance and mitigation of injuries, the requirements in the field of energy saving (manufacturing and operation), reduction of exhaust gas and noise emission

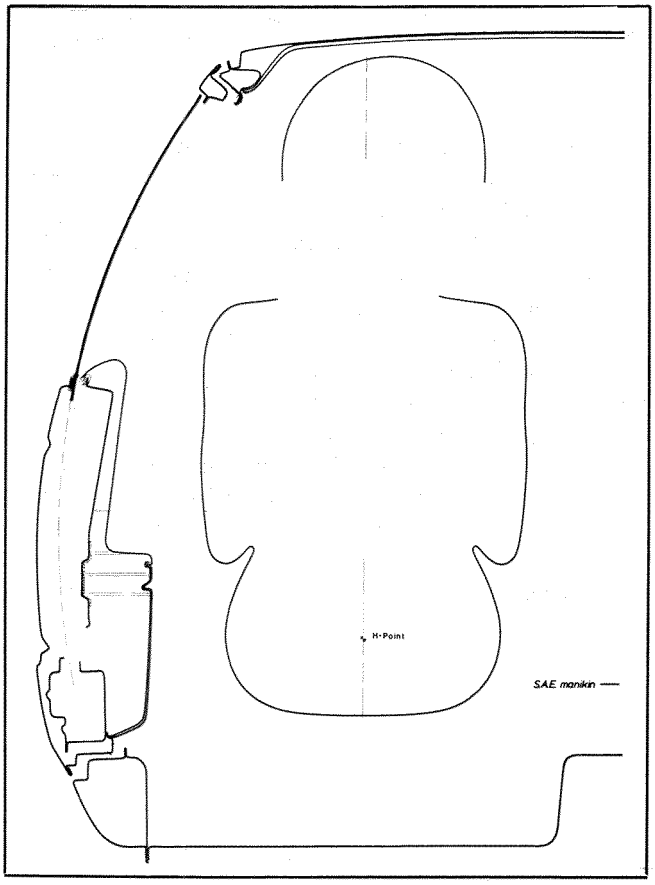


Figure 13. Door cross section.

Figure 14. Passive restraint system.

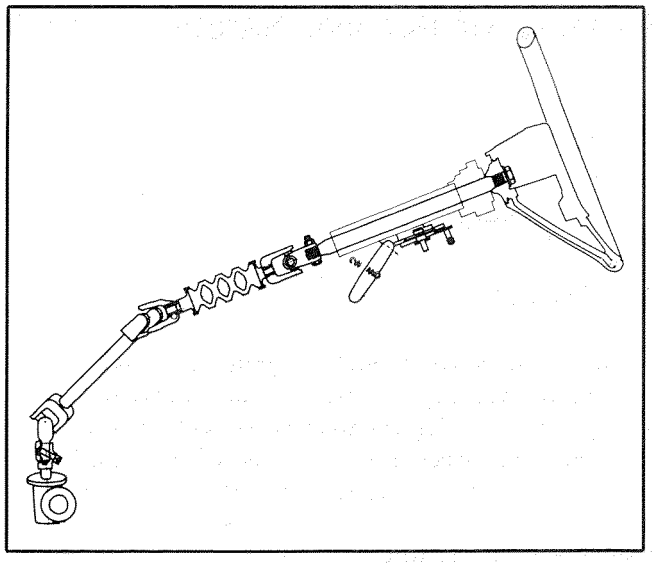


Figure 15. Safety-steering column.

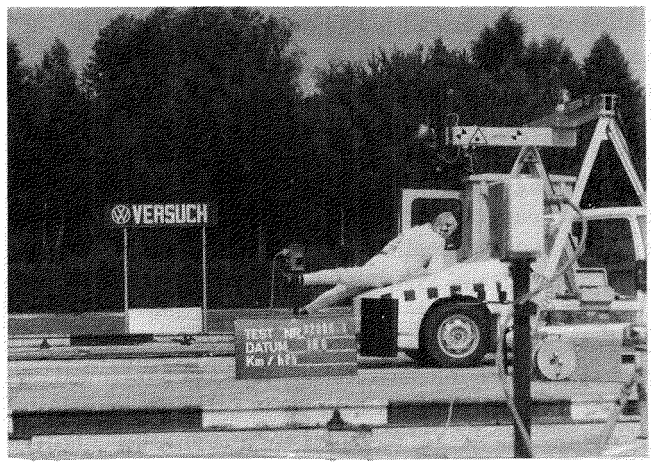


Figure 16. Collision of the Volkswagen-Auto 2000 with a pedestrian dummy.

as well as new products and production technologies must be taken into account. For the fields of vehicle safety, it would appear apparent that along with further steps towards optimization in the field of accident avoidance, the assessment criteria for the behaviour of vehicles in a real crash in particular, but also in simulated accident tests will have to be reformulated. This applies in particular to the side collision, which represents a new area of emphasis for research in the field of vehicle safety.

REFERENCES

1. Seiffert, "VW-Auto 2000" Automobiltechnische Zeitschrift 9/81
2. Eib, Gaschler, "Der direkteinspritzende Dreizylinder-Dieselmotor des VW-Forschungsautos" Automobiltechnische Zeitschrift 10/81

Aspects of Passive Safety in the Mercedes-Benz Research Car

GUNTRAM HUBER
Daimler-Benz AG, Passenger Car Development

ABSTRACT

Under a national research programme, supported by the Federal Ministry of Research and Technology, test vehicles for a touring car were developed which had to take into equal account aspects of energy savings, economy, environmental protection and safety. An important partial objective of this programme was the design and testing of measures with the prospect of a further 30% reduction in injuries and deaths of road users in accidents involving cars.

Methods of improving passive safety emphasizing "protection of car occupants in head-on and side collisions and protection of pedestrians and cyclists" are demonstrated on the research car.

In countries with right-hand traffic, drivers are subject to the greatest risk of injury in head-on collisions due to forces acting mainly on the left side, seat use pattern and the added danger from pedals and steering. This is countered by reinforcement of the left side of the body and improved restraint systems for all seats.

Increased resistance of the passenger compartment to deformation under transverse load and correspondingly re-designed interior surfaces of the doors are suited to reduce the load on the occupants in side collisions. Furthermore, a number of measures are currently being tested with the research car for the protection of pedestrians and cyclists, whose percentage involvement in accidents gains increasing importance due to the growing number of cyclists and the substantial advances made in car occupant protection.

The continued lack of suitable measuring devices and extremely fragmentary studies on the correlation of laboratory measurements with actual injuries suffered present great difficulties for coping with the challenge effectively.

INTRODUCTION

In contrast to ESV/RSV development in the 1970's, with its extreme one-sided safety-oriented emphasis on occupant protection, the design of the Mercedes-Benz research car was influenced by a broader requirement profile guided by considerations of practical value and advantage to society (Fig. 1).

Measures designed to conserve energy and resources and improve environmental compatibility and economy were accorded equal significance with active and passive safety. This frequently resulted in a search for a balanced compromise between contrary demands—for example, more safety for car occupants *and* road users outside the car coupled with reduced weight and economic recycling.

While the total advantage to be derived was specified, the freedom allowed the participants to choose the major objectives within this scope was felt to be a beneficial feature of the research programme which enabled more realistic experiences and initiatives to be introduced.

An important objective of the demonstration of automotive engineering advances in the research car, the development of which was supported by the Federal Ministry of Research and Technology, was the reduction of deaths and injuries in accidents involving cars by 30%.

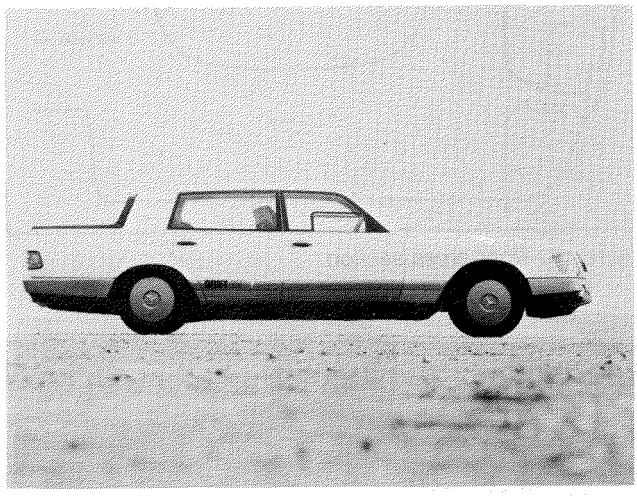


Figure 1. Mercedes-Benz research car.

As statistics show human error to be the cause of some 90% of all road accidents, measures to further improve passive safety can be expected to be more effective than improvements at the same effort and expense in the already highly developed active safety.

The new design features serve mainly the protection of car occupants in head-on and side collisions as well as the protection of pedestrians and cyclists, so that more than 80% of all injuries to persons in accidents involving cars are thus covered. The expected reduction in the consequential cost of injury on the basis of the familiar AIS scale is taken as the measure of progress. The better utilization of existing safety devices is not taken into account, moreover (for example, according to a BAST study a 30% higher rate of belt use corresponds to a 20% reduction in consequential cost of injury). In-depth case studies, an integral element of development and improvement of production vehicles at Daimler-Benz for many

years, are the precondition for achieving good results with the method selected (Fig. 2).

However, development work is rendered difficult by the lack of useful measuring equipment (side collision and pedestrian dummies) and extremely fragmentary research results on the correlation of measurable physical quantities from laboratory tests with the injuries suffered in accidents of comparable crash severity.

Passenger Protection in Head-on Collisions

Head-on collisions represent 60% of the car accidents with injury to passengers. They are by far the most frequent type of accident and entail a high risk of injury to vehicle occupants owing to the great changes in velocity. All endeavours to reduce these risks require reliable data on the frequency, severity and cause for a statistically relevant large number of vehicle collisions.

Figure 3 shows the distribution of head-on collisions—in the form of cumulative frequency curves—as a function of the energy equivalent speed EES, which characterizes the nature and extent of the deformation of the vehicle and thus the severity of the accident.

Two hundred forty frontal collisions causing at least one serious injury to or death of a passenger (MAIS 3^+) are taken into account. The EES was defined in connection with the reconstruction of highway accidents and has proven a far better descriptor of accident severity than the often used change of velocity Δ v.

From the distribution curves in Figure 3 we can conclude:

—60% of all serious to fatal injuries occur in the speed range with EES $\leq$ 50 km/h, mainly due to failure to use restraint systems.

—More than 50% of all frontal collisions with serious injuries involve the left-hand side of the vehicle in countries with right-hand traffic. This suggests a similar frequency on the right-hand side in countries where driving is on the left.

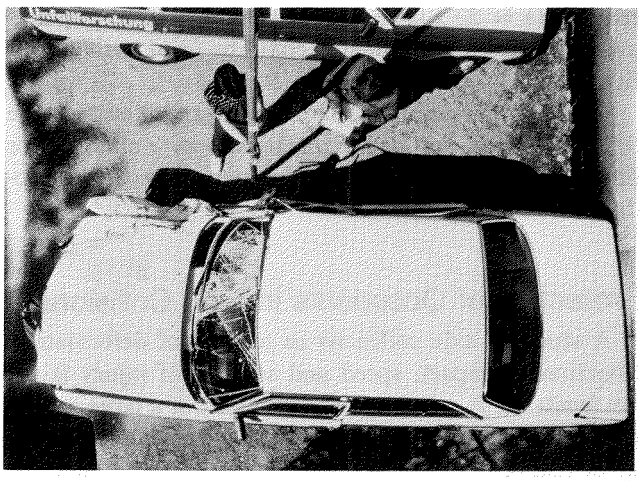


Figure 2. Accident investigation team on scene.

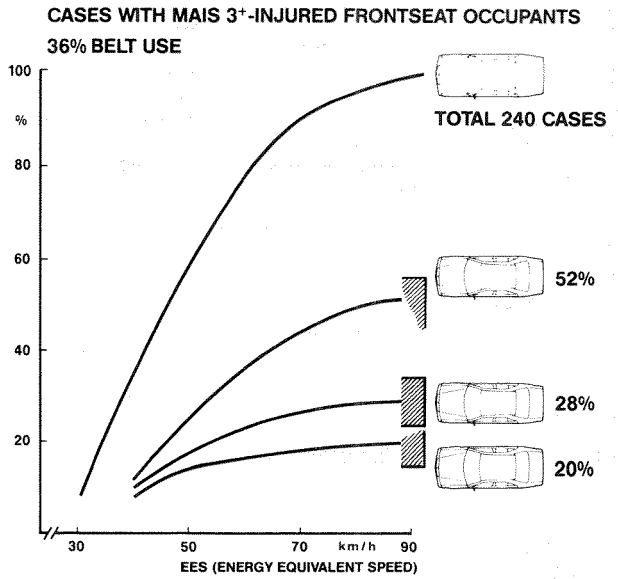


Figure 3. Distribution of head-on collisions.

—Only about 25% conform to the legally prescribed 0° barrier collision (3% of symmetric deformations occur in crashes against trees or poles).

—In the speed range 40 $\leq$ EES $\leq$ 60 km/h a sharp increase of cumulative frequency is recognized, caused mainly by collisions on the left-hand side.

—Speeds of EES $>$ 80 km/h are hardly relevant statistically because of glance-off and the small number of cases.

The analysis of the head-on collisions shows that the drivers are subjected to the greatest risk of injury. This can be explained by the additional danger coming from the pedals and steering, the preponderance of left-hand offset collisions and the frequency of seat occupancy (driver : frontpassenger : back seat = 4 : 2 : 1).

Consequently, improved occupant protection for the driver's seat in head-on collisions must be accorded special significance in terms of efficiency (benefit/cost/weight requirement). Special attention should be given to an aspect of left-hand collisions, particularly involving glance-off, in future accident evaluations and new vehicle designs (Fig. 4).

Serious injuries, which in most cases determined the maximum injury severity (MAIS), to the lower extremities were found in the study of 82 *belt-wearing* drivers whose cars collided in the left-hand offset mode. Due to the high intrusion speeds in the footwell and the smaller change of velocity Δv this trend is augmented in collisions involving glance-off (Δv $\leq$ 0.7 EES).

In addition to relatively minor head and thorax injuries specific injuries to the lower extremities were observed due to "impact shocks" from EES = 40 km/h upwards.

The investigation of all *belt-wearing* occupants in head-on collisions led to similar results: Injury severity MAIS

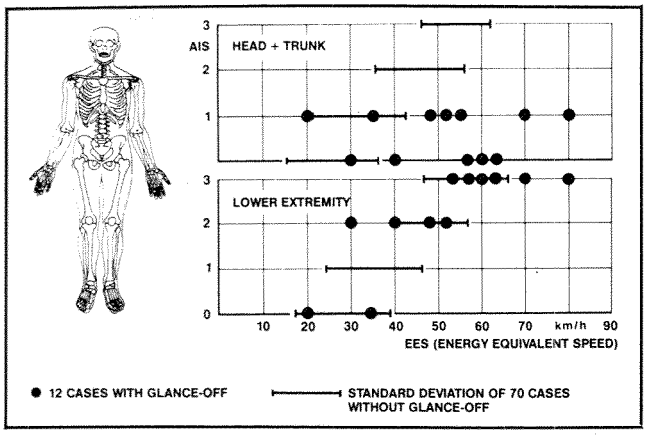


Figure 4. Injury severity of belted drivers.

3-6 occurred with the following frequency: lower extremities 40%, trunk 27%, head 27%, upper extremities 6%.

The following passive-safety-enhancing elements are being tested in the Mercedes-Benz research car:

—Reinforced front end and passenger compartment structure on left-hand side (asymmetric)
—Modified arrangement of components in the engine compartment to reduce residual block length after compression through crash forces
—Improved coupling of the right-side front-end structure, which is not directly loaded in a left offset collision, with the left-hand side, by means of a high strength bumper support and the hood, which is hinged on the left and locked in two places
—Control of front wheel turn (because of influence on leg room!); disconnection of steering gear—steering wheel link dependent on displacement (Aramid element in steering shaft); and direction of pedals forwards when more severe deformation occurs
—Improved three-point belts on the front seats with all belt anchorages in the seat structure; buckles integrated in the rear cushion (Fig. 5)
—Two-stage automatic support through belt tensioners on all seats and airbag in the steering wheel
—Windscreen made of laminated glass with anti-shatter film
—New type of child restraint system as integral part of the rear seat, adaptable as regards age and interchangeability.

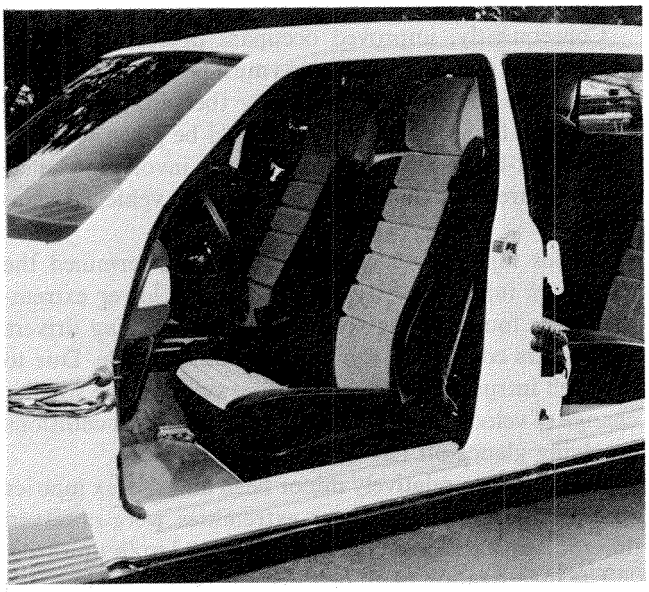


Figure 5. Front seats with integrated three-point belts.

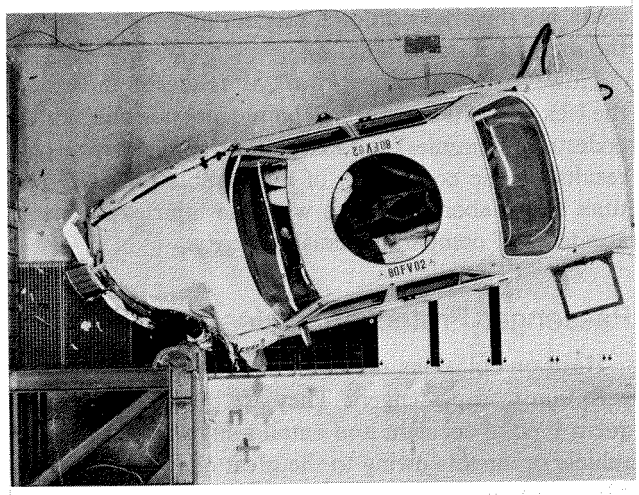


Figure 6. Frontal offset barrier test.

As test procedure the frontal collision at 55 km/h with a solid obstacle, offset to the left, with 40% overlap of the vehicle width was selected (Fig. 6).

Results:

First tests with modified production cars including evaluations on the Bendix-Accelerator have already given some positive results. For example, despite the extreme test condition the passenger compartment remained intact as a survival space while acceleration was appreciably reduced (a = 20 g instead of 33 g) and steering displacement lessened and occupants could be freed without difficulty (door opening forces < 50 N).

Through measures applied to the restraint system, the following values for load on occupants were obtained for driver and front passenger in comparison with the production cars (Fig. 7).

Protection of Occupants in Side Collisions

A study of side collisions as to type of deformation, direction of impact, speed and severity of injury is not yet available. A small number of cases but a large variety of parameters make conclusive judgments difficult. The great risk of injury in side collisions is brought about by the extent and shape of the intrusion, the intrusion speed

creased mileages of cars. By contrast, a sharp rise in injuries and deaths to motorized cyclists can be noted. Their accident balance, still little analyzed at this time, is difficult to influence by measures applied to cars owing to the large share of intrinsic energy, the higher riding position and the wide dispersion of contact points.

The degree to which external road users are endangered is represented in the case studies at hand by the injury risk ascertained in relation to contact areas on the vehicle (Fig. 10).

The greatest risk of injury to pedestrians stems from contact with the vehicle front, injury mechanisms of which have been adequately researched. For cyclists only few preliminary study results are available. In comparison to pedestrians the large percentage of side contacts is conspicuous.

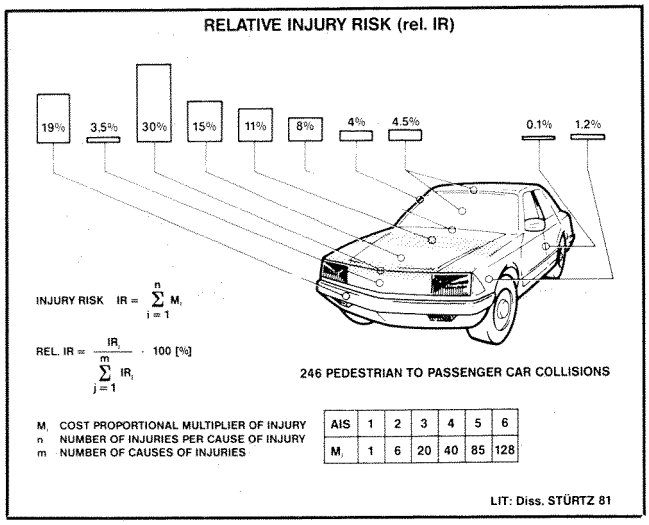


Figure 10. Causes and risk of injuries with car collisions to pedestrians.

The following injury-reducing measures, which mostly benefit also cyclists, are being tested on the Mercedes-Benz research car:

—Bumpers with energy-absorbing foam facing in front of the basebeam and Polyurethane spoiler with lower leg contact area moved downwards
—Soft face with radiator grille of fibre-reinforced polyurethane and yielding headlamp lenses of Polymethylmethacrylate.
—Fenders and complete panelling of A-pillars made of Polyurethane
—Hood edges and sealing hood / engine capsule / accessories partition with low resistance to deformation under vertical loading
—More deeply set nose contour (children) and completely recessed windscreen wipers
—Two-shell roof frame construction without roll-finished edge and projecting trim to reduce risk of injury to cyclists.

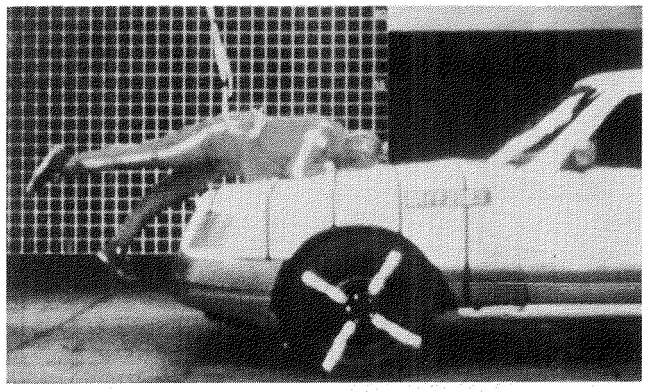


Figure 11. Car to pedestrian test.

As suitable test method a combination of pendulum tests on frequently impacted structural elements and model calculations is recommended. The latter serve to ascertain contact points and test parameters in the development phase of new vehicles.

In the absence of adequate experience with this method of optimization, dummy tests with the CCMC pedestrian position will be performed as a transitional arrangement (Fig. 11).

Results:

In Figure 12 first results of tests with a relatively frequent impact speed in city traffic of 25 km/h are shown. According to the results, all measurable load values with the exception of the head values for the child dummy could be reduced. The higher head load despite the soft nose is traceable to the front edge of the hood (conflicting targets load-bearing hood/head impact zone). Generally speaking, these test results should be viewed with caution due to only inadequate modification of the dummies and because measurements of this kind only partially reflect the risk of injury.

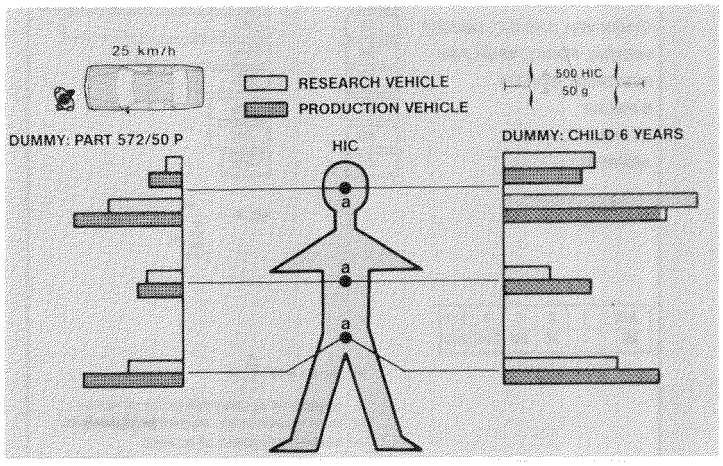


Figure 12. Dummy loads in pedestrian tests.

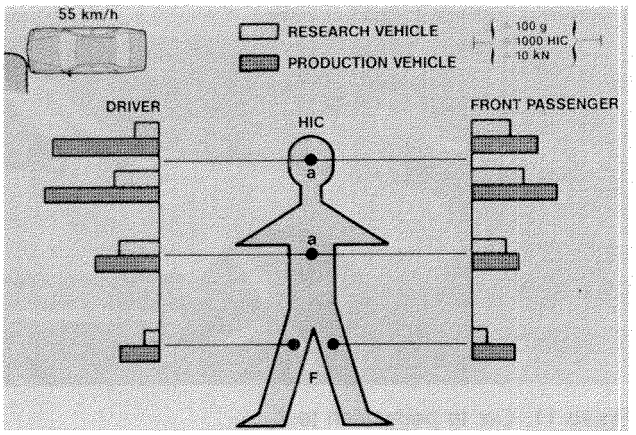


Figure 7. Dummy loads in front offset barrier tests.

of the impacted sidewall structure relative to the occupants and the limited capacity of the structural members and body panelling to absorb energy.

The risk of injury to the occupants can—as shown in Figure 8—be correlated with certain parts of the vehicle and can be determined from the frequency of contacts and the severity of the injuries using factors proportional to the consequential cost of injury.

Based on the results of the 222 side collisions with 336 injured passengers investigated by us we conclude:

—The most frequent cause of injury and thus the greatest risk of injury is attributable to the interior surfaces of the doors.
—The most serious injuries are attributable to objects outside the passenger compartment, chiefly because of contact with the head due to the breakage of prestressed glass panes and intrusions.
—A similarly high risk exists in the head impact area: doorposts, side roof frame and window frames, the latter particularly in conjunction with broken side windows.

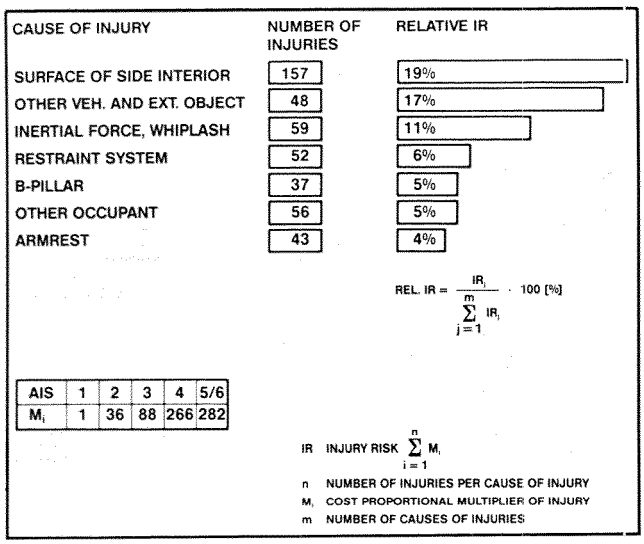


Figure 8. Cause and risk of injuries in side impacts.

The following elements for enhancing occupant protection in side collisions are being tested in the Mercedes-Benz research car (Fig. 9):

—Claw type overlap between all doors, the lower sections of which are reinforced, and the side members, transversely reinforced with interior plates; additional overlap of front doors at the reinforced bases of the centre pillars (bumper contact area!)
—Tension-compression connections in the doors between upper hinges and door latches
—Transverse stiffening of the passenger compartment through floor cross member including transmission tunnel bridge, recessed bulkhead and load-bearing seat structures (protective zones)

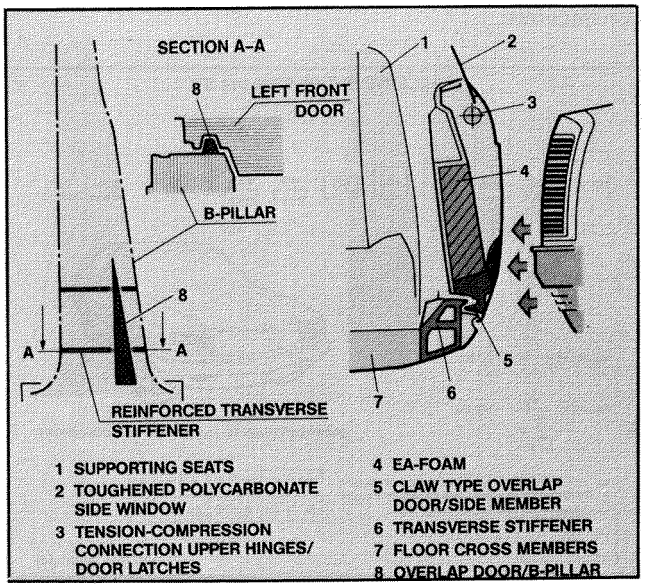


Figure 9. Improved occupant protection in lateral collisions.

—Expanded hip impact zones on all doors with approx. 80 mm thick energy absorbing foam members between inside and outside panels on the front doors
—All side windows made of Polycarbonate with high impact strength, firmly glued to the window frame
—Sandwiched prefab headliner with energy absorbing foam and Kevlar surface layer which yields fairly well under pressure in the head contact area
—All belt anchorages on the seat separated from the sidewall structure which takes the direct impact.

The measures were to be tested in impact tests with the moving barrier in accordance with ISO/TC 22/SC 10 striking the standing research car at 45 km/h at an angle of 90°. Results of the tests are not yet available.

Protection of Pedestrians and Cyclists

The number of injured and killed pedestrians shows a slightly declining trend, particularly relative to the in-

Influence of Research Results on Production Cars:

The research programme has accelerated the demonstration of some new steps suited to improve further on safety, economy and environmental compatibility of passenger cars. The profound examination of the demonstrated engineering solutions is still pending. Only those measures—even partially modified—may be found on future production cars which will be in strict correspondence with our standards regarding function, reliability and quality. To achieve economically justified results towards improved protection of road traffic participants, increased willingness of car occupants to use existing means for protection is a prerequisite.

Study of Devices Designed to Improve Safety Belt Performance

M. PETIOT and J. PROVENSAL
Renault State Owned Works
Research and Development Department

INTRODUCTION

Safety belt efficiency in head-on collisions has been confirmed by multidisciplinary analysis of actual accidents. However, this efficiency is limited, and wearing of a safety belt is not a guarantee of protection against impacts of any violence whatsoever. If the reader refers to a recent accidentology analysis performed by the Peugeot-Renault association, restraining improvement in the event of head-on collisions remains an essential priority. In fact, according to this survey, and in the hypothesis in which belts are worn at a rate of 100%, head-on collisions will still cause as many deaths as all other collisions configurations combined.

In a head-on collision, there are three main reasons why wearing a seat belt does not prevent death or severe injury:

—The occupant strikes an element of the compartment violently. This is due to an excessive movement of the occupant inside the compartment, and is favorized by a high intrusion level.
—The threshold of resistance of the occupant's thorax is exceeded, subsequent to excessively high forces in the shoulder belt.
—The occupant "submarined."

For the first two reasons cited, improvement in seat belts involves the resolution of a dilemma, increasing retention without increasing belt solicitations. The solution to this problem is known, and consists in improving coupling (or ride down effect), i.e., obtaining a better immediate coupling of the occupant to the vehicle, so as to use the stopping distance of the vehicle to the best possible advantage.

With a standard three-point belt, the part of the occupant energy dissipated by coupling is relatively low. Moreover, this is all the lower if the impact occurs at a high mean deceleration, i.e., over a short stopping distance. In the case of an orthogonal head-on collision, the occupant energy dissipated by the coupling is of the order of 25 to 35%.

Of the several factors which limit the share of coupling, two are regularly mentioned: first of all, the belt wearing slack, and secondly, movement of the webbing resulting from tightening of the strap reserve on the retractor spool (spool out effect).

Over recent years, devices to suppress these factors have been under study. Strap pretension devices concern wearing slack and, in part, movement. The belt locking devices are intended to suppress movement.

Renault is convinced that an improvement in coupling is still a highly interesting factor and, since 1970, has conducted studies in this field. In a previous paper, Renault presented its work concerning pretensioners (11).

Up to the present, the interest of web locking devices was cancelled out by systematic breaking of the straps due to the locking clamps or claws. Recently, research in this field was renewed, due to the availability of newly designed devices located at the retractor.

This paper is devoted to an examination of the progress actually due to these devices, omitting aspects relative to comfort. Renault considers that comfort cannot be neglected, and all the more so since unwinding and rewinding problems, together with difficulties in correctly adjusting the pressure on the thorax, are to be feared. However, in agreement with belt manufacturers, it has been admitted that the state of progress of the prototypes used does not, at least for the moment, enable an objective judgment to be made concerning the final performances of such devices in this field.

DEVICES TESTED

Presentation of Devices

In the present state of the technique, devices located at the D. ring were not retained due to breaking of the webbing at the clamping device.

Five different types of lockers located at the retractor were or are being tested.

These are broken down into two classes, according to their operating principle.

Type A

The web locker is independent of the retractor. Locking results from deceleration of the compartment. Deceleration causes movement of a flyweight, which actuates the locking device. In the open position, both locking clamps are open, and allow the strap to slide freely. This principle has no adverse effect on comfort.

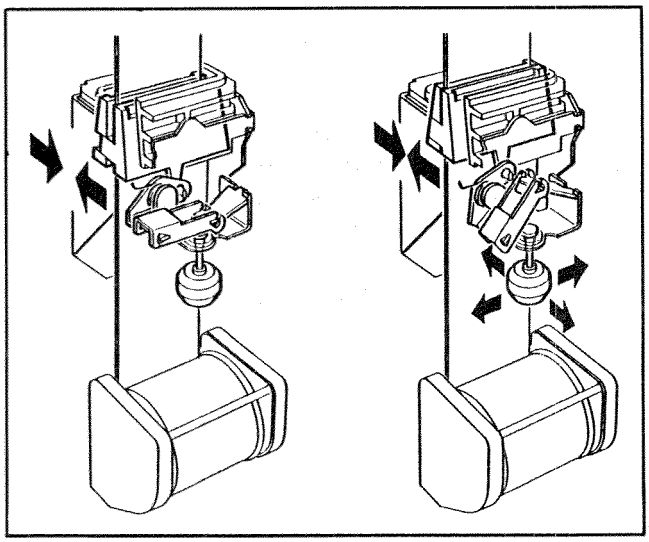


Figure 1. Web locker A.

Type B

The locking device is located under the retractor. Locking results from forces in the strap. Once the retractor has been locked, any pull on the strap causes the locking clamps to close in. The clamping pressure increases with belt webbing tension. When the roller is not locked, the clamps cannot close; this is the open position. With this principle, there will be a decrease in comfort if the device has not been carefully designed.

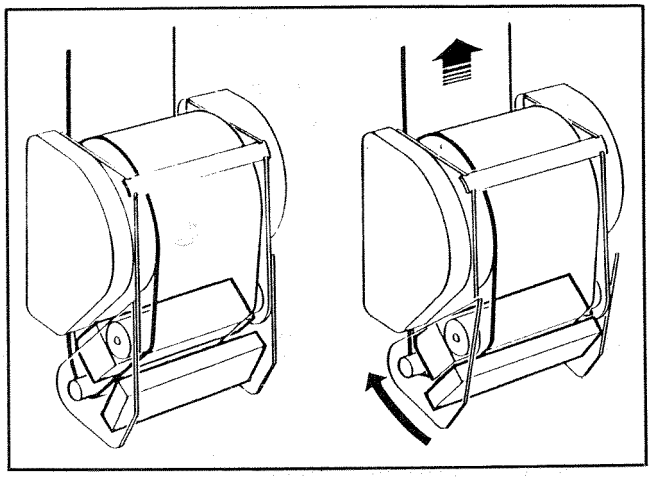


Figure 2. Web locker B.

Operation Validation

Webbing ruptures

Our work has demonstrated that the breaking resistance of the belt as a whole was not decreased with respect to that of a standard three-point belt.

During particularly stringent catapult tests, designed to approach the resistance limits of the safety belt, the percentage breakages, with or without a locker, were not significantly different. In 20% of the cases, breaking occurred with a three-point standard belt, and in 24% of cases with the locker. All breaks were located on the strap, the return loop or at the sliding buckle. Whatever the type of locker tested, there were never any traces of incipient tearing of the strap at the clamping device.

No breakages occurred during the barrier collision tests using the locker.

Spool out reduction

The use of a locker considerably reduces movement due to tightening of the webbing around the retractor spool.

This movement obviously increases with the length of the strap wound, the severity of the collision and the mass of the dummy.

Table 1. Average results of 18 sled tests with production cars (50 km/h - 0°).

	Conventional Retractor	Weblocker A	Weblocker B
Film spool (mm)	146	16,5	54
Head displacement (mm)	655	640	625
γ_L chest (g – 3 ms)	47	44	42
F shoulder belt (daN)	690	730	860

One gives, hereinafter, the mean travel values at the outlet from the retractor, obtained over 40 sled tests, performed under identical conditions; i.e., speed 50 kph, deceleration pulse for R.20 against 0° barrier, length of strap wound 800 mm, 12% elongation polyester strap, Hybrid 2 dummy. With a standard three-point belt, the mean spool out is 170 mm. For tests using a locker, the movement is reduced to 20, 30, 50 and 60 mm, depending on the prototype locker used.

The type A locker gave noticeably better performances than the type B. During subsequent tests, this was confirmed (see Tables 1 and 2). This advantage seems to be a logical consequence of the operating principle, which enables locking as soon as the flyweight moves. For the type B prototypes, clamping calls for locking of the retractor, then strap movement while the clamps close in.

LOCKERS ASSOCIATED WITH A STANDARD THREE-POINT BELT

0° Collision Configuration

Test program

—18 sled tests on R.18 body

The test conditions were as follows: speed 50 kph; R.18 deceleration law against 0° wall at 50 km per hr; dashboard, windshield and steering column removed; series production three-point belt with or without locker, H2 dummy installed in seat track mid-position. Six tests were performed using a conventional retractor, six with a type A locker and six with a type B locker.

—3 collisions against barrier with complete R.18 vehicle

The conditions were as follows: speed 50 kph, orthogonal barrier, H2 dummies installed in the seat track mid-position, three-point series production belt with or without locker. One collision was performed with a conventional retractor, one with locker A and one with locker B.

Results

Locker efficiency was estimated by measuring the characteristic restraining parameters, i.e.:

—Head movement within the compartment. This measurement was not retained when a head impact occurred.
—The driver HIC and the impact speed of the head, for barrier collisions. The HICs obtained without head impact are not characteristic of potential injuries, and were therefore not taken into consideration (however, time over 80 g's has always been mentioned).
—Thorax 3 ms deceleration.
—Force in the shoulder belt at the shoulder.
—Femur forces.
—"Submarining."

The results obtained call for the following comments (see Tables 1 and 2).

Head forward movement

Sled tests show only a slight reduction in head forward movement: 15 mm for the type A locker and 30 mm for

Table 2. Results of crash tests with production cars (50 km/h — 0°).

	Conventional Retractor		Weblocker A		Weblocker B	
	Driver	Passenger	Driver	Passenger	Driver	Passenger
Film spool (mm)	90	105	8	0	40	45
Head displacement (mm)	—	615	—	625	—	595
HIC (relative values)	100	—	116	—	62	—
t for γ head > 80 g (en ms)	0,8	0	8,7	0	0,8	0
Head impact speed (ms)	15	—	13	—	13	—
γ_L chest (g — 3ms) (ms)	57	50	44	39	45	43
γ_L Pelvis (g — 3 ms) (ms)	44	36	45	35	52	45
F shoulder belt (daN)	535	540	680	630	810	780
Femur load left (daN)	100	260	80	360	120	200
Femur load right (daN)	240	140	220	170	390	180

the type B locker. During barrier collision tests, an increase in head forward movement of 10 mm was observed with locker A, and a decrease of 20 mm with locker B. These differences remain of the same order of magnitude as those imputable to dispersions, and it would seem justified to conclude that no noticeable gain has been provided by the lockers.

In spite of the absence of head forward movement reduction, a certain reduction in shoulder forward movement was, however, noted. This contradiction can be explained by kinematic modifications. In particular, we observed that the use of a locker increases rotation of the thorax with respect to the shoulder strap—shoulder contact point. Strongly restrained by the shoulder strap at the shoulder, the dummy tends to turn towards the door. This twist explains the decrease in shoulder forward movement, without a decrease in head forward movement.

HIC and head impact speed

With respect to the series production three-point belt test, driver HIC increased by 17% with the type A locker, and decreased by 35% with the type B locker. These important differences do not, however, indicate a ranking of efficiency. These results from a minor modification of the kinematics. In one case, head-steering wheel impact took place at the hub, and the other at the rim.

The head impact speed was slightly decreased by the use of a locker. This gain may be the result of better restraining of the dummy at the shoulder. Because of the HICs obtained, it should, however, be noted that this gain does not provide a sufficient remedy to the differences in head impact location.

Forces in strap and head and thorax deceleration

Measurement of the force in the shoulder strap at the shoulder is a difficult operation. The results showed relatively high dispersions, and, considered isolatedly, the figures given should be considered with reserve.

However, for the overall tests, it is undeniable that the use of a locker is accompanied by an increase in forces in the shoulder strap; this can be estimated as between 5 and 15%.

It seems possible to explain this increase as follows: the use of a locker increases the overall stiffness of the safety belt, but does not noticeably increase that part of dummy energy dissipated due to coupling with the vehicle. Mainly, the share of this coupling is limited by the existence of occupant-belt slack. Tightening of the strap on the retractor spool influences this slack, but is not a preponderant element. The wearing of the belt, the stiffness of the seat cushion and deformation of the occupant forms the major part. This observation has been justified by a detailed energy study which it is not possible to develop here. At most, on the deceleration curves recorded during the barrier collision tests, it is possible to observe that the actual start of restraining of the dummy is hardly effected by the presence of a locker (see Fig. 3). It should be stated that this result, as observed for high mean deceleration collisions is not necessarily obtained for lower mean deceleration collisions. Now, it should be noted that accidentologists consider the latter more representative of accidentological reality.

On average, the use of a locker entails a slight increase in the thorax 3 ms deceleration criterion. Due to increase of the force in the shoulder strap, it is probable that this decrease results from an increase in rotation of the thorax as already mentioned. Therefore, this cannot be considered as an actual benefit in safety.

"Submarining"

The use of a locker seems to increase the tendency to "submarine." This phenomenon is closely related to the design of the overall restraining system. Also, and although the use of a locker has not excessively downgraded performances of the vehicle used for these tests, this problem should, in our opinion, be taken into consideration before making a decision to install a locker on a given vehicle.

Femur force

On the vehicle used, the values obtained with the three-point, series production belt were low, and this criterion cannot, therefore, be a discriminating factor in this type of collision.

30° configuration

Test program—7 collisions at 65 kph (30° left)

The (oblique) configuration is generally considered as more representative of actual accidents than an orthogonal collision. A study intended to quantize the efficiency of lockers in terms of actual safety must therefore involve certain tests in this configuration. The 30° left impact using a complete R.18 vehicle was retained. (In this configuration, the vehicle collided with the barrier from the left-hand side, the wall being inclined by 30° with respect to the longitudinal axis of the vehicle, see Figure 4.) Moreover, and in order to obtain extreme severity conditions, the collision speed was 65 kph. Under these conditions of severity, results are generally dispersed, and it was therefore necessary to conduct several collisions, i.e., three with a series production, three-point belt, and four with lockers.

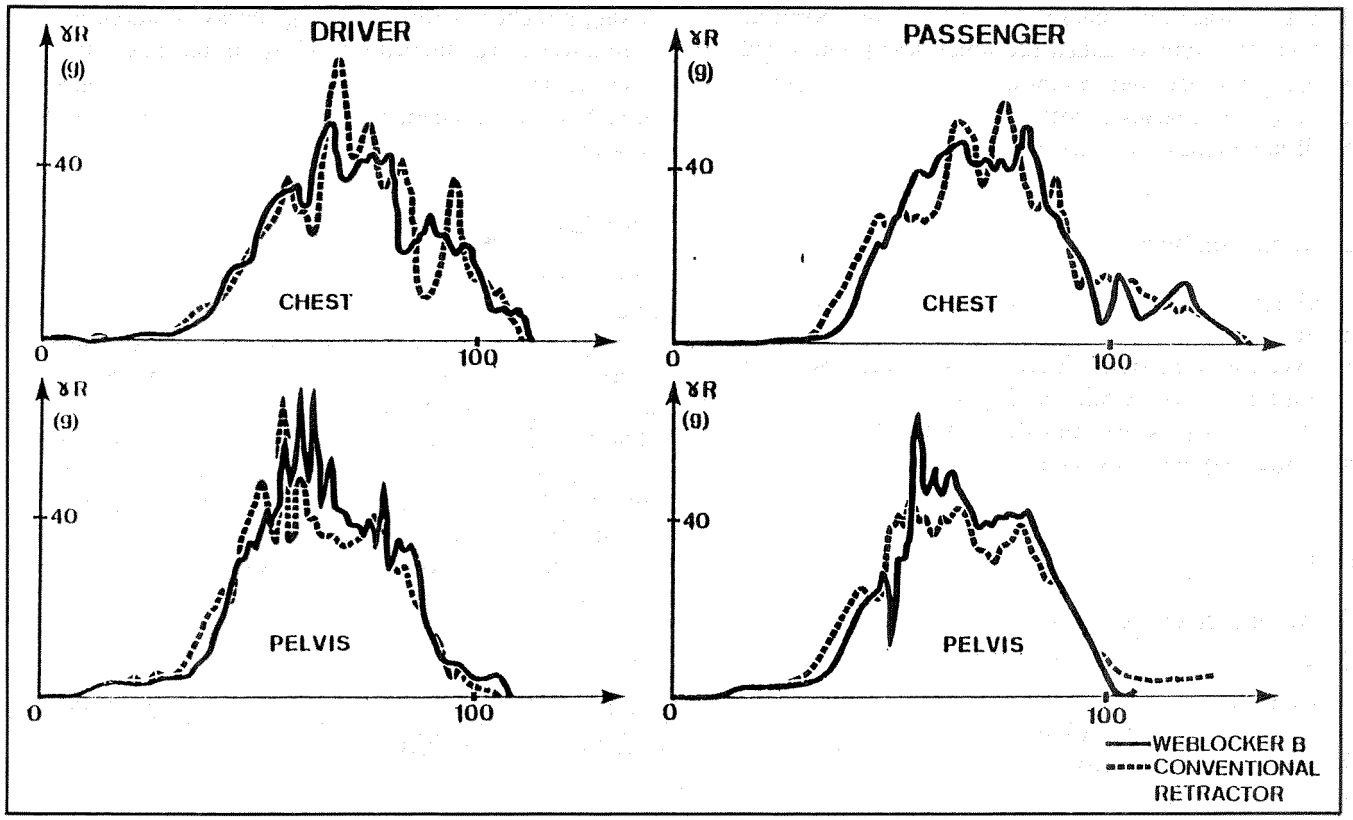


Figure 3. Chest and pelvis deceleration pulses.

Results

Injury criteria

The mean values obtained are combined in Table 3.

For the driver, and with the exception of the shoulder strap force, the use of a locker causes a general decrease in injury criteria. This decrease is obvious for HIC and femur forces, the mean values dropping by almost half.

In our opinion, the differences in HIC are once again due to a modification of the kinematic. This point is developed below.

Conversely, a single, more efficient restraint seems to explain the decrease in femur forces. Due to the order of magnitude of the values, the decrease obtained can be considered as particularly interesting. In fact, and if it is admitted that the mean human tolerance corresponds to a value of 1,000 daN, this signifies that it was possible to avoid dangerous impacts.

Table 3. Average results of 7 crash tests with production cars (65 km/h — 30°G).

	Conventional Retractor		Weblocker	
	Driver	Passenger	Driver	Passenger
Film spool (mm)	97,5	123	24	25
HIC (s)	1580	—	907	—
t for γ Head > 80 g (ms)	13,3	6,6	2,4	4,6
γ_R chest (g — 3 ms) (ms)	58	42	47	44
γ_R Pelvis (g — 3 ms) (ms)	69	58	60	52
Femur load left (daN)	432	510	160	223
Femur load right (daN)	1.038	213	495	196
F shoulder belt (daN)	580	785	725	785

For the passenger, the results are globally positive. However, the gains obtained are much less pronounced than for the driver, and cannot be considered as actually representative in terms of real safety. This is all the more clear if kinematics are taken into account.

Kinematic analysis

With respect to the 0° collision, this type of impact is dissymmetric. Simultaneously to the transverse movement of the vehicle to the right, there is a transverse movement of the dummies to the left. See Fig. 4.

This transverse movement calls for separate analysis of driver and passenger restraint.

Driver

Driver movement to the left, without locker,

—favorizes a correct position of the shoulder strap on the shoulder
—decreases thorax rotation
—moves the head impact towards the outside of the steering wheel, the impact location itself being shared between the rim and the hub.

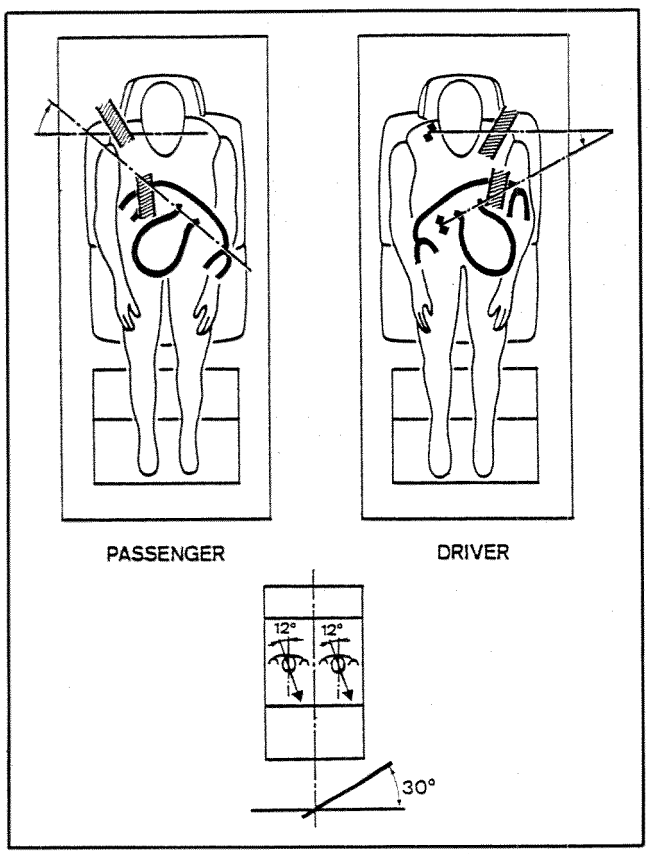


Figure 4. 30° angled barrier test at 65 km/h.

Using a locker, while increasing thorax rotation, also accentuates lateral movement of the head. The consequences of this are to move the impact point of the head completely on the steering wheel rim, *thus reducing collision severity.*

Passenger

Without a locker, movement to the left of the passenger causes slippage of the belt on the shoulder; the strap, which catches in the articulation of the arm, produces important rotation of the thorax. The dummy has a tendency to escape from the belt.

The use of a locker accentuates thorax rotation, thus increasing the risk of escape. If this escape possibility, which was highlighted using an H2 dummy, is obtained with an actual occupant, it can be considered that the use of a locker under these conditions is useless, and even dangerous.

LOCKERS ASSOCIATED WITH AN OPTIMIZED THREE-POINT BELT

Parameters Modified

Allowing for previously acquired information, optimization concerned:

—the position of the three belt attachment points
—the percentage elongation of the strap (6, 12, 17%)
—the seat cushion stiffness and geometry.

The *only* objective sought was to improve efficiency of the lockers. To achieve this, efforts have been made to:

—limit rotation of the thorax
—accentuate shoulder restraining
—avoid the risk of "submarining."

Test Program

Over an initial stage, twenty sled tests were performed to study the effect of each of these parameters. In order to judge the effect of the modifications on locker efficiency, each configuration was tested once without the locker, and once with. Only the principal conclusions are mentioned here, so as not to complicate this paper.

The position of the attachment point is, by far, the most discriminating parameter. However, it seems preferable to use a strap of 6% elongation, with a relatively stiff seat cushion.

The position of each of the 3 anchorage points has a notable effect, but it was only by raising the shoulder strap point that it was possible to fully monitor rotation of the thorax.

Subsequent to this study, the following optimum configuration was retained:

—shoulder strap point raised by 100 mm
—outside lap belt point advanced by 100 mm
—inside lap belt point back by 100 mm and lowered by 50 mm
—6% elongation strap
—seat cushion reinforced.

After sled testing, this configuration was subjected to two 50 km/h orthogonal barrier collisions, using a complete R.18 automobile, one with conventional retractors and the other with lockers.

Results

Results obtained during the catapult and wall tests are given in Tables 4 and 5 respectively.

The basic conclusion that can be drawn is that optimization of the various items involving restraining as a function of locker presence has, as expected, increased the efficiency of the locker as far as the occupant movement is concerned.

With the sled, it was possible to obtain a head travel of 500 mm. This represents a gain:

—of 155 mm, with respect to the reference tests (baseline car + conventional retractor)
—of 130 mm with respect to tests using the locker only (baseline car + locker)
—of 95 mm with respect to the modified car test (modified car + conventional retractor).

Table 4. Results of sled tests with modified cars (50 km/h — 0°).

	Conventional Retractor	Weblocker A
Spool film (mm)	80	0
Head displacement (mm)	595	500
γ_L chest (g — 3 ms) (ms)	47	52
γ_L Pelvis (g — 3 ms) (ms)	36	37
F shoulder belt (daN)	N.A.	720

Here, it is worth noting that the use of a locker with a standard three-point belt gave a reduction of only 15 to 30 mm on average, depending on the type of locker.

For the barrier test, a head travel on the passenger side of 520 mm was obtained. This represents a gain:

—of the order of 100 mm with respect to collisions using the standard three-point belt. It should be remembered that, under these conditions, the use of a locker did not provide any noticeable gain;
—of 55 mm, with respect to the collision in the optimized configuration with a conventional retractor.

In the optimized configuration, and for barrier impacts, an important decrease in driver HIC was noted with

Table 5. Results of crash test with modified cars (50 km/h — 0°).

	Conventional Retractor		Weblocker A	
	Driver	Passenger	Driver	Passenger
Film spool (mm)	95	130	0	0
Head displacement	—	575	—	520
HIC relative values standard belt	75	—	54	—
t for γ head > 80 g (ms)	2,9	0	1,5	0
Head impact speed (ms)	14	—	11,7	—
γ_L chest (g — 3 ms) (ms)	49	42	40	35
γ_L Pelvis (g — 3 ms) (ms)	48	34	41	37
F shoulder belt (daN)	770	760	710	720
F pelvis belt (daN)	770	760	860	830
Femur load left	125	160	170	150
Femur load right	155	150	120	180

respect to the value obtained using the series production vehicle. This decrease can be explained by the different head impact locations. In both cases, impact occurred against the top of the steering wheel. The difference between these two tests may result from the difference between the two impact speeds. However, it should be noted that the values obtained are both below what is considered to be the tolerable threshold. The difference obtained therefore does not necessarily signify that injuries can be avoided.

As far as the other criteria are concerned, the results do not seem to question the conclusions obtained subsequent to tests performed with a standard three-point belt.

CONCLUSION

This study has shown that several retractor located belt locking devices which operate correctly are at present available on the market. Use of these considerably reduces strap movement at the outlet from the retractor, without noticeably increasing the risk of overall rupture of the safety belt.

The effects on restraining, which are imputable to the use of lockers of this type, are complex and difficult to estimate. However, some major points can be highlighted.

The use of a locker does not increase coupling sensitivity, and, in particular, this applies to a high mean deceleration collision. Suppression of spool out increases the overall stiffness of the restraining device. Solicitations on the occupants due to the forces developed on the belt are therefore conserved or even increased.

By "stiffening" the restraining device, a locker can increase retention. However, and allowing for the operation of a standard three-point belt, this gain in stiffness does not necessarily result in a reduction of the travel of the dummy inside the passenger compartment. To obtain positive results, optimization of the restraining device may be necessary. While potentially obtainable, the limits of an optimization of this type should be noted.

a. The geometric position of the attachments has been optimized for a given model size and a given seat adjustment. In other cases, this may be inefficient or even dangerous.
b. The developed optimization was tested for orthogonal collisions only, and it is not certain that this will be efficient in other collision configurations. For example, and according to our study, suppression of model rotation in the event of a 65 km per hour 30°L collision would render the impact of the driver's head against the steering column more severe.
c. For this optimization, only the efficiency criterion was taken into account. Now, it should be noted that the newly developed belt geometry is not compatible with the various criteria which a restraining device must meet. In particular, this applies to comfort. The shoulder strap is too high at neck level. It should also be noted that the new outside attachment point of the lap belt is no longer located in the zone mandated by the standards.

As far as the fundamental object of this study is concerned, i.e., examination of progress in actual safety provided by the use of such devices, the state of progress of our work indicates contradictory results which are difficult to estimate. However, if the various corporal segments involved in head-on collisions are treated separately, several trends become clear.

Lower members

In our study, the use of a locker can, in some cases, avoid dangerous solicitations of the femur, and cannot be considered as unfavorable. The gain involved is difficult to estimate. Moreover, it must be considered that the severity of injuries on the femur segment is potentially less important than to other segments.

Abdomen

"Submarining," implying loading of the soft parts of the abdomen, on the one hand, and the spinal column, on the other, due to the lap belt can be the origin of severe injuries. Therefore, this phenomenon cannot be neglected. The use of a locker seems to increase this risk. However, prior to installing a locker on a given vehicle, it would be at least desirable that this does not lead to unacceptable "submarining."

Thorax

Injuries to the thorax result either from the safety belt itself, or interaction with the steering column. As far as injuries caused by the belt alone are concerned, it would seem preferable to consider the shoulderstrap force at the shoulder, instead of the thorax 3 ms deceleration criterion. Since injuries are a function of the occupant's age, and knowing that the lower age groups are over-represented in accidents, it is legitimate to have efficient restraint, limiting travel and implying a tolerably high shoulder force for young occupants. However, the use of a locker notably increases this force, and it is impossible not to fear supplementary injuries to the thorax.

Our study does not provide a response as far as injuries associated with interaction with the steering column are concerned.

Head

The majority of head injuries, if not all, result from direct impact against the steering column, the dashboard and the front pillars, etc. The results obtained call for differentiation between driver and passenger seats.

—Driver's side

The noticeable feature is that the use of a locker has not enabled avoidance of existing impacts. Has severity been decreased? We know that this depends mainly on the characteristics of the zone actually impacted.

Our study shows that important differences in HIC are all correlated to different points of impact. This point, which is subject to very small variations, is impossible to monitor, and then only in a purely experimental configuration. Therefore, our results cannot be considered as an actual benefit in safety.

—Passenger side

As the vehicle used and the belt equipping it prevent any impact with the dashboard in the types of tests conducted, the results obtained cannot be discriminant. The slight reduction in head travel might, however, have been decisive on another vehicle.

This study is not complete. Renault is continuing its research. Tests, which have not yet been analysed, have been conducted for a lower mean deceleration. Moreover, a further optimization of the restraining system has been concerned, this time allowing for all criteria. It would also be desirable to conduct some tests with cadavers. In fact, some points raised in this study could be strongly correlated to the inadequacy of the Hybrid 2 dummy. Mainly, this involves the nonrepresentativity of the pelvis, the shoulder and thorax stiffness, which can respectively influence "submarining" aspects, slippage of the belt at the shoulder and rotation of the dummy. Also, it would be of interest to conduct a severe head-on collision between two vehicles, leading to a certain intrusion into the compartment.

Without trying to anticipate future results, it is, however, to be feared that antagonistic effects exist between improvement in restraining, on the one hand, and an increase in belt solicitations on the other. In this case, the use of a locker cannot be considered an absolute measure, but approached as a possible solution of an existing problem for a given vehicle and restraining device.

BIBLIOGRAPHY

1. Sacreste et al.: Laboratoire de Physiologie et de Biomécanique PSA/Renault—Tolérance thoracique des porteurs de ceintures de sécurité. J. Traumatologie 1980 Tl No. 2, pp. 105–113.
2. Thomas et al.: Laboratoire de Physiologie et de Biomécanique PSA/Renault—Influence de l'âge et du niveau d'effort de retenue sur la gravité des lésions thoraciques subies par les occupants ceintures en accidents réels. Proceedings of the 4th IRCOBI, September 1979.
3. NHTSA—Automobile occupant crash protection. Progress Report No. 3, July 1980.
4. Heinrich Hontschik et al.—Necessities and possibilities of improving the protective effect of three-point seat belts. 21st STAPP CAR CRASH CONFERENCE.
5. M. Ramet and O. Cesari—Behavior of restrained dummies and cadavers in frontal impacts. Proceedings of 4th IRCOBI, September 1979.
6. D. Adomeit et al.—Evaluation methods for the biomechanical quality of restraint systems during frontal impact. 21st STAPP CAR CRASH CONFERENCE.
7. D. Adomeit and A. Heger—Motion sequence criteria and design proposals for restraint devices in order to avoid unfavorable biomechanic conditions and submarining. 19th STAPP CAR CRASH CONFERENCE 751146.
8. L.G. Svensson—Means for effective improvement of the three-point seat belt in frontal crashes. 22nd STAPP CAR CRASH CONFERENCE 780898.
9. G. Danese—A research study for an energy absorbing sliding seat. 5th International Technical Conference on Experimental Safety Vehicles, p. 699.
10. H. Stanley et al.—Part 572 crash test dummy response and the effects of shoulder belt location and impact vector direction. 8th International Technical Conference on Experimental Safety Vehicles, p. 417.
11. M. P. Bereau—Amélioration des ceintures de sécurité par utilisation des dispositifs pyrotechniques de rétraction. Ingénieurs de l'Automobile No. 3, March 1979.
12. G. Hoffman et al.—The influence of preloading on the efficiency of belt systems. ISATA 1978.
13. R. Weissner—A comparison of advanced belt systems regarding their effectiveness. SAI 1978 PAPER 780414.
14. M. Dejeammes et al.—Improvement of the automatic belt: the possible efficiency of the pyrotechnical retractor. 8th International Technical Conference on Experimental Safety Vehicles, p. 379.

A Lightweight Two-Passenger Automobile Combining Improved Crashworthiness, Good Performance, and Excellent Fuel Economy

MICHAEL R. SEAL
Director, Vehicle Research Institute
Western Washington University

MICHAEL FITZPATRICK
Fitzpatrick Engineering

ABSTRACT

The Viking Six Integrated Research Vehicle was designed under contract to the National Highway Traffic Safety Administration of the Department of Transportation to demonstrate that it is possible to obtain superior fuel economy and performance without compromising passenger safety. The Viking Six has achieved occupant survival in a 41.2 mph barrier crash, fuel economy of 40.4 mph city and 66.6 mph highway, and has met 1982 exhaust emission standards. It can accelerate from 0-60 in less than 9 seconds and shows outstanding stability on corners and in crosswinds.

INTRODUCTION

The Viking One through Five series of experimental vehicles have demonstrated ability to achieve extremely high fuel economy and the ability to meet stringent exhaust emission standards. The Viking Six vehicle breaks new ground because a high degree of crashworthiness and occupant safety has been achieved without compromising exhaust emissions or fuel economy.

SAFETY FEATURES

Crashworthy Structure

Viking Six was designed to see if it would be possible to build an ultralight (1320 lb, 600 kg) fuel efficient vehicle capable of providing safety at least as good as that provided by full sized cars. Its performance in a crash test at Dynamic Science in Arizona on May 29, 1980 showed an ability to provide survivability for the occupants in a 41.2 mph (66 kph) crash. In order to provide good crashworthiness in such a vehicle many unusual design steps were taken. To make sure that the occupants would not be crushed in the crash event the central monocoque chassis section was made extremely stiff as shown in Figure 1 with 1.5 mm to 2 mm 7075 T-6 sheet and hat section riveted together. This structure was obviously stiff enough as it only suffered a 4 mm permanent deformation after the crash event. The front and rear chassis sections were designed to crush at much lower loadings to provide a manageable crash pulse. To this end the front and rear chassis panels were made from 6061 T-3 .75 mm thick. The nose section of the structure ahead of the toeboard was filled with aluminum honeycomb material. (Fig. 2.) On the advice of Mr. Sol Davis of Dynamic Science it was decided to use aluminum honeycomb material with a crush strength of 100 psi (7 kg per cm^2) over an area of 400 sq. in. (2581 cm^2) for a 40,000 lb (18,182 kg) force through the available 29.5 in. (75 mm) crush stroke of the front end of the car.

Passive Restraint Airbelts

Although the original design of the car had called for a passive belt design the only pyrotechnic inflator available at this time mandated an active belt system for the crash test. (Fig. 4.) Late in 1980 Mr. M. Fitzpatrick of Fitzpatrick Engineering designed and static tested an "in-belt gas generator" which Vehicle Research Institute personnel have installed in a functional passive restraint air belt system on the second iteration of the Viking Six design. (Fig. 3.)

Once the problem of the in-belt inflator was solved it became possible to complete the passive restraint design originally intended. Unfortunately if we were to use the force limiting system developed for the first crash test we would have to devise some system for automatic decoupling when the hatch is raised for occupant entry or egress. A simple peg-in-hole system independent of the main hatch latching system solved the problem and the belt end was riveted up to the hatch with aluminum rivets that shear off at about 200 lb force. (Fig. 5.) A notch is cut into the forward face of the peg so that relative motion during the crash sequence will shear the rivets before the 2200 lb force limiters started to stroke ensuring that there would be no excessive g loading at the beginning of the stroke.

Gas Generator

Figure 6 shows the gas generator chosen. It is manufactured by Thiokol and weighs only 6 oz fully loaded for each occupant as opposed to 7.6 lb for the former gas generator used in the crash test. Although the in-belt gas generator has only 12 gms of propellant per occupant vs 57 gms per occupant in the old system, the gas would be much hotter at 1600 degrees Fahrenheit (871 degrees Celsius) as compared with 600 degrees Fahrenheit (315 degrees Celsius) of the previous system which would help to bridge the gap. Also assisting in this regard was the

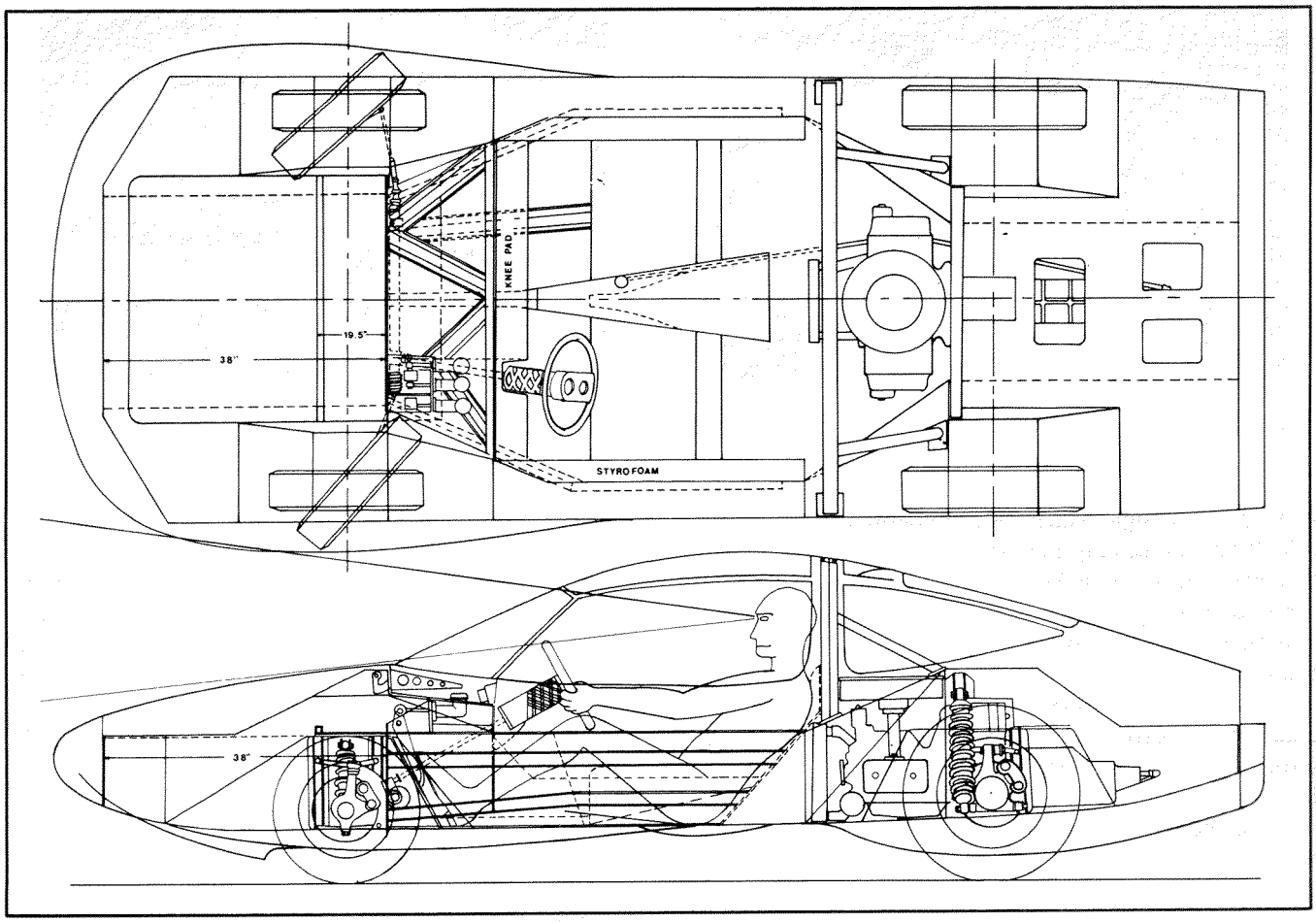


Figure 1. Viking Six chassis drawings.

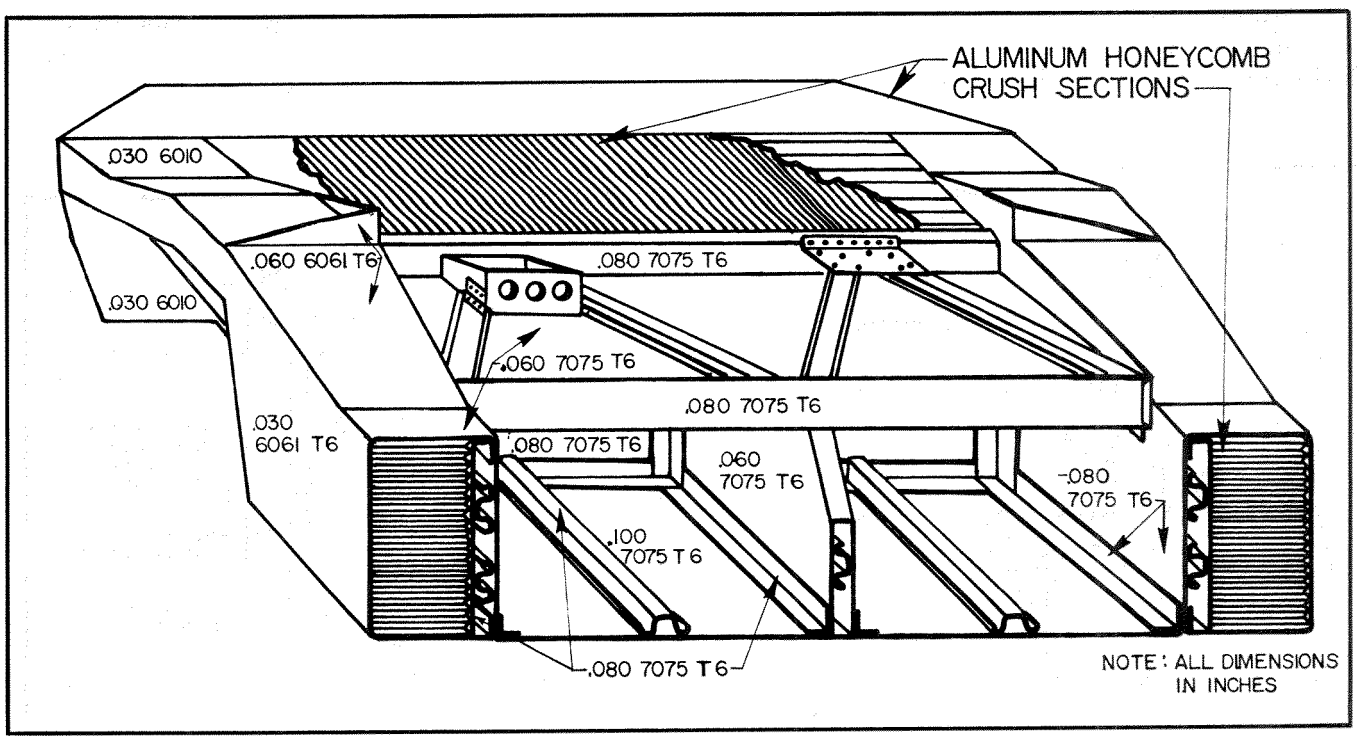


Figure 2. Front chassis pictorial.

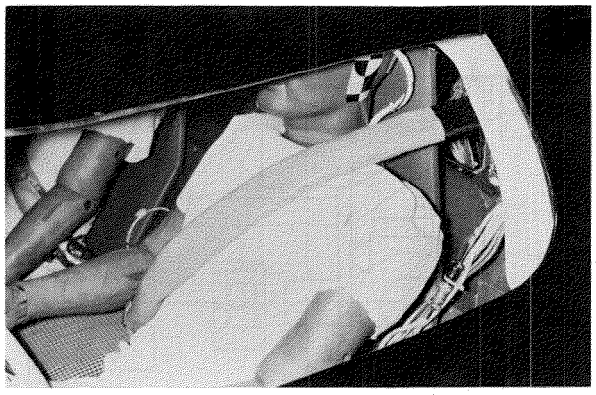


Figure 3. Belts on dummies.

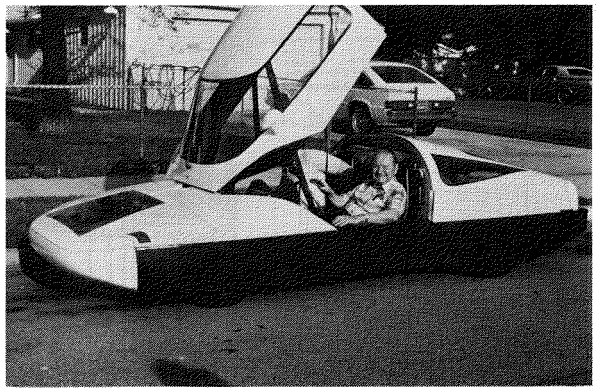


Figure 4. Viking Six MK II seat belts.

new airbelt design which was configured to have the airbelt volume in only the area required for proper performance. As airbelt inflation is used primarily to prevent forward rotation of the head almost all of the available volume within the airbelt was devoted to supporting the head.

As a result of a number of static tests and mathematical analyses Fitzpatrick concluded that a 550 cu. in. volume airbelt loaded with 12 gms of propellant activated 20 ms into the crash event should provide performance equivalent to the crash test performed on the first Viking Six vehicle.

FITZPATRICK ENGINEERING REPORT

As Mr. M. Fitzpatrick had the primary responsibility for restraint system design the following excerpt from his final report to the NHTSA is presented here.

RESTRAINT SYSTEM DESIGN

At the conclusion of the four sled tests Fitzpatrick Engineering settled on a total restraint system design which was judged to have the most potential for meeting the Federal Motor Vehicle Safety Standards (FMVSS) 208 injury criteria in a frontal barrier crash of 40 mph. The 40 mph impact velocity was chosen based upon sled test results as well as predicted behavior of the vehicle structure in the crash.

Gas Generator

The gas generator chosen for use as the inflation source for the airbelt systems was a generator originally manufactured for installation in a steering wheel hub and used with a driver airbag system. The gas generator was supplied by Thiokol and loaded with 115 grams of DLZ 113 gas generant (50 gms of pellets 0.120 in. (3 mm) thick

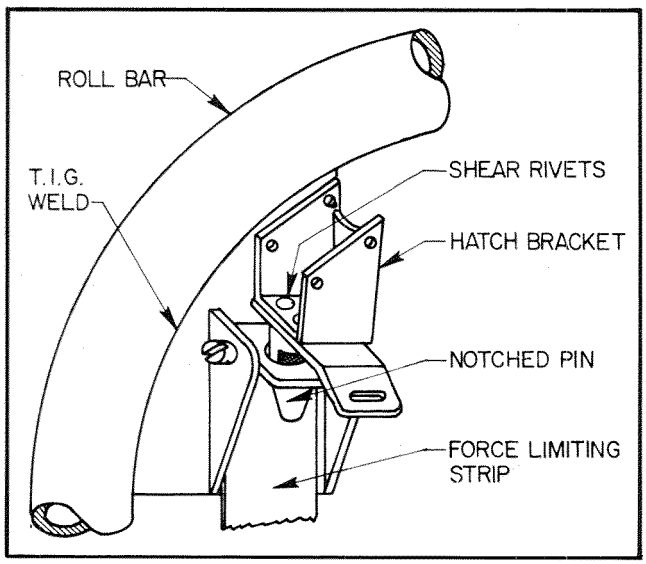


Figure 5. Belt decoupler drawing.

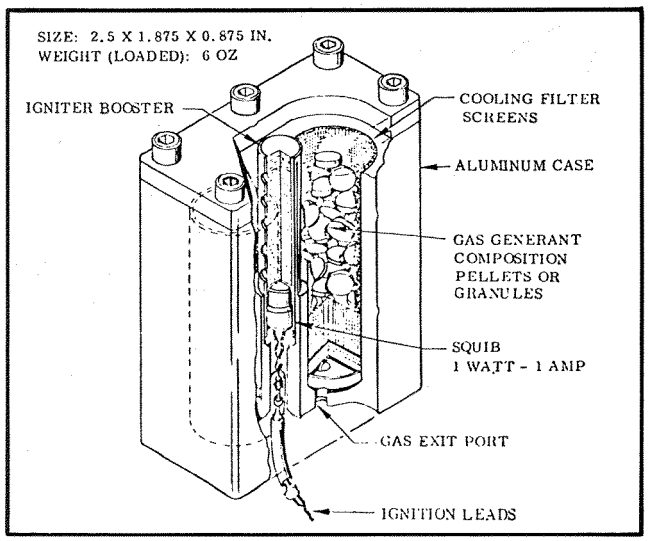


Figure 6. In-belt gas generator.

and 65 gms of pellets 0.060 in. (1.5 mm) thick). The igniter charge was 3 gms of UIZ-172 with 12 gms of $FeSO_4$ as a neutralizer. The cooling screen was 0.7 in. (18 mm), 21 strand Gold with a 2-12 mesh and 3-40 mesh filter screen.

The gas generator is bolted to a gas distribution manifold with two three-quarter inch (19 mm) I.D. exhaust parts which distributes one-half of the total flow to each of the two airbelt systems as shown in Figure 6. This type of gas generation distribution system was based upon that used in the Calspan RSV as modified by Fitzpatrick Engineering.

Airbelt

The airbelt design was based upon a design by Fitzpatrick Engineering and Calspan for the Calspan RSV. Certain changes to this basic design were necessary prior to using it in the Viking Six. To be consistent with desired anchor point locations in the Viking Six, the inflatable portion of the belt was shortened. Also, due to the fact that no force limiting belt webbing was readily available, standard nylon webbing was used with the idea that a mechanical force limiter could be implemented later if desired. (Fig. 7.) The retractor used with the airbelt system was a VW Rabbit retractor. A Honda pivot loop became necessary in the final design iteration.

Seats

Due to the nature of the seat design which has very little padding and the rather high rearward angle in which the occupants recline in order for the vehicle to have as little air resistance as possible, we became concerned early in the program that the occupants might receive excessive g loads up through the spine. In an effort to attenuate these g loads, a crushable, aluminum honeycomb block of 24 psi (1.7 kg per cm^2) crush strength (part #38-5052-.0007-1.0) and 45 sq. in. (290 cm^2) area was placed under the driver and passenger seats for the test. Unfortunately, due to lack of headroom, it was not possible to place the honeycomb under the seat; space only exists under the seat leading edge.

During sled testing we noticed that the best overall trajectory control and underseat honeycomb crush for the occupants was maintained if we allowed certain rivets that connected the seat body to the floor bracket to shear, thereby allowing the seats to rotate forward and stay with the occupants. (Fig. 8.) This rivet shearing concept was retained for the crash test.

Knee Restraint

Since the airbelt was a two-point design (torso belt only as shown in Figure 4), some form of lower body restraint was necessary. Originally, W.W.U. had installed a VW Rabbit knee bolster in the Viking Six; however, it was determined during sled testing that it was simply too "hard" for integration into the Viking Six structure; so it was discarded in favor of a new knee restraint designed specifically for the Viking Six. (Fig. 10.)

Force Limiter

Due to the fact that the crash pulse of the Viking Six could only be estimated since no crash history for this vehicle exists, and due to our desire to maximize the stroke efficiency of the airbelt system, Fitzpatrick Engineering designed a mechanical force limiter for use with airbelt systems. (Fig. 7.)

For the Viking Six crash test an energy absorber system composed of a tape width of 0.75 in. (19 mm) a tape thickness of 0.071 in. (1.8 mm), and a roller diameter of 0.250 in. (6 mm) was used for both the driver and passenger systems. The rollers and tapes were lubricated with grease before the test.

Anchor Point Locations

With an airbelt design it is very important to locate the belt anchors so that the belt passes across the chest

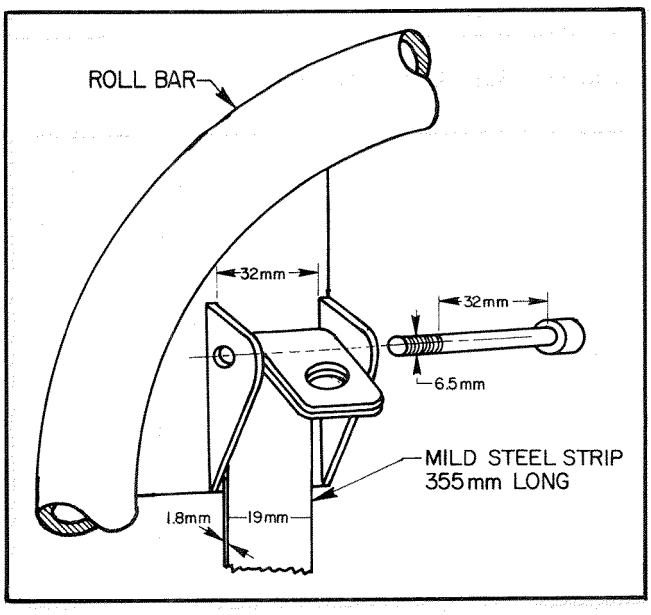


Figure 7. Force limiter.

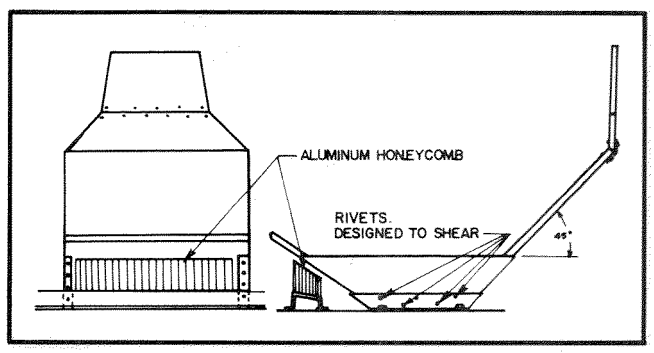


Figure 8. Seat shearing rivets.

in a manner where proper head support will be maintained as the head rotates forward during the crash. Additionally, the anchors must be located so the belt force transmission angles are as efficient as possible. In order to accomplish this it was necessary to move the lower anchor 3 in. (76 mm) rearward to the bulkhead immediately behind the seats and to move the upper anchor upward and inboard a total of 8¾ in. (222 mm) on the roll bar from the original W.W.U. positions.

Pre-Test Configuration

Figures 9 through 12 show the pertinent restraint system dimensions in schematic form. In addition, the anchor point locations mentioned above are shown.

For this test, 50th percentile Part 572 dummies were used in both the driver and passenger positions. Since we wanted to be sure that the test velocity was at least 40.0 mph (64 kph), we chose a test "window" for velocity of 41 ± 1 mph. Any velocity outside this range would result in an aborted test. The vehicle front end energy absorber selected for this test was 75 psi (34 kg) crush strength aluminum honeycomb which was expected to exhibit a static crush of approximately 22.5 in. (572 mm).

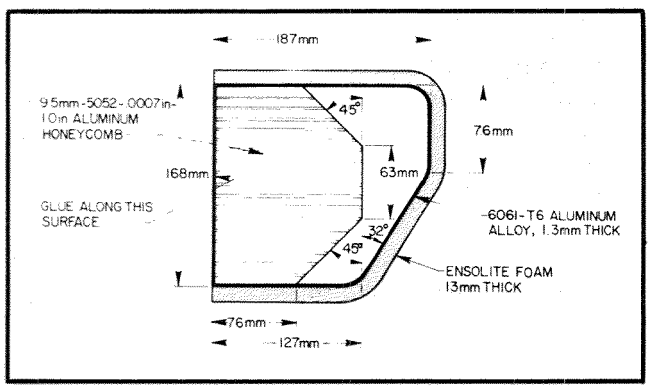


Figure 9. Viking Six knee restraints.

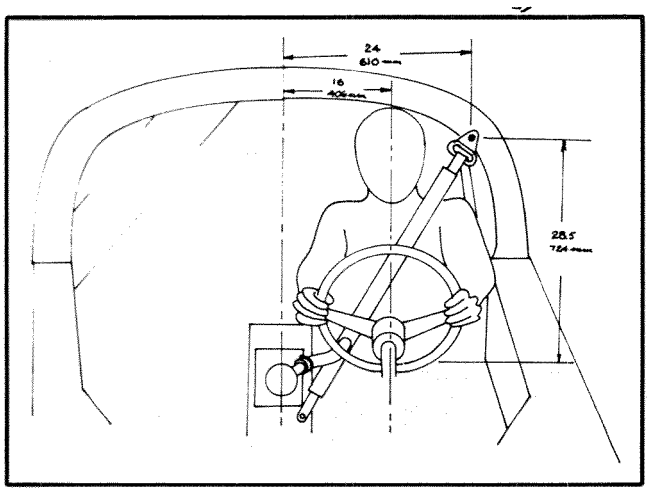


Figure 10. Viking Six belt set up, front view.

TEST RESULTS

The Viking Six crash test was conducted by Dynamic Science on May 29, 1980. The actual crash velocity was 41.2 mph (66 kph) with a rebound velocity estimated at 3 mph (5 kph). Sensing time for airbelt actuation was selected and verified at 11 ms.

As is evident from Table 1, all the measured injury parameters are well below the FMVSS 208 injury criteria limits. We believe these results are especially pertinent since they show that it *is* possible to design a very small car and still protect the vehicle occupants within established injury guidelines even at velocities greater than required by present standards. Admittedly only one impact mode was tested here; however, we believe in a program where more development and testing were possible, these results could be extended to other accident modes as well.

The seats performed pretty much as expected in that

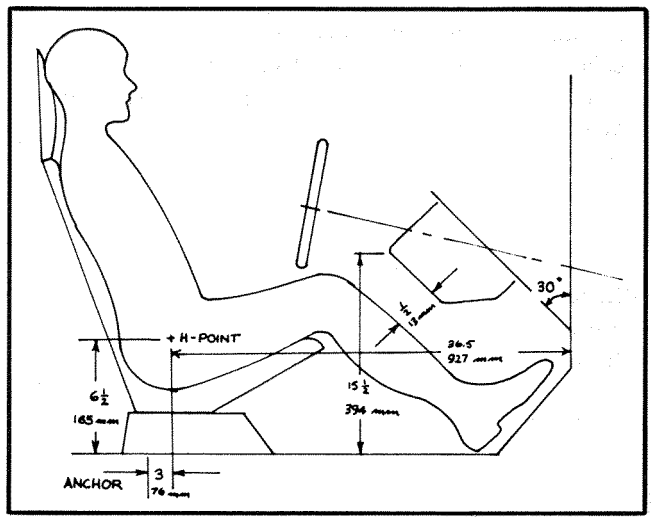


Figure 11. Viking Six belt set up, side view.

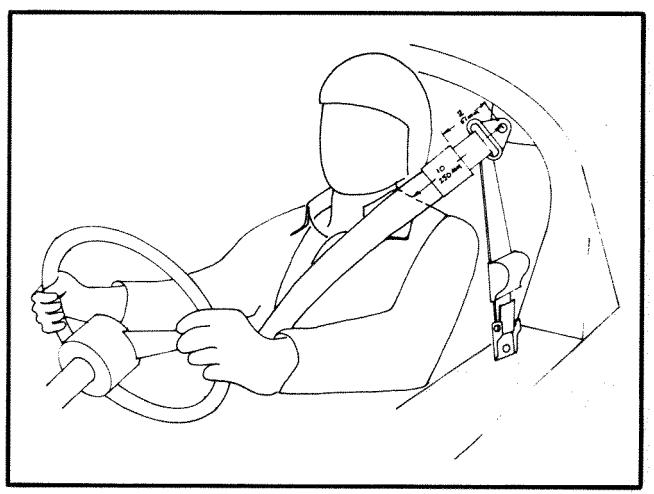


Figure 12. Viking Six belt set up 3/4 view.

Table 1. Injury measures received for the driver and passenger.

	Driver	Passenger	"208" Std.
HIC	*552	286	1000
Pk. Res. Chest G's (−3 ms)	44	51	60
Pk. Vert. Chest G's (−3 ms)	24	24	NA
Pk. Femur Loads			
Left	1031	1080	2250
Right	1130	819	2250
*Roll bar hit dummy on side of head controlling HIC			

the rivets previously discussed sheared according to plan. However, not quite as much honeycomb was crushed under the seat pans as desired. The reason for this is that some other rivets holding the plate to which the under seat honeycomb had been bonded, sheared allowing the honeycomb to slide partially out from under the seat pans. Perhaps if this had not happened, the chest vertical g component would have been a little less than the 24 g's actually measured.

There was very little knee restraint crush for either the driver or the passenger (0-½ in., 13 mm) as the upward tilt to the seat pan effectively prevented the lower body from translating very far and absorbed, through bending and crushing the honeycomb, most of the lower body energy. Sled test #2 on the driver side was the sled test in which the seat and the knee restraint were configured most nearly like this test and exhibited nearly identical results in that, here too, the knee penetration was only about ½ in. (13 mm).

Perhaps if the vehicle was designed to have slightly more headroom, the occupants could be seated more nearly erect and absorb more of the lower body energy through the knee restraint rather than the seat pan. This should help lower the chest vertical g's which are a little higher than we think is necessary.

The crash pulse g's were fairly high in the beginning of the crash. However in spite of the fact that these g's peaked at approximately 56 g's and were quite high for a relatively long time resulting in a very short crash pulse duration of only 72 ms, the force limiter operation effectively limited body g's to rather low values.

One might wonder, given the severe roll bar bending that occurred, whether the roll bar may have added to the force limiting thereby resulting in chest g levels that were artificially low. We wondered about this, too, but close inspection of the films and data show that roll bar bending did not begin until approximately 85 ms and was over at 90 ms, very late in the event and much later than peak chest g's were experienced. This is corroborated by the g "spike" on the dummy's head at 90 ms when contacted by the roll bar at maximum roll bar rotation and by the sudden drop off in chest longitudinal g's for both the driver and passenger at approximately 85 ms.

Film and data analysis show that peak chest g's and force limiter stroke were over when the roll bar collapsed. The dummy and vehicle had both stopped moving forward when this event happened. Here again, one might wonder why the roll bar collapsed when the belts which were loading the roll bar had reached their peak loads sometime before and were now much lower as evidenced by the drop off in chest g's. The answer, we feel, lies in two related facts. First, the rivet failure at the roll bar base that led to its collapse, probably started earlier in the impact event without any apparent movement of the roll bar. However, as the rivets continued to tear out of the sheet aluminum, a point was reached—rather late in the event—where the roll bar strength was now less than the force applied even though the force was now much reduced. (Fig. 14.) Secondly, there may have been another contributing factor to roll bar collapse. The buckling of the structure immediately aft of the roll bar may have dumped its load into the roll bar base structure. If so, this would also tend to explain the late failure of the roll bar, significantly after the peak belt loads were experienced.

The driver side force limiter stroked approximately 3 in. (76 mm), 2 in. (51 mm) normal stroke plus 1 in. (25 mm) weld tearing at the point where the force limiter tape attached to the retractor. The passenger side force limiter stroked 6 in. (152 mm) in normal fashion.

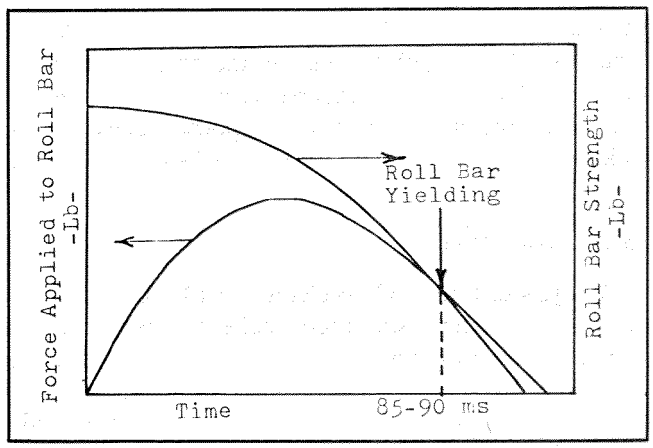


Figure 13. Roll bar deformation.

The reason for the difference in total stroke for the two systems is not entirely clear; however, it may be that the honeycomb on the passenger side being a little less securely fastened (due to riveting space restrictions) due to fewer rivets, allowed the honeycomb to slip out from under the seat earlier in the crash event. If so, this would mean that less energy would be absorbed necessitating more stroke by the upper torso force limiter.

The crush of the vehicle front end was qualitatively much different than anticipated; although quantitatively the crash pulse g levels were not a great deal different than expected with the exception that the peak levels were somewhat higher. The reason we say the crush was different than anticipated is that rather than crushing accordian fashion the remaining half over-rode the correctly crushed section and was incompletely crushed. As it turned out however, the rest of the vehicle structure absorbed more energy than anticipated, which apparently helped offset the odd crush behavior of the aluminum honeycomb itself.

There was significant pitching of the vehicle late in the crash event; however, we believe the center-of-gravity of the vehicle was artificially high due to instrumentation mounting locations being generally much higher than normal vehicle C.G. In addition, we do not believe that pitching is necessarily detrimental to the occupants as it adds more overground stroke in which to bring the occupants to rest and does not appreciably affect vertical g-levels "seen" by the occupants as it occurs over a relatively long time period late in the impact event.

Static crush of the vehicle was estimated at 18-19 in. (460–480 mm) while dynamic crush measured from the films was approximately 25-26 in. (650 mm). This is quite a difference indicating that the vehicle may have had a fairly high rebound velocity. The actual rebound velocity is a little difficult to establish however. This is because the vehicle accelerometers underwent such gross movements and rotations due to severe buckling in areas where the accelerometers were mounted. For example, of the three compartment-mounted accelerometer traces only one showed a return to zero in vehicle velocity when integrated. The other two showed a residual vehicle velocity of 6–8 mph (10–13 kpm) in the original direction of travel which is clearly impossible. Film analysis shows the vehicle rebound velocity to be approximately 3 mph (5 kph) for a total vehicle "delta V" of 44 mph (70 kph).

SIDE IMPACT

Analysis of force and acceleration suffered by the impacted car during a side crash make it apparent that it is not feasible to provide a side crush zone wide enough to absorb the energy released when the striking vehicle impacts at 40 mph (60 kph) (30 inches (76 mm) would be required on each side of the car). If a measure of safety is to be provided then the side of the vehicle must be made stiff enough to force the striking car to provide nearly all of the ride down distance through crush in its nose.

The Viking Six used side boxes 6 in. (152 mm) by 13 in. (330 mm) in cross section made from 7075 T-6 aluminum sheet 115 mm thick reinforced at critical points with 2 mm thick 7075 T-6 hat section. A transverse panel of 7075 T-6 1.5 mm thick behind the seats anchors the rear end of the box while the upper dash panel structure provides a front transverse stiffener as well as providing a reaction point for the knee bar. A tranverse member under the front edge of the seats further stiffens the middle of the structure. Additional stiffening is provided by aluminum honeycomb bonded to the face skins with expoxy adhesive. The inner surface of the side tanks had a 500 mm thick layer of rigid polyurethane foam covered with 13 mm of ensolite foam. The entire cab is skinned with dark brown vinyl upholstery material.

The windshield is mounted well forward of the driver to give maximum ride down space for the occupants' heads during a crash when they are riding forward in their belts, which are stroking the force limiters previously described. Other benefits of the forward mounted windshield are that the angle of vision subtended by the A pillars is very small and the degree of sunshielding makes separate sun visors unnecessary.

WEIGHT SAVING

Extensive use of aluminum played an important part in weight reduction. Not only were all major castings for engine, transmission, steering, suspension, and brakes made from aluminum alloy, but also the chassis lower body monocoque tubs were made from aluminum sheet. All of the parts cast in the Vehicle Research Institute (VRI) were cast from 356A-T6 alloy with strontium modification to improve grain structure. The parts were heat treated to T-6 or T-61 to improve strength and machinability. (Fig. 14.)

The center monocoque was made from 7075 T-6 alloy 0.080 in. (2 mm) for the critical toeboard which serves

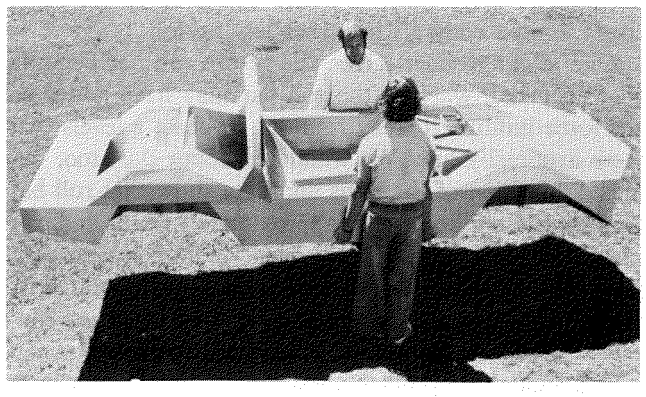


Figure 14. Viking Six chassis.

as the reaction member for the aluminum honeycomb deformable section in the nose of the car. Localized longitudinal and transverse stiffening was provided by corner reinforcement angle sections and 0.060 in. (1.5 mm) 7075 T-6 alloy hat sections. The forward and rear bays were made from 0.050 in. (1.2 mm) 6061 T-4 sheet to form a structure strong enough and stiff enough to carry normal usage loads but able to deform at a survivable rate during a crash. The overall weight of the hull was kept to 225 lb (102 kg). Previous experience with Viking Four aluminum aerodynamic skin and Viking Five's glass reinforced polyester matrix body led us to believe that there is not a lot to choose between the two materials for one off prototypes in terms of weight, and the glass reinforced polyester skin is far easier to build. As a matter of record it does seem that bringing a body up to show quality with liberal quantities of filler material has more effect on body skin weight than the initial material chosen. As a consequence we attempted to make aircraft quality body skins from fiberglass. The body skins for both cars were initially very light (220 lb, 90.7 kg) and the panels used on the crash test car had very little filler. The second fuel economy, emission, and performance car suffered from a misunderstanding with the campus janitor service. They took it upon themselves to destroy some of the body plugs and mold before the final body parts were fabricated. As a consequence the show car on display in Japan weighs about 50 lb (22.6 kg) more than planned.

SUSPENSION AND BRAKE MATERIALS

Suspension components were specially fabricated to save unsprung mass for improved ride and roadholding. The wishbones for the unequal length nonparallel system were made from 0.040 in. (1 mm) thick 4130 chromemoly steel tubing 0.750 in. (19 mm) in diameter. The suspension system makes use of coil springs wrapped around the shock absorbers, forged steel spindles and uprights at the front, mount forged aluminum 6061 T-6 steering arms. (Figs. 15 and 16.) Aluminum discs with copper-iron metal spray surfaces were cast and machined for front and rear. The front units have given no trouble, but the more heavily loaded rear units have actually melted the aluminum from the middle of the iron-aluminum-iron sandwich. As a consequence the experimental discs have been replaced with cast iron units. The front wheel diameter was kept as small as possible for several reasons. The elimination of bumps in the upper body to allow for the wheel travel of larger wheels improves aerodynamics. Smaller intrustion into the car center at full lock make it possible to fit a good aluminum deformable structure. Smaller skirts could be put over the front wheels at full lock which saves frontal area.

BODY DESIGN

Styling

The styling of Viking Six was based on the premise that a smooth aerodynamic form could provide an attractive appearance. The rounded elastomeric urethane five mph bumper provides a curved surface unlikely to injure a pedestrian struck in a low speed impact. (Fig. 17.) In fact the 40 degree sloping windshield would be likely to deflect a person clear over the vehicle with a minimum second impact injury. The headlights were set

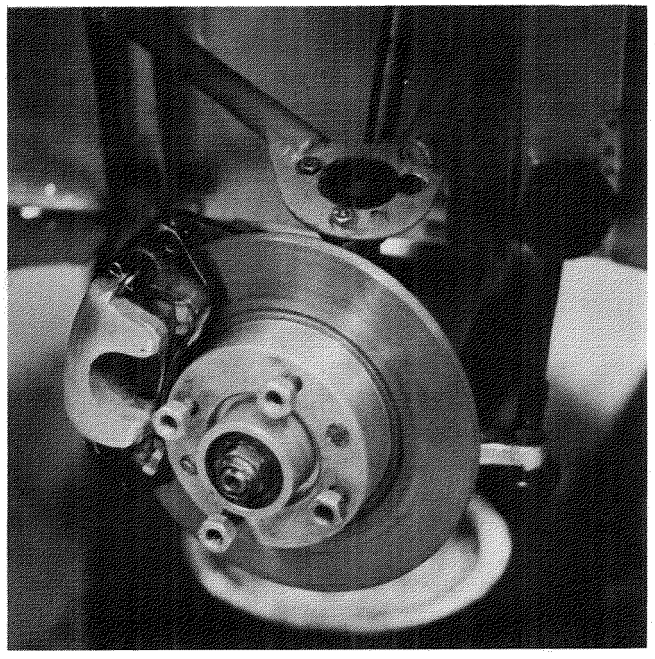


Figure 15. Front suspension.

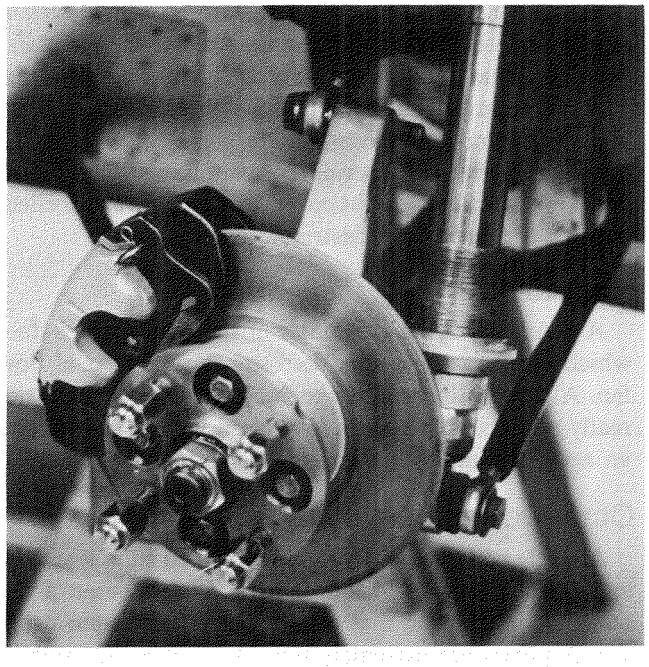


Figure 16. Rear suspension.

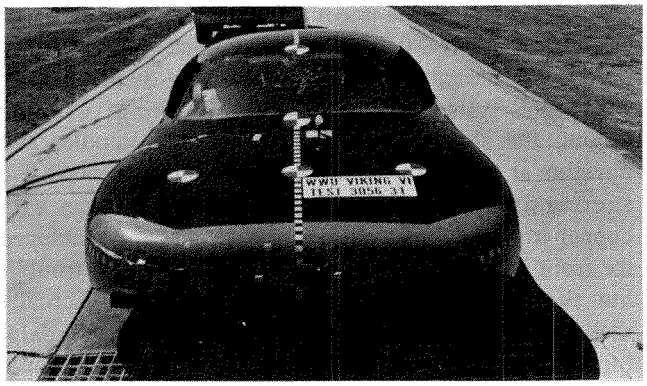


Figure 17. Viking Six MK I.

well back from the front so that they will be out of the 5 mph bumper strike zone and because the front of the car is low enough that the most forward part of the body high enough to meet the Federal headlight height regulations is almost at the leading edge of the windshield.

Headlight Cover

Early in the design program it was decided that good aerodynamic form would be required to give the expected fuel economy. Initial wind tunnel tests on one-eighth scale model indicated that a drag coefficient (Cd) of .26 would be possible on the already low frontal area of 15.1 sq. (1.4 sq. meter). Subsequent coast down tests and rolling drag measurements done at the California Subaru Engineering Center indicate that the actual Cd is closer to .21. Removal of the headlight cover panel increases the Cd to .25 and increases wind noise from a very low level to more normal levels. Fuel economy could be expected to be noticeably poorer on a highway driving cycle. The panel used is a flat wrap panel of hard abrasive-resistant polycarbonate. During the first year of use the panel has been remarkably free from scratches, but a demister-defroster system will be necessary for some conditions. During a snowstorm in the mountain passes of Oregon the headlight range was seriously compromised by snow build-up. The flexible light cover does provide an excellent cushion for a struck pedestrian, however.

Ventilation

A NACA Duct in the center of the hood feeds a duct which contains the heater-defroster core and axial flow fan. Although the need for such a duct inlet shape is not really necessary on such a low speed vehicle it does add an aerodynamic styling appeal.

Other Design Features

A single wiper centrally mounted wiped sufficient area to give good forward vision. It parks in the center of the screen in a manner that minimizes aerodynamic drag. The A pillars are extremely thin (1½ inches, 38 mm) to maximize forward vision. The line of the windscreen top and bottom continues into the compound curved side windows. The windscreen is made from safety plate so that a windshield wiper will not scratch it, but all other windows were made from scratch resistant hard surfaced polycarbonate to save weight. The hatch for occupant access hinges at the forward edge and is counterbalanced with gas struts to make it virtually effortless to lift. The flush fitting exterior door handles are pressed at the upper edge to make the lower surface pop out for easy lifting of the hatch.

Inflatable air belts are attached to the top of the B pillar on the hatch edge so that the engagement pin releases when the hatch is unlatched and the belts rise out of the way when the hatch rises to allow entry or exit. The steering column tilts upward to provide easy access for the driver who must step over a relatively high sill. (Fig. 18.)

Aerodynamics

The rear view mirror sits on a long airfoil-shaped strut to minimize aerodynamic interference drag. The mirror itself is enclosed in a streamlined pod and is adjustable from inside the car.

An unusual feature of the car is that all four wheels are enclosed to reduce aerodynamic drag. Although one might suppose that the enclosed front wheels would require either a narrow front track or an increased turning circle such is not the case. The car has a 30-ft (9 m) turning circle. The underbody is sloped upwards towards the rear to reduce aerodynamic lift and the windshield is given pronounced curvature in plan form to direct air to the sides of the vehicle, not over its roof where it would contribute to a high velocity low pressure area on the top surface of the vehicle. Cooling air is taken in through a NACA Duct in the center of the underpan where it is ducted through the radiator and into the engine compartment. The exit duct for engine compartment air is through a clear polycarbonate duct behind the drivers head (the one place the driver cannot see anyway) and out through an aircraft style exit vent in the roof in a

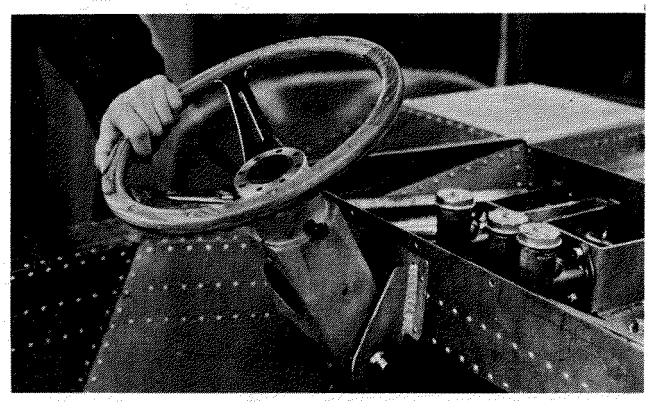


Figure 18. Tilt Steering Wheel.

natural low pressure zone. (Fig. 19.) When the car is operating at normal speeds natural air flow is sufficient to cool the engine. At idle, convection currents cool the engine. There are some conditions when the thermostat controlled electric fan is required however. When crawling up a steep grade in heavy traffic, the fan comes on to cool the engine.

Aerodynamic stability was a matter of some concern as the center of gravity of the vehicle is well to the back and the lateral center of pressure of well streamlined vehicles tends to be well forward. As a result the nose section of the car is quite low and has well-rounded contours. The rear sections are quite slab sided and the rear wheel skirts drop to within several inches of the ground. The net result of moving the center of lateral effort aft and fitting the rear end with tires of much larger footprint than those of the front gives very satisfactory crosswind performance. All turn signals and repeater lamps are fitted flush with the body to further reduce aerodynamic drag. The rear lamps are mounted just ahead of the rear clear polycarbonate cover to maximize rearward vision in parking maneuvers. In fact the driver can actually see the rear bumper when backing up.

COMPONENT ACCESSIBILITY

It was considered desirable to provide easy access to all mechanical, electrical, and plumbing components of the vehicle. The rear body panel tilts back on hinges at the extreme rear of the body providing good access to the engine. By simply removing the easily accessible hinge pins the entire rear aerodynamic skin comes off the car. As there are no electrical connections to this panel, removal is very easy. A number of easily accessible cap screws that hold down the transaxle cover can be removed and the entire powertrain is exposed and can be worked on from above rather than below. The battery is easily accessible in the extreme right rear section of the chassis.

When the hatch is lifted and the instrument backing panel lifted off (no fasteners), all of the instruments and associated wiring is exposed for easy servicing. In addition, the three clutch and brake master cylinders are exposed. When the cover to the tunnel between the seats is uncovered the switches and attendant wiring are exposed. The seat belt retractors and shift linkage also lurk in this tunnel. Removal of the front wheels does present a problem however. The car must be jacked up so the wheel nuts are exposed and the wheel will only come out of its well when pointed straight ahead.

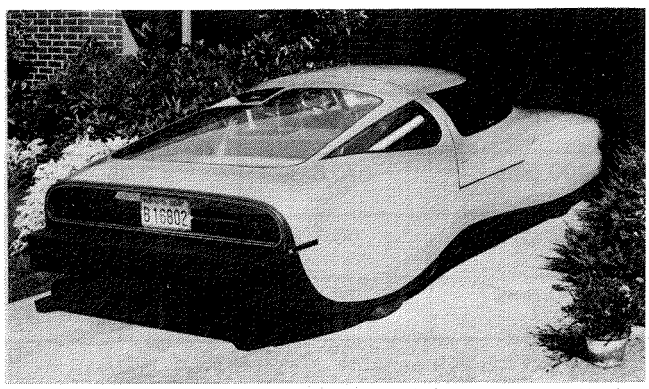


Figure 19. Viking Six MK II.

Seats

Finding seats that will fit into this low built car that can be adjusted to fit a 95th percentile male and a 5th percentile female without incurring a weight penalty proved to be a problem. Finally it became necessary to design and construct special seats. The seat chassis was made from 2024 T-6 aluminum skinned balsa core material riveted together with doublers at high stress areas. The seats were then upholstered in conventional materials. The adjustment mechanism is unique. It was determined that the best driving position for a tall person was a steep reclining position, while best vision and comfort for a short driver was achieved by providing a more upright driving position with the seat closer to the dashboard. The 105 degree angle between the seat back and seat bottom is maintained at all times. Standard seat rails were mounted outboard of the seats to give the lowest possible seating position, while the seat angle adjustment was provided by means of an adjustable aluminum wedge controlled by a simple knob on the floor.

Luggage Space

Although Viking Six does not have a great deal of luggage space it was sufficient to carry luggage for two weeks for two people to California and back from the VRI Research Laboratory in Washington State. The rear hatch pivots around its rear attachment hinges to provide access to the luggage space. The insulation fitted around the exhaust system to provide early catalyst light off serves to keep the luggage compartment at the satisfactory temperature in 25 degrees Celsius.

ENGINE EFFICIENCY IMPROVEMENT

At the beginning of the research project a search was made for a lightweight engine of good efficiency and smoothness able to meet exhaust emission standards. Engines of less than four cylinders were rejected because it was not thought that adequate smoothness and refinement would be available from such powerplants. The Subaru 1600 cc aluminum engine was chosen because of its light weight (185 lb, 84 kg), boxer layout, and its proven ability to meet exhaust emission standards. Unfortunately the engine has somewhat too much displacement for best fuel economy. It was decided to use Eaton valve disablers on the intake and exhaust valves on the front cylinders of

each bank so that the driver can switch off two cylinders in situations not needing high power output. Although the front two cylinders are motoring there is very little power loss because pumping losses are almost eliminated as the valves are closed. The energy required to compress the air in the cylinder is almost entirely recovered on the expansion stroke. The remaining two cylinders are able to function at much higher Brake Mean Effective Pressure (BMEP) which provided improved thermal efficiency. (Fig. 20.)

Because of low vehicle drag a low numerical final drive ratio can be used with large diameter wheels and tires. At a given vehicle speed in top gear the engine will operate at reduced rpm and increased throttle opening which reduces pumping losses.

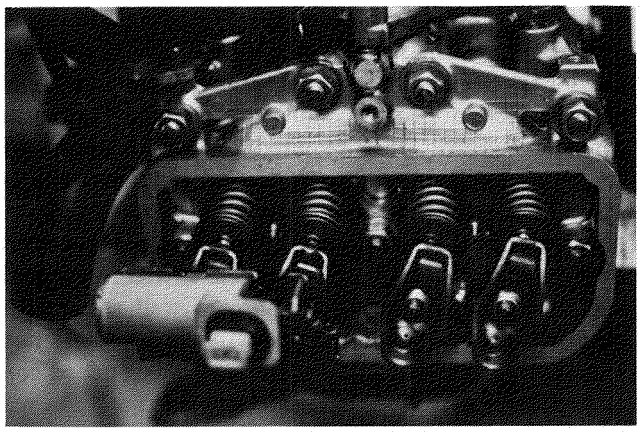


Figure 20. Valve disablers.

FUEL ECONOMY

One of the prime objectives of this integrated research safety vehicle was to improve vehicle fuel efficiency without compromising safety goals. Improvements in engine efficiency, aerodynamic drag, and weight reduction all played a part in the demonstrated high mileage of the vehicle. On an EPA city test 40.4 mpg (5.84 liter per 100 km) was achieved and a highway figure of 66.6 mpg (3.55 liters per 100 km) was achieved. Gravimetric data showed that even better results could be obtained with further engine optimization.

PERFORMANCE AND HANDLING

Although acceleration, braking, and handling were not the highest priorities for the Viking Six program, VRI personnel have a long standing personal interest in these aspects of vehicle design. The basic suspension system utilizes coil-over shock absorber units located by a long and short arm nonparallel wishbone system at each end. The roll center at the front is 50 mm above ground level, while the rear roll center is 100 mm above ground level. The virtual swing arm length both front and rear is 190 mm. Camber gain at 3 degree roll maintains the outer wheel perpendicular to the road surface. The tire footprint at each end of the vehicle is high for the load carried and in direct proportion to it.

Nine-inch disc brakes are used at each wheel with aluminum brake calipers. Two master cylinders are used with a balance beam mounted integral with the pedal so that a simple screw adjustment can adjust the percentage braking each end of the vehicle receives. At this writing the unit is not servo controlled by weight in the trunk.

At this time only acceleration and coast down tests have been run on the car. It has achieved a 8.95 s time from 0-60 mph (0-96 kph) and a time of 16.8 s for the standing start quarter mile. This writer has driven the car down the freeways from Bellingham, Washington to Santa Ana, California and back up the coast of California, Oregon, and Washington and can report that the car is

Table 2. Steady state fuel economy 1,625 pound inertia—3.2 hp.

Speed (MPH)	Gear Used	Time Min: Sec 7	Fuel Used (gms)	MPG	Liters 100 Km
50 (4 Cyl)	5th	2:56.98	100 gms	68.4	3.45
50 (2 Cyl)	5th	3:39.76	100 gms	84.9	2.78
55 (4 Cyl)	5th	2:46.09	100 gms	70.6	3.35
55 (2 Cyl)	5th	2:45.91	100 gms	70.6	3.35
45 (4 Cyl)	5th	3:07.43	100 gms	65.1	3.63
45 (2 Cyl)	5th	3:45.39	100 gms	78.7	3.07

$$\text{Fuel Consumption (MPG)} = \frac{\text{Speed (MPH)} \times \text{Time (Min)} \times 46.37}{\text{Fuel Used (gms)}}$$

Table 3. Exhaust emission data.

Test Date	Test Type	Emission Data HC	CO	NO_x	Fuel Economy CO_2	CB
3 25 82	CVS — H	.09	.89	.86	202.4	43.4
3 27 82	CVS — CH	.25	1.13	.89	237.5	36.9
3 29 82	CVS — CH	.25	6.62	1.23	208.2	40.4
3 29 82	HFET	.05	2.51	1.42	129.0	66.6

comfortable and surefooted on all types of roads. In fact the car compares favorably in roadworthiness to a Chevrolet Corvette and Lotus Europa.

EXHAUST EMISSIONS

Viking Six was tested for exhaust emissions at the Subaru Technical Center in Santa Ana. After some preliminary work to dial in the best compromise for fuel economy and exhaust emissions the following results were posted.

SUMMARY

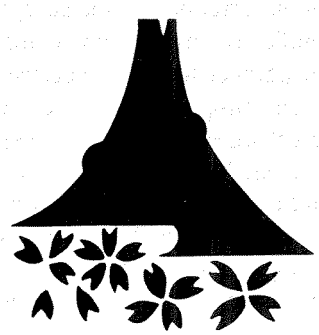
Viking Six met the 1982 exhaust emission requirements without a feedback loop carburetor or fuel injection. This is a graphic example of what a reduction in weight and aerodynamic drag can do to reduce emissions and improve fuel economy while limiting hardware costs.

Fuel economy could be improved still further by using a smaller displacement engine optimized for a car of this weight. We plan to try a 1300 cc engine of the same type in the near future.

A very significant conclusion based on the results of this program indicates that it is indeed possible to protect occupants in a very small lightweight vehicle in a crash situation. The work done with in belt inflator shows that effective passive restraint air belt systems are viable and show promise of combining the best features of air bags and belts albeit at a high cost. Further work with the front crush zone suggests that with suitable redesign the aluminum honeycomb may not be necessary. (Fig. 21.)

Figure 21. Dynamic science crash test.

Section 4: Panel Discussion on ESV/RSV Development



Mr. John Furness, Chairman, United Kingdom

Panel Member Statements

MICHAEL M. FINKELSTEIN
United States

The purpose of the initial experimental safety vehicle program was to test, on an experimental basis, new ideas of automotive safety incorporated in a vehicle which has been designed, fabricated, and tested as a total system. The basic objectives of the program were to determine the technical feasibility of making significant safety performance improvements in motor vehicles, to stimulate public awareness of the long-term social and economic advantages to be gained from the savings of lives and injuries resulting from advanced auto safety design, to encourage the industry to increase their efforts in auto safety design, and finally, to establish the technical base for the development of improved motor vehicle safety standards. How well have we, this confederation of concerned nations, done in the past 12 years? Have we accomplished our initial objectives, or is there work yet to be done?

I believe this international cooperative program has been perhaps not in the way originally envisioned successful. Automobiles produced today are safer, more fuel efficient, less polluting, and more economical to maintain than those manufactured only a few years ago. Automotive technology has made impressive advances. Questions of how much of this was related to ESV/RSV is a subject that no two individuals would agree on.

The technology of the ESV/RSV includes among other items the relocation of fuel tanks over the rear axle, the integration of restraint systems with structure crash performance, the application of advanced electronics including the miniprocessor, diagnostic displays and information displays, application of lightweight material in improved structures, improved restraint systems, the use of computer simulations of advanced design concepts, the construction of advanced safety testing facilities, and finally the creation of a new awareness of safety performance as a design requirement.

How many of these advances were the product of the ESV/RSV or how much was proved by this project is interesting to consider since we are not able to fully determine sources of technology changes.

Over the years, we have come to know each other better and now work together in cooperative research efforts. We share technical progress through personal contacts and through international forums such as this Conference where we gather to exchange research results and discuss mutual safety problems. Our research and knowledge in automotive safety, like our ESV/RSV performance specifications, have matured and grown. I believe our progress has exceeded our most optimistic expectations of 12 years ago. Indeed, as one participant once stated, "The real result of the ESV program may well be not the questions answered, but the questions asked but yet unanswered."

To try to find answers to the questions yet unanswered we in the United States are in the process of analyzing all available accident data to determine the principal causes of death and injuries in traffic accidents. The results of this analysis in the crashworthiness area have already been presented during the SAE Conference of last February. The same detailed analysis is now in progress for the accident avoidance area, and the results of this work will be presented at the SAE Conference in February/March 1983. The "easy" solutions to improved safety performance are already known and have been or are being implemented. Future improvement will require hard cost/benefit analysis, detailed economic impact analysis, and conclusive research results.

The United States has no near-term plans for the construction of additional complete experimental vehicle systems. Our plans now are, based on the analysis mentioned

above, to turn our attention to the subsystems which our analysis has indicated are a major contributor to death and injury. In parallel with this subsystem research we will continue our supporting research in accident data analysis, biomechanics, and human factors. The possibilities for an *immediate* and *dramatic* reduction in traffic fatalities do not exist in the vehicle safety design area but in a change in social behavior patterns such as increased belt usage and a reduction in the number of drunk drivers. These areas are receiving major attention as our highest priority programs.

However, we know that improvements in the safety design of vehicles still require our serious attention: improvements in the front and side structure; improvements in braking and handling, lighting and visibility; improvements in the interior compartment, steering column, and glazing; improvements in restraint systems; further advances in material substitution to reduce weight and improve safety and fuel economy; more incorporation of advanced electronics for improved driver displays, warnings, and improved engine/transmission performance. Improved safety designs in all of these areas and many others can result in a significant contribution to a reduction in deaths and injuries. I personally believe that our knowledge and engineering expertise have advanced to the point where we can accomplish these improvements without weight or fuel economy penalties. Our engineers must be allowed to practice their trade and apply their knowledge.

For the automotive engineer to introduce this new available technology requires serious management support. As new designs are developed in response to consumer demands, many tradeoffs are required. The impact of the introduction of advanced automotive technology is considerable. The manufacturing process must change, new suppliers are required, new test and reliability procedures must be developed to mention only a few; however, in this the space age and in this the safety, environment, and fuel economy age we must accept the challenge. The technology is available; our task is to transfer this technology into production cars.

As we enter this age of the world car, as we fine tune our research programs, and as we work together in this common effort, I believe that the international ESV program was the initiative from which we started and the base from which we can now advance.

Panel Discussion on ESV/RSV Development: Panel member statement for EEVC

PROF. DR. BERTIL ALDMAN
Sweden

The European Experimental Vehicles Committee has followed closely and with great interest the ESV/RSV programme in all its phases of development. Over the years it has been possible to note how the basic philosophy behind this programme has gradually penetrated into the general discussions among legislators, car manufacturers, and researchers in Europe. Of particular interest in this context is of course the principle that safety should be built into cars from the beginning and not added afterwards.

Traditionally in Europe a number of regulations and directives have been applied, which have mainly been design or construction standards often related to component testing. During the last decade, however, attempts have been made to arrive at performance standards with a more global concept of the vehicle, its occupants, and other road users.

When EEVC in 1974 presented its report "The Future for Car Safety in Europe" at the fifth ESV Conference in London the basic approach was that eventually a few full scale car tests should be used to demonstrate that a desired level of safety for the occupants had been achieved. The approval would be based upon a set of requirements related to human tolerance levels and the kinematic response of appropriate anthropomorphic test dummies.

However, a working group, set up by EEVC, presented a report at the sixth ESV Conference which revealed gaps in the knowledge of biomechanics and lack of biofidelity in current test dummies. EEVC then aided the Commission of the European Economic Community in setting up a coherent Biomechanics Programme to tackle these problems. It has monitored very closely the realization of this programme and in particular that part of it which has dealt with the closing of the gaps in our knowledge about human tolerance levels.

For the development of a suitable side impact dummy intended for legislative testing and for research puproses EEVC formed an ad hoc group with the responsibility to draft desirable requirements and lay down provisional performance specifications for such a dummy. Liaison was established with NHTSA and the group monitored the development work carried out within the framework of the EEC Biomechanics Programme. The work resulted in a number of new dummies whose components interface with contiguous parts of the Hybrid II dummy. This enabled comparative testing of one American and three

European complete side impact dummies to be carried out. It is expected that this ongoing project will eventually lead to the formulation of an acceptable performance specification for a side impact dummy to be used for legislative purposes.

Two other EEVC working groups, reporting at this conference, have addressed the problem of testing to check occupant protection in side impacts and the protection of pedestrians when impacted by the front structures of cars. These problems will continue to be monitored by the committee through its working groups. It is hoped that more light will be shed on the problem of optimizing the frontal car structures to reduce their aggressivity in pedestrian collisions and to increase their compatibility with other cars in side impacts. The results are not expected to be available until late 1983 and late 1984 respectively.

Over the last few years many countries in Europe have seen a considerable increase in the number and usage of bicycles. Many of these are lighter and capable of higher speeds than earlier models were. This creates more conflicts with other road user categories. The most frequent serious accidents for two-wheelers being those where an impact with a car takes place. At the initiative of The Netherlands the EEVC main committee recently decided to set up a new working group to tackle the safety of bicycles and in particular this problem. The group will mainly be concerned with bicycles and the light type of mopeds which resemble bicycles in their main construction. Heavier mopeds and motorcycles will not be studied by this group.

The task of the group will be to study available data on accidents and injuries to riders of light two-wheelers in Europe. Particular interest should be given to the sex and age distribution of the victims since bicycles are becoming more popular to adults than they used to be. The group shall make recommendations including priorities for action for bicycles and the vehicles striking them in order to reduce the severity of such accidents and injuries. The group itself will give priority to the possible influence on the safety of bicyclists from certain already proposed measures, so that changes to the car can be considered with respect to the benefit of all non-occupant road users as well as to the occupants of the vehicle. It is expected that the results from these studies will be available in 1984.

During the period of time over which the ESV/RSV programme has developed into its present state, it has been of great interest to watch how the concern of researchers, car manufacturers, and legislators in Europe gradually has changed. It has turned from components for safety, such as the safety belt or the air bag, to larger systems including seats and other structures in the car. In this context also luggage and fellow occupants are of interest as interaction may occur in some types of accidents. Finally the entire vehicle has been taken into consideration not only in a few specified situations but in all its aspects of safety in a variety of accident situations for both occupants and other road users. The interest also embraces the normal driving conditions where problems related to fuel conservation and reduction of noise and pollution are being discussed.

The EEVC sees this as a logical line of development for Europe and the lead times necessary for the car manufacturers to make their products conform with the new ideas have to be added to those needed for the researchers and the testing institutes who have to learn to handle the more complex test situations. In this latter context the ESV/RSV programme has been beneficial to all concerned in this field.

Panel Statement ESV/RSV Development

P. VON MANTEUFFEL
Federal Republic of Germany

This morning members of the German delegation reported on our recent research car project. Other reports by our delegation will cover work in the areas of side collisions, field performance of an automatic restraint system, modifications of an integrated research vehicle for improved crashworthiness, a statistical analysis of the influence of vehicle size on safety, injury risks at higher test speeds as well as questions of terminology and definitions of passive safety and compatibility.

Besides the work to enhance safety within the individual companies themselves German car manufacturers and some vendors have combined their research efforts and—some ten years ago—formed the "Research Association on Automobile Technology (FAT)."

Of the 24 reports on research projects hitherto published, 11 deal with various aspects of automotive and traffic safety. One of our speakers here in Kyoto will report on the status of a particular project dealing with dummy/cadaver comparison in head-on collisions.

For our following panel discussion I would like to raise a few topics of general interest, and I shall put them forth partly in the form of a hypothesis.

1. Hypothesis No. 1 is the following: The decade of spectacular presentations of complete ESVs/RSVs is over.

Insight into the technological means to improve particularly passive safety has been tremendous. In this respect I agree completely with Mike Finkelstein. Actual safety progress on production cars, however—working under the constraint of cost/benefit aspects—is harder to achieve. Is this so?

2. My second hypothesis offered for discussion is as follows: The days of safety devices with high benefit/cost ratios on production cars (such as the safety belt) are over. Air bags and antilock brake systems are much more expensive and statistically less effective. Would you agree, then, that safety progress on production cars can be expected to gently level off, that technical improvements will, in future, rather have to rely on the effects of many detail advancements?
3. Harmonization/Trade Barriers:
   One of the most important aspects in international automobile design, manufacture, and trade is the harmonization of regulations. We welcome particularly the positive attitude which NHTSA is taking toward this common goal. At the same time industry cannot be content with the actual progress achieved in this field as of today.
   In spite of these efforts, the tendency to invent new automobile regulations and approval methods thus obstructing trade is, in many countries, increasing. How can we create a forum for a broad harmonization program?
4. Another subject I would like to offer for discussion is the minimum/maximum philosophy of standards which to me seems endangered. Generally, in a given testing discipline, either a certain minimum value must be reached or exceeded, or a certain maximum value may not be exceeded.
   A heavy strike against the basics of this philosophy was, in my opinion, the 35 mph crash test program in the U.S. Similar elements of violation of the minimum/maximum philosophy can today be found elsewhere, also in Germany.
   I believe it is important to accept the fact that a maximum standard is simply an upper limit. Engineers create different technical solutions which give certain performance readings below the limit value thus introducing the element of competition. From there on market forces should take over. I frankly believe that unless this is recognized, the maximum/minimum philosophy of setting standards is endangered.
5. Fifth, I should like to touch upon the question of how to continue these ESV conferences.
   As much as we see these conferences as a forum to exchange views between government and industry of various nations, and because our delegation has always contributed very actively to this exchange, we dare to appeal to this assembly to discuss its own future plans. If it is true that the years of design of complete ESVs are over, and this was my first hypothesis, should we not contemplate to reorganize this exchange of views by embedding the reports on safety work into other existing regular conferences (such as, for example, next week's FISITA) where safety is regularly on the agenda?
   Again I say this not without bowing before DOT/NHTSA and our Japanese hosts for staging this and the preceding conferences.

Our efforts for safer road vehicles must not be regarded as the one and only means to improve road safety. Driver behavior, improved roads, and organization of traffic are other important factors. A concerted safety effort requires careful assessment of all factors, including the driver, in a totalistic approach.

Most important of all we must increase the general public awareness of road safety aspects. In Germany, unfortunately, some people presently seem to be more concerned about 11,000 trees when an airport runway or a road is to be built than about 11,000 road fatalities.

Finally, let me close with a request to our Japanese panel member, Goto-san, to please, if appropriate, describe the key elements of the highly successful Japanese road safety program.

Thank you for your patience.

Panel Statement on ESV/RSV Development

I. D. NEILSON
United Kingdom

In the United Kingdom the distribution of fatalities in road accidents is different from that for many other countries. Under 40% are killed in cars, whilst pedestrians account for 33%, and pedal and motor cyclists 25%. About 14% of fatalities are in accidents involving a Heavy Goods Vehicle. The relatively high numbers of motorcyclist casualties and of accidents involving Heavy Goods Vehicles are the reasons why safety developments for these vehicles have been studied for some years. There have been both a UK demonstration safety motorcycle and an articulated vehicle. It is good to be able to report that there have been many positive results from these developments. Sintered pads for disc brakes for motorcycles are now in large scale production. Antilock brakes are almost developed for motorcycles and are being in-

creasingly adopted for both the semi-trailers and the tractor units of articulated vehicles. Two-wheeler riders are becoming increasingly conscious of the need to use lights or wear conspicuous garments. Heavy Goods Vehicles will be required to have sideguards and underrun protection at the rear, and a standard for spray suppression is being discussed urgently in the British Standards Institution which it is intended will become mandatory if a satisfactory conclusion is reached.

There has been little obvious progress towards improving the safety of cars but research and development for cars as well as for other vehicles is continuing in the United Kingdom. An impetus is being given by the belated introduction of the compulsory wearing of seat belts and of restrictions on the positioning of unrestrained children. We are glad that the long development of child safety seats and related items has been recognized by one of the NHTSA Awards at this Conference.

Looking to the future, one outcome of all the work on vehicle safety Research and Development seems likely to be the adoption of antilock braking for motorcycles as well as for articulated vehicles. Car design will incorporate protection for pedestrians as well as for occupants in side impacts. Protection of the occupants of small cars in frontal impacts can be improved but the will to do so is required. The present question for vehicle safety legislation is whether progress can be made by updating current minimum standards or whether Crashworthiness Ratings of cars can be introduced to the extent that car purchasers consider the quality of the safety offered in the new cars available to them. If so, they would encourage improved safety through the pressures of the market place.

Panel Discussion on ESV/RSV Development

ENZO FRANCHINI,
Italy

The ESV program has developed through distinct phases that have assumed different characteristics over the years.

—The first phase began with the definition of an experimental safety vehicle that would meet extremely severe requirements. On the one hand it led to models not suitable for production and moreover excessively heavy; on the other hand to Fiat ESVs having a limited weight but a cost increased by 40 per cent.
—The second phase defined a research safety vehicle with less severe requirements aiming at its producibility. Even if less heavy models were developed, in the light of the 1973 energy crisis weight and consumption resulted to be prohibitive.
—The third phase has begun in the recent past in which the energy crisis, combined with the economic crisis, has put industries, in particular the automobile industry, in serious difficulties.

These difficulties concern numbers of interacting problems such as consumption reduction (hence energy waste), weight reduction (hence cost), low pollution and acceptable safety.

The solution lies in innovation. Innovation in structure and engine design, materials and electronics applied to motorcar, production technology.

Today the automobile industry is making extensive research and investing large amounts of money in those fields. The recent Italian accomplishments, Fiat VSS and Alfa Romeo Svar, are mentioned in the Italian Government status report.

Industry's efforts call for cooperation by governments in the field of economics and in the field of regulations. These must be such as not to cause disadvantages in certain areas (e.g., weight, consumption, cost) with the purpose of giving advantages in others (e.g., pollution and safety). Regulations must not be antithetical in their aims, but it is necessary that they have a realistic and thought-out basis.

Panel Discussion on ESV/RSV Development

DOMINQUE CESARI,
France

During the last decade, the number of traffic accident victims decreased while the vehicle miles traveled increased. A great part of this improvement is certainly due to consequences of ESV/RSV program which allowed the rapid introduction of safety research results into production cars.

However, traffic accidents still remain a serious problem for the industrialized countries; and it is, therefore, necessary to continue our research efforts to reduce their very serious consequences.

Future programs should mainly address specific im-

provements in subsystems without necessarily developing complete prototypes of full scale cars. The field of work is extremely broad, and I would now like to discuss the topics which we feel are most important.

The French Government recently decided to set up an accident investigation program which would deal with severe and fatal traffic accidents. This program will be principally concerned with vehicle crashes in the field of active safety.

During the past few years, car design has been improved to reduce fuel consumption. In this connection, there are in France at this moment two projects for the design of cars which use less than 3 liters of gasoline to travel 100 kilometers. These cars will have interior space similar to present cars, but they will be much lighter. Due to the importance of the loading of these cars compared to their curb weight, it is necessary to accomplish the gain in fuel consumption without decreasing their safety performance.

In the same way, the manufacture of future cars will more and more involve new materials. These new materials have a behavior during impact which is not fully understood. This behavior must be determined to establish protection levels for occupants and other road users.

France has participated in the establishment of an integrated test procedure for frontal impact and contributed to the definition of a test procedure for side impact proposed by the European Experimental Vehicles Committee. The results of this work will be presented during this Conference. We think that an integrated test procedure is a good way to improve the safety of cars; however, there are problems with its applications which must be resolved.

In the same field, it would be interesting to make an evaluation of the gain in safety as a result of the integrated test procedure in frontal impact. The problems in dealing with integrated tests concern the behavior of dummy improvements, and improvements in our knowledge of injury mechanisms and human tolerance in order to choose realistic protection criteria.

Another specific improvement one can think of is restraint systems design. The protection offered by safety belts could be increased by improving their performances during accidents and by increasing their acceptability to users.

In the field of side impact protection, injury mechanisms are presently known and specific solutions are proposed by the car industry, but evaluation methods are still uncertain.

Finally we think that international cooperation is necessary to proceed more quickly and more efficiently. This is especially true in the field of biomechanical research and dummy improvement.

Panel Statement: A Future Plan for the ESV/RSV Program

KENICHI GOTO,
Japan

I have the pleasure of speaking to you about my private views on the future plans for the ESV and RSV program. In the first place, it is necessary to review the progress of the program to date. The development of Experimental Safety Vehicles began in 1970 with the announcement of the ESV program. Although there might be some debatable points, I think that the specifications were epoch-making in the safety design of vehicles. In order to satisfy these specifications, auto manufacturers in the participating countries, after major design efforts, finished the evaluation tests of ESV's in 1974. It should be pointed out, however, that the manufacturers could not develop safety vehicles capable of fully meeting all the safety requirements. The major question pertained to body weight. Vehicle weight had to be increased to reinforce structure strength. An alternative solution was conceived to the effect that impact energy could be absorbed by the vehicle body without reinforcing the structure strength. The design characteristics of the past which put emphasis on improving operational durability on bad roads were advanced taking into consideration the absorption of impact energy. This was a great achievement of the ESV program.

Based on the results of ESV program, the RSV program was initiated to develop a production car applicable to the mid-1980's. The results of this program have been presented during the Eighth and current Ninth ESV Conferences. I have some doubts about the success of the RSV program. I suppose that the types of vehicle produced after Phase 2 were developed by putting emphasis on the specifications for crashworthiness. Such a vehicle should not be evaluated as a model of production cars for the mid-1980's. In my opinion, the RSV program was not successful, whereas the ESV program was successful.

The IVS program was introduced as a follow-on program to ESV and RSV. The current status of this program is unknown. My comments on the IVS program are that it should not aim at developing a safety vehicle but at developing a vehicle of the future. Automobiles should be designed on a well balanced basis covering all requirements, not just safety. The IVS program calls for more specification items than for the RSV. I assume that the large manufacturers are obliged to develop and complete an IVS. Furthermore, they have to expedite the devel-

opment of their own production models capable of competing in the current innovative age. In these circumstances, manufacturers may be reluctant to develop an IVS. Then, what should we do? I would like to suggest that fundamental studies on problems relating to safety be encouraged. Although it is attractive work to complete an IVS as early as possible, I fear that the RSV program experience may be repeated.

I have two concerns regarding the IVS program. The first concern is that the program supports rulemaking and the other concern is that the program still places emphasis on vehicle performance during collision. As to the first concern, I understand that rulemaking is an easy way to enforce the application of safety requirements. The manufacturers are not in a position to easily adopt safety devices since these devices are difficult to market. However, the persons engaging in safety problem have as their final object the reduction of injuries in vehicle accidents and not in rulemaking. My second concern addresses the possibility of the occurrence of an accident where crashworthiness is required. With these points in mind, I would like to stress that accident prevention should be emphasized rather than crashworthiness. I agree with the current NHTSA program addressing the prevention of accidents involving drunk drivers. As is often pointed out, the safety problem consists of the automobile, the human, and the environment. In consideration of what is most important in these factors, I would like to say that emphasis should also be placed on the other problems relating to the automobile.

The best way to reduce injuries in vehicle accidents is to investigate the causes of accidents and then to find a way to remove the causes.

In conclusion, I propose that if we are to continue the International Technical Conference on ESVs hereafter, the first thing we should do is to clarify the role of these conferences and change the name to the International Technical Conference on Automotive Safety. Thank you.

Section 5: Technical Sessions

Frontal Crash Protection and Pedestrian Protection

Technical Session No. 1

Mr. Philip W. Davis, Chairman, United States

Compatibility and Passive Safety Terminology and Problematics

Dr. ULRICH BEZ and
Dr. WALTER SCHMID
Bayerisch Motoren Werke AG Germany

ABSTRACT

The different, semantic use of problem-relevant terms is proving an increasing obstacle to understanding among different experts and authors of technical literature. When is a vehicle safe, when is it compatible, what is risk of injury?

These are only a few of the fundamental terms whose meaning differs from author to author, from automobile manufacturer to automobile manufacturer, from country to country.

As a result of their work in various national and international bodies, the authors of this paper are constantly confronted with the problems resulting from different interpretation of such terms. Drawing on their own understanding of the problems involved and the effects of stipulations, the authors in their paper attempt to explain such terms on an application-oriented basis, to define them and to supplement, or at least round off, the "structure" by means of new terms. This paper is intended not only to be an aid to experts in informing others of their results but is also aimed at enabling the reader to understand what has become rather complex material.

INTRODUCTION

The subject of SAFETY IN ROAD TRAFFIC is as old as the invention of the wheel. In recent times—since 1970—efforts relating to this subject have intensified on a wide, international level.

Despite the age of this subject and the application of a massive engineering potential, there are problems of understanding on a national and international level—among experts and their discussion partners—greatly impeding the efficiency of all these efforts.

A study of the contents of literature meanwhile available regarding, e.g., COMPATIBILITY of vehicles in traffic accidents particularly reveals the problems involved.

What dominates is co-existence and ignorance.

The aim of this paper is to improve mutual understand-

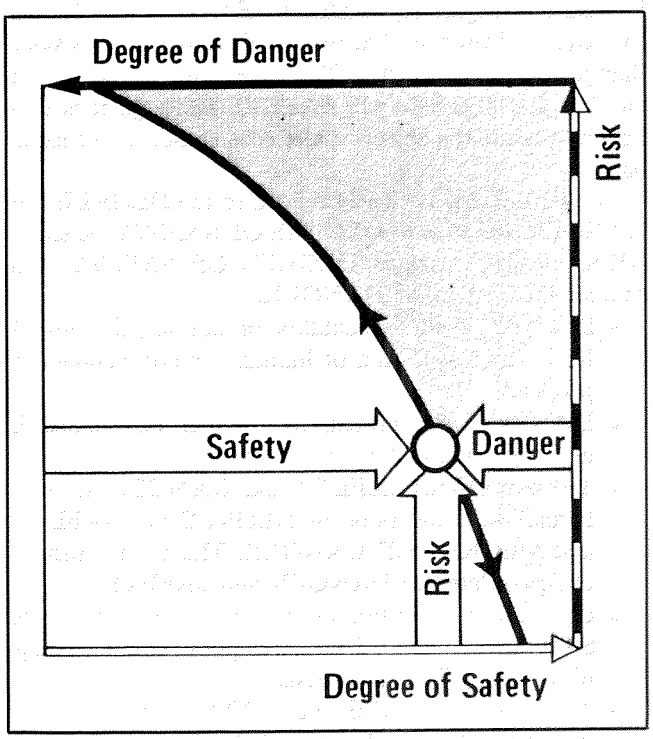


Figure 1. Scheme: Risk - Danger - Safety.

*Dr. Ing. h. c. F. Porsche AG until September 1982

ing between experts in industry and administration and to offer the experts a sound basis for a common goal-oriented approach.

Although the authors of this paper are aware of how difficult it is to change opinions once they have become ingrained and the problems which might confront common terminology, they nevertheless attempt to clarify the meaning of the terms PASSIVE SAFETY and COMPATIBILITY by means of a comprehensive consideration and then to define them relative to each other. For this consideration, it is necessary to somewhat delineate the meaning of terms in general usage such as DANGER, RISK or SAFETY.

SAFETY—DANGER—RISK

Life in itself is dangerous. The definition in DIN 31004 "SAFETY is the absence of DANGER" does admittedly imply a state of absolute safety. If, however, the focus of this consideration regarding SAFETY is humans with their health and wellbeing, an absolute level of safety is absolutely impossible for humans—due to the very nature of the matter.

As shown in Figure 1, there are only conditions described by a particular DEGREE OF SAFETY as well as by a DEGREE OF DANGER. It is not possible to transfer DEGREE OF SAFETY into AN OBJECT IS SAFE. Such statements are arbitrary.

This description of state does however enable a comparison to be made, e.g., of different means of transportation—whether expressed positively as DEGREE OF SAFETY or negatively as DEGREE OF DANGER. We can say, for instance, that means of transport A is safer than means of transport B. This necessitates laying down an absolute DEGREE OF SAFETY although it is sufficient to relate the objects under comparison to the same basis.

The term RISK is closely related to the DEGREE OF DANGER and thus to DEGREE OF SAFETY. A small RISK means a greater DEGREE OF SAFETY and smaller DEGREE OF DANGER.

- SAFETY is the probability of non-impairment of health and wellbeing of humans or non-damage to property.
- DANGER is the probability of impairment to health and wellbeing of humans or damage to property.
- The expressions SAFETY and DANGER are colloquial simplifications of DEGREE OF SAFETY and DEGREE OF DANGER. The term RISK is closely related to DANGER and SAFETY.
- Comparative considerations with the adjectives SAFE and DANGEROUS are possible, the prerequisite being: The same basis.
- The adjectives SAFE and DANGEROUS do not determine the actual state or behaviour of an object.

SAFETY IN ROAD TRAFFIC

Following the preceding section which was devoted to higher-order aspects dealing with terms, we now provide an overview of the complex known as road safety. A particular aim is to classify the terms PASSIVE SAFETY and COMPATIBILITY.

The four principal sectors determining safety in road traffic are:

The HUMAN
The VEHICLE
The ENVIRONMENT
The RESCUE SYSTEM

The human is a significant risk factor on the one hand as an active participant in traffic—being able to both avoid as well as to cause an accident as the result of his capabilities—and on the other hand in his capacity as a passive participant in an accident is the victim of the danger which he himself has frequently influenced. (Fig. 2.)

Depending on his constitution, his physical and psychic state, he represents a greater or smaller accident risk and consequently also an injury risk for himself and other humans, whether as driver of a vehicle or pedestrian by reacting, acting, judging in different ways.

The impairment of human health is influenced by the mechanical loads which can be sustained by head, thorax, pelvis and extremities. It can today be stated as a reliable

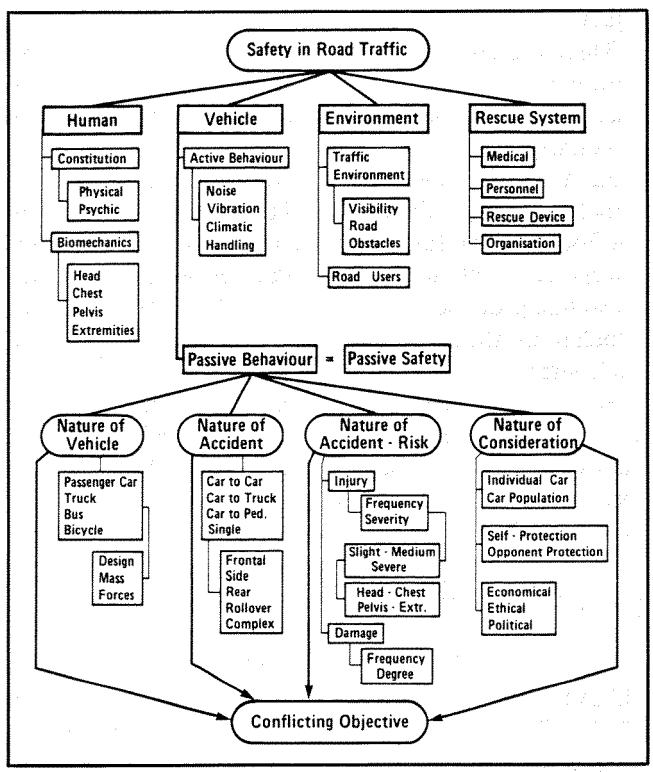


Figure 2. Structure of safety in road traffic.

fact that this load factor varies from human to human and is greatly dependent on age.

The behaviour of the vehicle is usually split up into an active and a passive sector.

In the active sector, a vehicle which is as quiet running as possible, dampens vibrations to the maximum extent possible and in which the air is properly conditioned provides the ideal requirements for maintaining the driver's concentration at a high level. Good road behaviour also comes under this sector. The terms PASSIVE SAFETY and COMPATIBILITY can be found under the heading of passive behaviour.

The environment affects vehicle safety inter alia by the visibility conditions existing, the condition of roads and any obstacles present. An essential factor is also the nature of other road users, e.g., other vehicles or pedestrians.

Rescue is significantly influenced by the human as rescuer and helper, by medicine (e.g., shock prophylaxis) by means of technical aids such as salvage tools or medical apparatus, as well as the organization set up to ensure that the right helpers are on the scene as rapidly as possible with the right equipment.

An attempt to change the degree of PASSIVE SAFETY results in fundamental conflicting objectives from the mutual influencing of the aforementioned principal sectors of passive safety, it being one of the principal tasks of the engineer to solve or reduce these conflicts.

Passive Safety

The definitions specified here are closely related to the terms elucidated.

- PASSIVE SAFETY deals with the effect of vehicle technology on the risk of injury to the human and property in defined accidents and with the biomechanical capacity of the human, which is assumed to be known.

The remarkable bandspread characterizing all known analyses of real traffic accidents is attributable primarily to the large bandspread of the biomechanical capacity of the human and the different accident conditions.

Measures to change PASSIVE SAFETY therefore require to be oriented on statistical characteristic values. Improvements to PASSIVE SAFETY result in a reduction in the ACCIDENT RISK by reducing INJURY SEVERITY and MATERIAL DAMAGE (Fig. 3.).

Using the designation, common in safety science, the severity of an accident becomes DEGREE OF DAMAGE S and the frequency of accident becomes PROBABILITY OF OCCURRENCE OF DAMAGE W and thus ACCIDENT RISK R.

$$R = S \cdot W$$

- PASSIVE SAFETY influences the degree of ACCIDENT SEVERITY primarily and independently of whom is involved in the damage or of how it is distributed.

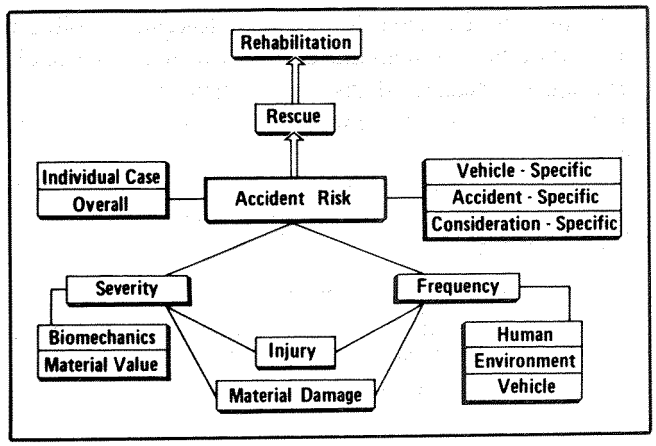


Figure 3. Structure of accident risk. Rescue as a filter function determines final rehabilitation.

Conflicts

Changing individual elements of the four principal sectors of PASSIVE SAFETY (Fig. 2) is still the method most widely used today to improve the degree of safety.

Development engineers in the automobile industry recognized early on, however, that a consequent reduction of the risk of injury, e.g., when impacting against a solid wall, can increase the risk of injury in other types of accidents, such as a head-on and side collision involving different vehicles.

It is therefore questionable in respect of a large number of legislative efforts based on individual elements—e.g., impact against wall, post laterally, etc.—whether they in fact increase PASSIVE SAFETY.

Solving such conflicts first of all demands researching the causes and mechanisms contributing to the occurrence of damage. It is then necessary to balance the attainable improvements on the one hand with any impairments which may have to be accepted on the other hand.

- Problems of the DISTRIBUTION OF ACCIDENT RISKS thus exist in the cases of conflicts.

Compatibility

Based on the knowledge of this problem of distribution, the following terminology is therefore proposed.

- COMPATIBILITY is concerned with the mutual influencing of elements of the four principal groups of PASSIVE SAFETY:

  Nature of collision
  Nature of vehicle
  Nature of risk
  Nature of consideration

Nature of collision is, e.g., single-vehicle collision, front-end, side or rear-end collision with other vehicles or rollover. Nature of risk of accident relates, e.g., to material damage or slight or severe injury to different parts of the body.

Apart from different types of private cars, we must reckon with collisions concerning trucks, buses and two-wheeled vehicles.

- COMPATIBILITY PROBLEMS are problems in which defined vehicle changes on the one hand increase PASSIVE SAFETY, reduce the risk of accident at that point while on the other hand increasing another ACCIDENT RISK.
- Compatibility influences the statistical accident risk of the entire number of all accidents via the distribution of the accident risk in the individual case and thus the DEGREE OF PASSIVE SAFETY.

In the same way as with the term SAFETY, a state of complete COMPATIBILITY is not possible since defined distributions are in themselves only variants which can only be assessed and arranged by employing further criteria. For this reason, the DEGREE OF COMPATIBILITY is decisively influenced by the criteria employed.

When dealing with compatibility problems, the viewpoint of the observer is of elementary significance. The primary consideration may be self protection, protection of other traffic users, losses to the economy or insurance economic aspects.

The conclusion to be drawn from this is that the strategy of the observer is of significant influence.

COMPATIBILITY STRATEGIES

If Chapters 1 to 3 are used in assessing technical literature—referred to in the Appendix—it can be stated that all the principal work can be arranged in the terminology stated. On the other hand, the statement and results differ due to the application of different strategies.

The strategy determines the results like a filter of spectral analysis, employed for input data with the same origin.

To aid understanding, it is urgently necessary in future for all authors, speakers, organizations, industry and authorities to clearly set out what is the strategy basis of their knowledge or requirements.

Figures 2 and 5 are an essential aid in this respect. Figure 5 presents the principal strategies and possibilities for mixing in a systematical form. Mixing takes place not only via the three circles MOTIVATION, FILTER, SPACE but also within each circle. It is seldom a matter of the PURE FORM of a strategy.

For instance, if the economic aspect dominates—whether national or private economic aspects—political (company or state) factors or humanitarian (moral or ethical) factors always play a role.

The middle circle, the FILTER CIRCLE, shows that the motivation aspects are filtered in a purely arbitrary manner or with focal points—e.g., dealing exclusively

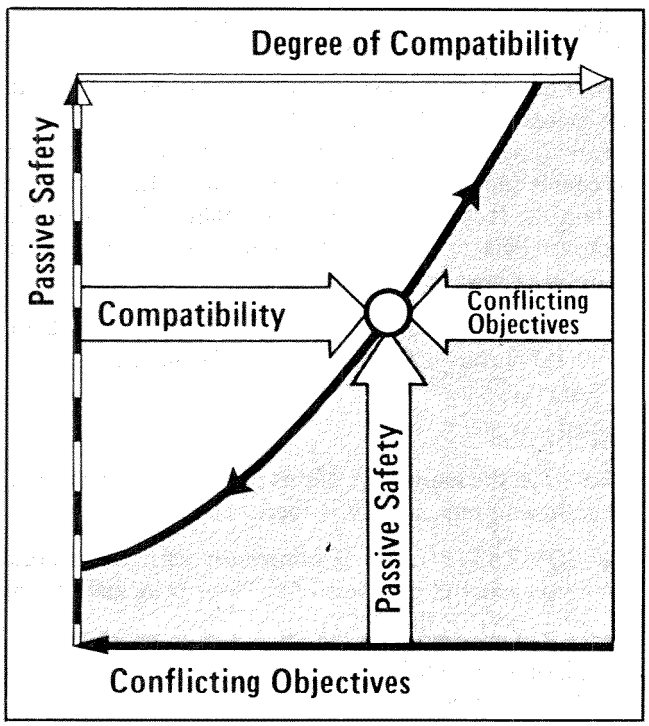


Figure 4. Scheme: Passive safety - Compatibility - conflicting objective.

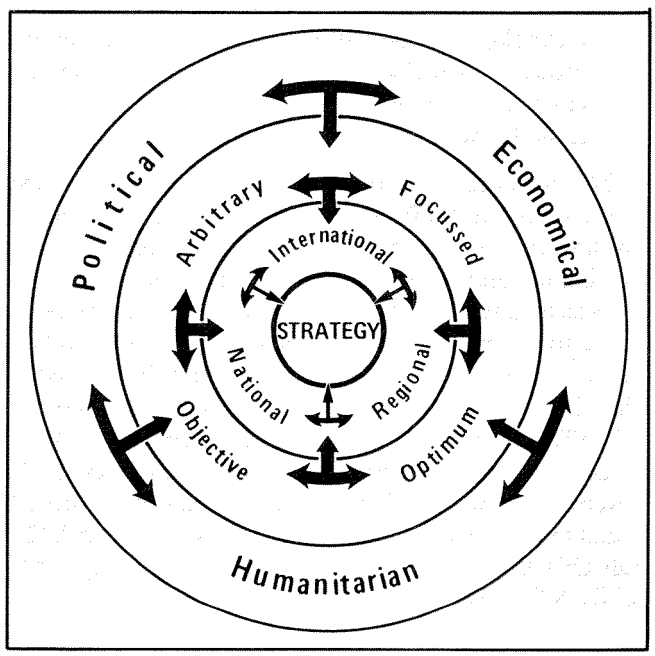


Figure 5. Presentation of important compatibility strategies and their correlation (motivation circle, selection circle, space limitation circle).

with car-to-car frontal accidents—or ideally with exclusive orientation to minimizing overall risk or objectivity—with as uniform possible distribution of risks.

The inner circle or SPACE LIMITATION CIRCLE finally provides information regarding regional, national or international applicability or interpretation of the criteria mentioned.

In the authors' view, the project supported by the German Ministry for Research and Technology, the abbreviated title of project Phase 1 being COMPATIBLE VEHICLES, pursues on the basis of this arrangement principle an

economically focused/optimum national strategy.

This eliminates any further RIGHT or WRONG in the discussion of compatibility, leaving only a co-existence of different approaches, which the individual author then must also explain.

Points of controversy are then no longer COMPATIBILITY PROBLEMS but the decision in favour of the criteria of the three STRATEGY CIRCLES to be employed.

SUMMARY

As a result of their work in various national and international bodies, the authors of this paper are constantly confronted with the problems involved from the different interpretation of terms. From their own knowledge of these problems and a study of the comprehensive technical literature meanwhile available, they explain the terms PASSIVE SAFETY and COMPATIBILITY on an application-oriented basis and define them relative to each other so as to cover all known terms. Only by introducing the term COMPATIBILITY STRATEGY and the variations which it offers is it possible to achieve a breakdown ensuring extraordinary transparency.

- PASSIVE SAFETY thus means effort to reduce the OVERALL ACCIDENT RISK.
- COMPATIBILITY means a proper distribution of unavoidable risks based on a specified strategy.

A Collection of Relevant Papers to the Term Compatibility

1. Appel, H.: Optimum deformation characteristics for front, rear and side structures of motor vehicles in mixed traffic; 2. ESV-Conference, Sindelfingen 1971
2. Appel, H.: Aggressivität von Fahrzeugen als Teilproblem der passiven Sicherheit; ATZ 75 (1973) 12
3. Appel, H.: Ergebnisse und Schlußfolgerungen aus dem ESV-RSV-Programm und der BMFT-Studie "Technologie für die Sicherheit im Straßenverkehr"; 4. Statussemin. Kfz- u. StV-Tech. BMFT, 2. Jtag. VDI-Gesell. Fz.Tech. 1976
4. Appel, H.: Hofmann, J.; Rau, H.: Entwicklung kompatibler Fahrzeuge—Analytische Abschätzung der Unfallmechanik der Unfallgruppen. 5. Statussemin. d. BMFT 1977
5. Scott, Basil Y.: Large and Small Car Accident Performance: A Large Scale Accident Data Base Analysis; SAE 750113
6. Beermann, H.J.: Verformungsverhalten von Personenkraftwagen an Unterfahrschutzeinrichtungen. Dt. Kraftfahrforsch. u. Straßenverkehrstech. H. 259 Düsseldorf
7. Bez, U.: Sicherheitsmaßnahmen imStraßenverkehr—Ergebnisse einer Nutzen/Kosten-Analyse von ausgewählten Maßnahmen. VDI-Berichte Nr. 418
8. Boehly, William A., Lombardo, Lois V.: Safety Consequences of the Shift to small cars in the 1980's; NHTSA, HS-805 506
9. BLMC: A house paper which describes a computer simulation of a car-to-car head-on impact to investigate vehicle aggressiveness.
10. Bühler, O.P.: Neue Chancen gegen Verkehrstod? Hydrauliksystem verbessert Unterfahrschutz an Lkw und Anhängern. Kfz-Anz. 32 (1979) 15
11. Carlson, W.L.: Crash injury and vehicle size mix. Conf. Amer. Assoc. for Automot. Med. and 7. Conf. Int. Assoc. for Accident and Traffic Med. Vol. 2
12. Carter, R.L.: Passive protection at 50 miles per hour. DOT HS 810 197
13. Chandler, E.: Car-to-car compatibility, a brief survey 4. ESV-Conference, Kyoto 1973
14. Chillon: The importance of vehicle aggressiveness in the case of a transversal impact; 1. ESV-Conference, Paris 71
15. Coquand: Vergleich der Sicherheit gewisser Klassen französischer Tourenfahrzeuge mit großer Verbreitung. Anhang IV zum Bericht vom 30. Juni 1972 (VDA Kommission für die Sicherheit von Fahrzeugen)
16. O'Day, James and Kaplan, Richard: How Much Safer Are You in a Large Car; SAE (Feb. 75) 750116
17. Davis, S.; Pierce, S.; Van Crashworthiness and Aggressivity Study; SAE 810090
18. S. Davis, R. Yee: Development of a Test Methodology for Evaluating Crash Compatibility and Aggressiveness DOT HS-805 063
19. Danner, M.: Entwicklung kompatibler Fahrzeuge—Bildung einer Rangreihe von Unfallgruppen anhand einer Untersuchung realer Unfälle; 5. Statussemin. d. BMFT 1977
20. Danner, M.; Langwieder, K.: Schwerpunkte des realen Unfallgeschehens und Auswirkungen auf Kompatibilitätsrelevante Einflußgrößen; BMFT-Statussemin. 1978

21. Langwieder, K.: Aspekte der Fahrzeugsicherheit anhand einer Untersuchung von realen Unfällen; HUK-Verband
22. Langwieder, K.: LKW-Kollisionen mit Personenwagen und Ansatzpunkte zur Verbesserung des Partnerschutzes TÜV-Rheinland
23. Fiat: Analysis of statistical data on road accidents in Italy (1969–1970); A Magara 2nd ESV-Conference 1971
24. Fiat: Technical presentation; 6. ESV-Conference in Wash.
25. Fischer, J.: Analyse der passiven Sicherheit: Partnerschaft auf italienisch. Der häufigste Unfall simuliert: Wagen mit 1100 kg gegen 800 kg mit je 40 km/h frontal und versetzt; Automob.-Rev. 74 (1979)
26. Fischer, R.G.: Occupant protection in car-to-car impacts 4. ESV-Conference, Kyoto 1973, SAE 740316
27. Fischer, J.: Frontal-Crash zwischen zwei extrem unterschiedlich großen Wagen. Analyse der passiven Sicherheit Automob.-Rev. 73 (1978)
28. Hutchinson, T.P.: On the relative frequencies of collisions between vehicles of different masses; Z. f. Verkehrssicherh. 25 (1979)
29. MacLaughlin, T.F.; Saul, R.A.; Daniels, S.: Causes and Measurement of Vehicle Aggressiveness in Frontal Collisions; SAE 801316
30. MacLaughlin, T.F.: Derivation and Application of Restraint Survival Distance in Motor Vehicle Collisions; SAE 810092
31. Makay, Murray; Ashton, Steve: Injuries in Collisions Involving Small Cars in Europe; SAE 730284
32. Middelhauve, V.; Breitbach, P.: Panzer der Straße? LKW-Unfallsimulation an der TU Berlin; Lastauto Omnibus 56 (1979) 6
33. Ragland, C.: Vehicle Aggressivity Measurement and Evaluation; SAE 790297
34. Randall, R.B.; Hee, J.: Cepstrum analysis; Bruel and Kjaer tech. Rev. (1981) 3
35. Renault: Point du probleme compatibilité (note RNUR)
36. Renault: A Method to Approach the Problems of Vehicle Compatibility; 3. Intern. Congress on Automotive Safety, San Francisco 1974
37. Renault: Compatibility between Vehicles in Frontal and Semifrontal Collisions; 5. ESV-Conference in London 1974
38. Renault: Classification des chocs. Compatibilité (note RNUR)
39. Ventre, P.: Homogeneous safety amid heterogeneous car population? 3rd Internat. Conference on ESV, Wash. 1972
40. Ventre, P.; Rullier, J.C.: Proposals for test evaluation of compatibility between very different passenger cars. 4. ESV-Conference, Kyoto 1973
41. Reidelbach, W.; Schmid, W: An Attempt to Define and Evaluate Vehicle Compatibility; 3. International Congress of Automotive Safety, San Francisco, 1974
42. Schmid, W.: Über Massenverhältnisse bei Fahrzeugunfällen im gemischten Straßenverkehr; Automobiltechnische Zeitschrift 77 (1975) 5
43. Reidelbach, W.; Schmid, W: Compatibility of Passenger Cars in Road Accidents; 6. ESV-Conference, Washington Oct. 76
44. Schmid, W.: Mathematical Modeling of Occupant Biomechanical Stress Occurring During a Side Impact; SAE 780670
45. Reidelbach, W.; Schmid, W.: Realistic Test Conditions for Evaluation of Passenger Car Occupant Protection 7th ESV-Conference, Paris, June 1979
46. Schmid, W.: Vermindertes Verletzungsrisiko bei Verkehrsunfällen durch Fahrzeug-Kompatibilität; FISITA-Congress, Hamburg, Mai 1980
47. Schmid, W.: Minimum Risk of Injury on the Road, a Paradox; 8th ESV-Conference, Wolfsburg, Oct. 1980
48. Schmid, W.: The increase in the risk of injury in traffic accidents as a result of higher test impact speeds; 9. ESV Conference, Kyoto 1982
49. Panik, F.; Schmid, W.: Die 7. ESV-Konferenz—Überblick Automobiltechnische Zeitschrift 82 (1980) 1
50. Saul, R.A.; MacLaughlin, T.F.; Ragland, C.L.; Cohen, D.: Experimental Investigation of Crash Barriers for Measuring Vehicle Aggressiveness—Fixed Rigid Barrier Initial Results; SAE 810093
51. Searle, J.A.: The estimation of an aggressiveness coefficient from barrier impact test results. Working paper
52. Solomon, D.: Highway research and vehicle design for the 80s; SAE 770039
53. Stuhler, T.; Stankovic, P.: Vermeidbare Unfallfolgen? Z. f. Verkehrssicherh. 24 (1978) 4
54. Stcherbatchef, G.; Provensal, J. (F): Identification des facteurs de compatibilité des vehicules en choc lateral; VDI-Berichte Nr. 268, 1980
55. Stewart, J.R.; Stutts, J.C.: A Categorial Analysis of the Relationship between Vehicle Weight and Driver Injury in Automobile Accidents; HSRC/DOT HS-803 892
56. Stratmann, J.G.: ADAC-Untersuchung: Welche Vor- und Nachteile hat ein großes oder kleines Auto? ADAC-Mot.-Welt (1980) 10
57. Seiffert, U.: Crashworthiness regulations will be hard on small cars; SAE-Journal 4/73
58. VW: Realistic compatibility concepts and associated testing; 6. ESV-Conference in Washington
59. Seiffert, U., Hamilton, J. and Boersch, F.: Compatibility of traffic participants; 3. Intern. Congr. on Automotive Safety, San Francisco 1974
60. Seiffert, U.: Kompatibilität auf der Straße; ATZ 77 (1975)

61. Danckert, H.: Development of crash energy management solutions; SAE 760793
62. Weissner, R.: Fahrzeugtechnische Schwerpunkte zur Verminderung von Unfallfolgen; 4. Statussemin. Kfz- u. StV-Tech. BMFT, 2. Jtag. VDI-Gesell. Fz-Tech. 1976
63. Weissner, R.: Fahrzeugtechnische Möglichkeiten zum Schutz der Verkehrsteilnehmer; Kongr. d. Ärztl. Kraftfahrerverein. Österreichs, Wien 1977
64. Schimkat, H.: Entwicklung kompatibler Fahrzeuge—Zielsetzung und Arbeitsablaufplan; 5. Statussemin. d. BMFT 1977
65. Schimkat, H.: A concept of increasing compatibility of passenger cars; Int.Tech.Conf. on Exper.Saf.Veh. (US Dep.)
66. Weissner, R.: Kompatibilität von Personenkraftwagen unter Berücksichtigung unterschiedlicher Kollisionstypen Kongr.-Ber.Jtag. 1979 d. Dt. Gesell. f. Verkehrsmed. Unfall- u.Sicherh.Forsch. im Straßenverkehr
67. Bauer, A.; Richter, B.; Schimkat, H.; Weissner, R.: Entwicklung kompatibler Fahrzeuge—Grundlagen zur Erarbeitung von Maßnahmen für kompatible Fahrzeuge. BMFT-Statussemin. 1978
68. Zimmermann, P.; Oberdieck, W.; Richter, B.: Optimisation of energy absorbing structures for the improvement of the compatibility of passenger vehicles; 8. ESV-Conference, Wolfsburg 1980
69. Oberdieck, W.; Richter, B.; Zimmermann, P.: Optimierung von Deformationsstrukturen zur Verbesserung der Kompatibilität von Pkw; 18. int. FISITA-Kongr. Hamburg.
70. Oberdieck, W.; Richter, B.; Zimmermann, P.: Verbesserung der Kompatibilität von Fahrzeugen auf theoretischer Basis durch Einsatz eines Optimierungsverfahrens Automob.-Ind. 26 (1981)
71. Dreyer, W.; Richter, B.; Zobel, R.: Handling, Braking, and Crash-Compatibility Aspects of Small Front-Wheel Drive Vehicles; SAE 810792
72. Taylor, H.: Strukturverhalten der Kraftfahrzeuge bei Aufprall, Kompatibilität zwischen Fahrzeugen, Agressivität gegenüber anderen Verkehrsmitteln und Fußgängern. Akten d. Eur. Symp. f. Kraftfahrzeuge (1975), bd. 1 Brüssel
73. Thomas, C.; Faverjon, G.; Henry, C.; Got, C.; Patel, A. PSA, FR, Hop. Raymond Poincare: Comparative study of 1624 belted and 3242 non-belted occupants: Results on the effectiveness of seat belts; 24. Conf. of the Amer. Assoc. for Automot. Med. 1980
74. Wagner, R.: Market related passenger car design to improve collision protection for "own" vehicle and "other" vehicle; 7. ESV-Conference, Paris 1979
75. Warner, C.Y.; Peterson, R.: Automobile-attenuator compatibility in 1985: Some designer guidelines; 54. Annu. Meet., Transp. Res. Board
76. BMFT-Studie: Technologien für die Sicherheit im Straßenverkehr, Oktober 76
77. Verformungsverhalten von Fahrzeugstrukturen bei Unfällen VDA-Schriftenreihe 22 AUTO UND SICHERHEIT, 1976
78. TÜV-Rheinland, Köln: Partnerschutz vor Selbstschutz. Maßnahmen zur Verbesserung der äußeren Sicherheit an LKW Lastauto Omnibus 55 (1978)
79. Entwicklung kompatibler Fahrzeuge; BMFT- u. BMI-UBA-Semin. 1979
80. Dt. Verkehrswacht, Bonn: Verkehrswacht-Umfrage zur Sicherheit in kleineren Autos: Sparsam, leicht, lebensgefährlich? Autohaus (1980)
81. Evans, Leonard: Car Mass and Likelihood of Occupant Fatality; SAE 820807
82. Bez, U.; Hamm, L.; Hoefs, R.: Repräsentativität von Bezugsfahrzeugen und Wirkungsfeld von Sicherheitsmaßnahmen; Status-Seminar BMFT 1981, Ulm
83. Ardoino, P.L.: Capability of the Car to Minimize the Global Damage in Road Accidents; Course on Vehicle Design and Safety, Amalfi, May 82
84. Bez, U.; Rauser, M.: Specific energy absorption and vehicle weight criteria to be observed in body development for improved occupant protection and compatibility; 8. ESV-Conference 1980, Wolfsburg

NHTSA Frontal Structures Research

CARL L. RAGLAND
National Highway Traffic Safety Administration

ABSTRACT

A methodology is being developed to assess fleet safety in the frontal crash mode. While many individual safety contributions have been made in improving safety potential of one vehicle, few studies have successfully predicted net safety gains which may be obtained by relatively minor vehicle changes (in some cases) applied to large portions of the fleet. This study addresses the methodology for predicting the net gain in safety benefit by manipulation of input vehicle/fleet parameters (stiffness, weight, fleet distributions, accident distributions), and occupant injury predictive analysis. The application of this methodology is the identification of optimized vehicle structural input parameters which result in minimum risk to the population as a whole.

INTRODUCTION

Even though protection of occupants in frontal crashes has been a major focus of safety efforts in recent years, frontal crashes still continue to present the largest risk to passenger car occupants. For instance, 50% of all passenger car fatalities and 53% of all light vehicle serious injuries (AIS $\geq$ 3) result from frontal accidents. These data are obtained from NHTSA's Fatal Accident Reporting System and from the National Crash Severity Study.

To investigate this problem, NHTSA frontal structures research is undertaking a systems approach quantitatively identifying problem areas, conducting parameter studies to optimize structural/safety design and performance parameters, and finally recommending countermeasures that would be most effective in a specific fleet environment.

The first step of this approach is identifying all pertinent factors which influence occupant risk. These factors include exposure factors and physical factors such as stiffness, crash pulse shape, intrusion, and vehicle interior geometric and restraint data, all of which will be derived from various data sources including but not limited to:

—accident data
—crash test data
—registration data
—fleet weight data
—analytical studies
—vehicle studies

The next step will attempt to assess the effect of these risk factors to determine the potential for occupant harm. This risk assessment will be accomplished using simple but valid trend predicting analytical techniques. These techniques will relate the risk factors and changes in risk factors to overall fleet risk which allows the final step to be accomplished.

The final step in the approach utilizes an accounting model which sums the risk potential for all input scenarios to determine the optimum physical parameters for any given exposure which minimizes occupant risk. The output of one such study is shown in Figure 1. This study shows that for the range of input parameters there exists a minimum harm level associated with stiffness for every theoretical crash pulse shape. This result is very important in indicating the need for optimizing stiffness. However, the sample output shown here is not relatable to the real fleet because the definition used for stiffness is not applicable to car-to-car collisions and the crash pulse shapes are too theoretical (not linked to specific cars). This output is useful, though, to predict expected results from a more refined study. This paper will discuss the efforts to refine a methodology to assess present and future fleets and determine expected safety improvements associated with fleet/vehicle changes.

RISK FACTOR

Data Collection

The first step in the research approach is the collection and compilation of data necessary for input to the accounting methodology. As a major source for crash test and vehicle data, including weight, stiffness, geometry,

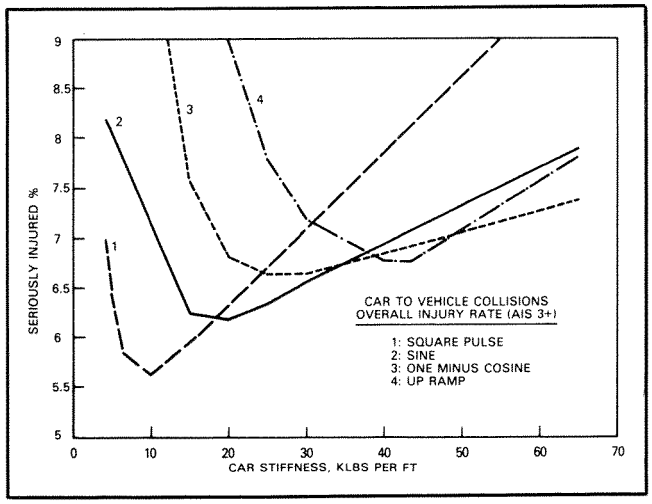


Figure 1. Injury frequency vs. stiffness by crash pulse shape.

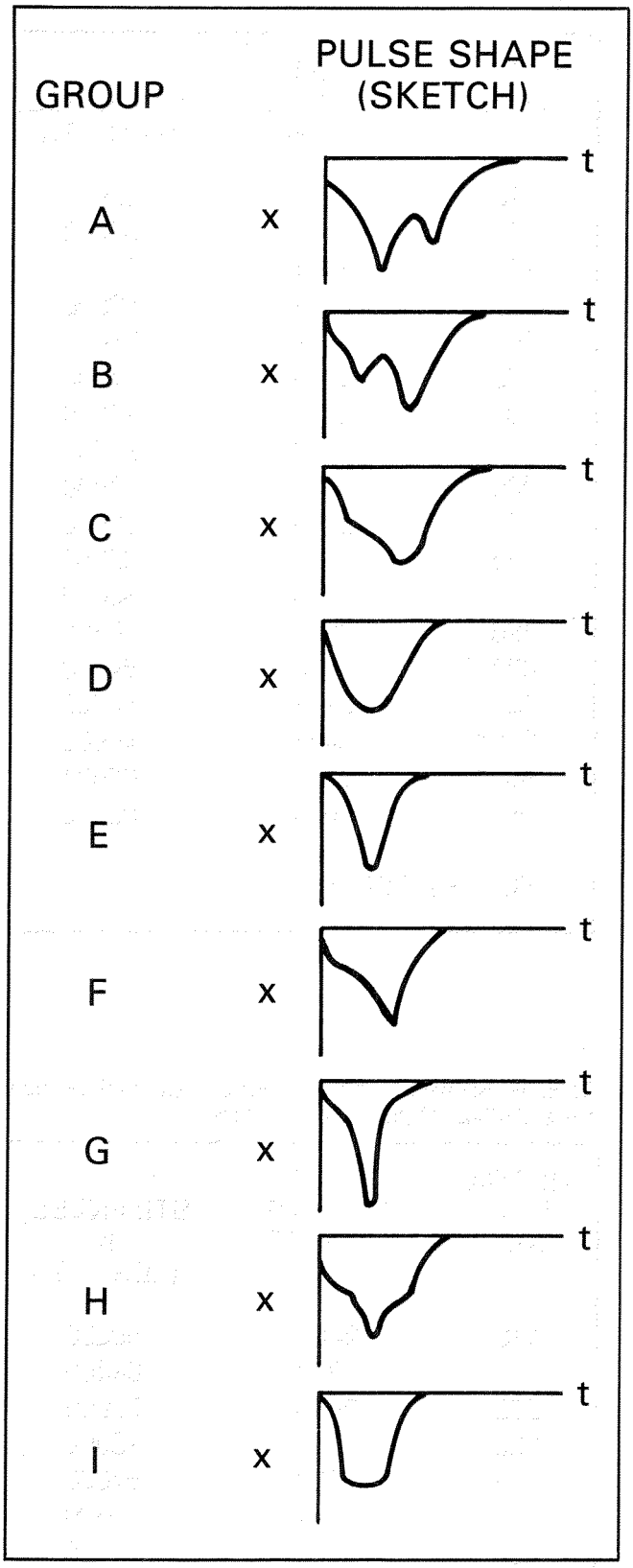


Figure 2. Generic crash pulse shapes.

etc., the NHTSA has collected in a data base system over 460 records of crash tests of various types performed over the past several years. Of these crash tests, approximately 240 include tests in which at least one of the vehicles were impacted with a predominantly frontal PDOF (principal direction of force). These records will be the primary emphasis of this study along with other necessary fleet properties, distributions of weights (current and projected), etc.

Collection and compilation of the crash test data are being performed to present the data in a format which is compatible with accident data. These data will be presented in tabular form showing distributions of delta V's, striking and struck car weights, collision types, and impact types. Comparisons will then be made with accident data to determine commonalities and voids in test data.

As shown in Figure 1 and in other research findings, crash pulse shape can have a significant influence on occupant frontal crash protection (1). Therefore one of the primary physical factors associated with occupant risk is crash pulse shape. This factor has been condensed from the 240 crash tests into 9 generic crash pulse shapes as shown in Figure 2 (2). These data will be useful as input to the accounting model for identifying one of the primary characteristics of the existing fleet.

From this sample of crash pulses it can be determined that, while variations of crash pulse shape are available, these variations may be narrowed down to perhaps 5 or 6 basic shapes. Future research work will concentrate on sales weighting these data to determine a representative fleet distribution.

Another structural parameter which can be linked to crash pulse shape is structural stiffness. Here stiffness is defined as the combination of factors influencing resistance to crash forces. Where specific stiffness is unique to each crash event, generally stiffness may best be derived from dynamic loads measured during a specified crash event such as a fixed load cell barrier test. The NHTSA has collected and compiled such force-crush curves using a NHTSA designed load cell barrier. This barrier, shown in Figure 3, is constructed of rigid supporting structure

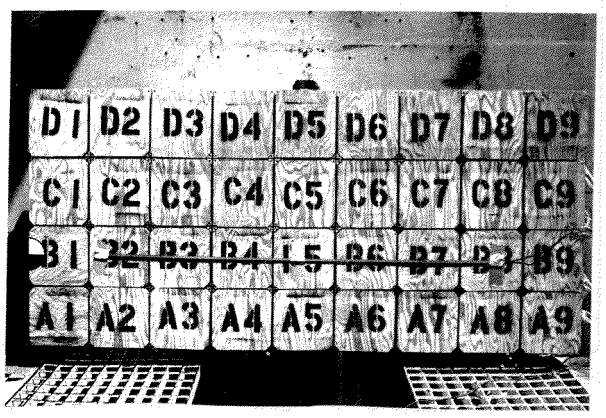


Figure 3. NHTSA load cell barrier face.

used to mount thirty-six, 50,000 pound capacity load cells, capable of measuring a 25,000 pound off-axis load when combined with a 25,000 inch pound moment. Extremely good data are being collected from this device. Integration of load-time histories indicates virtually no loss of load based on impulse-momentum balance. Additionally there is very negligible noise content in data.

Force-time data from the load cell barrier have been collected on a small sample of test vehicles. These data include approximately 14 model year 1980 cars, 12 model year 1980 cars, and 24 model year 1982 cars (1982 model year testing is currently in progress with approximately 10 model year 82 tests completed at date of writing). Utilization of these data has been primarily to determine stiffness of the crash tested cars and hence to extrapolate stiffness properties to the entire fleet.

A sample of the total load-time data digitally filtered at 300 Hz cut-off is shown in Figure 4.

Two secondary benefits have resulted from load cell barrier data. First, load data, unlike accelerometer data, have proven to have low susceptibility to noise and vibration. Therefore load-time data, can be used to "match" the best accelerometer response, when several redundant accelerometers are available in the vehicle compartment. Secondly, the actual structural response is measured with a high degree of precision. This allows assessment of repeatability of test car structures under similar test conditions. Load data, in this case, can identify structures that behave differently in tests due to manufacturing/ design changes, etc.

Complete load cell barrier data (load-time) are stored

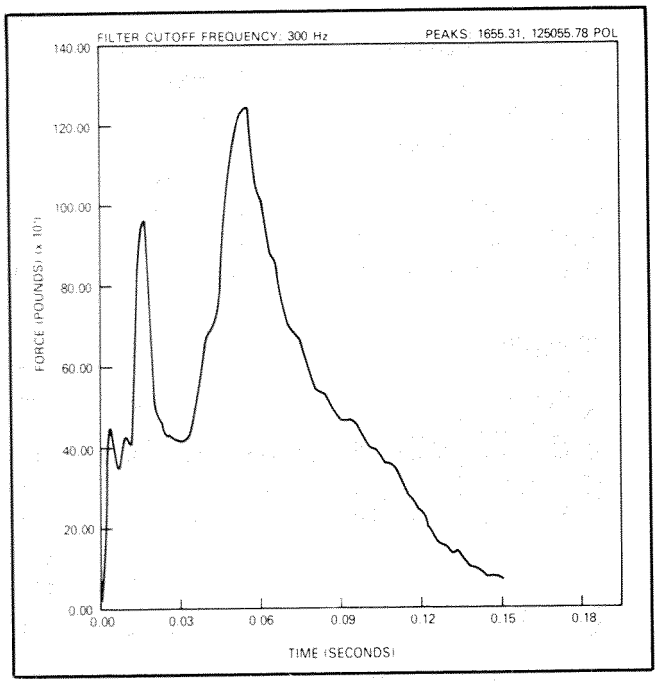


Figure 4. Load-time data filtered at 300 Hz. 1981 Mercury Marquis, 35 mph load cell barrier total force vs. time.

Table A. Stiffness comparison for 35 mph load cell barrier tests.

NHTSA TEST NO.	TEST VEHICLE WEIGHT	STIFFNESS, (LBS./FT.)
118	3066	55900
119	2404	69200
122	2314	58400
137	3714	80900
194	2707	75000
273	2456	77000
333	2214	73000
334	3417	87800
365	2650	57000
380	3965	52000
386	3930	93882
425	4615	89000
426	2641	60300
427	3880	84600
428	2767	58500
999*	3428	45600
999*	3060	65581
999*	2584	88000

* TO BE ASSIGNED

Table B. Stiffness comparison for 35 mph load cell barrier tests, 2100-2700 pound weight class.

NHTSA TEST NO.	TEST VEHICLE WEIGHT	STIFFNESS, K (LBS./FT.)
119	2404	69200
122	2314	58400
273	2456	77000
333	2214	73000
365	2650	57000
426	2641	60300
999*	2584	88000

* TO BE ASSIGNED

Table C. Stiffness comparison for 35 mph load cell barrier tests, 2700-3300 pound weight class.

NHTSA TEST NO.	TEST VEHICLE WEIGHT	STIFFNESS, K (LBS./FT.)
118	3066	55900
194	2707	75000
428	2767	58500
999*	3060	65581

* TO BE ASSIGNED

in the NHTSA data base. Table A presents one form of comparing these data using the definition that stiffness, K, is the maximum force divided by the dynamic crush which occurs at the same time as that maximum force value. While this straight line force-crush is not totally representative of overall stiffness, it serves as a reasonable approximation in most cases for classifying the selected test cars by stiffness. A weight breakdown of this small sample of data is presented in Tables B through E. Future attempts will be made to expand this sample size to include a cross section of cars in terms of stiffness. Then, association of crash pulse shapes with stiffness will be used as input to the accounting methodology to be described in the following section.

Other data required to analytically assess the frontal crash environment include interior geometry of occupant compartments, fleet weight distributions for current fleets as well as projected fleets, closing velocity frequency distributions, and relationships between occupant injury severity with both intrusion and occupant impact speed (with interior vehicle components). Interior geometry can

Table D. Stiffness comparison for 35 mph load cell barrier tests, 3300-3900 pound weight class.

NHTSA TEST NO.	TEST VEHICLE WEIGHT	STIFFNESS, K (LBS./FT.)
137	3714	80900
334	3417	87800
427	3880	84600
999*	3428	45600

* TO BE ASSIGNED

Table E. Stiffness comparison for 35 mph load cell barrier tests, over 3900 pound weight class.

NHTSA TEST NO.	TEST VEHICLE WEIGHT	STIFFNESS, K (LBS./FT.)
380	3965	52000
386	3930	93882
425	4615	89000

most simply be expressed as a frequency distribution of the shortest distance between an occupant's head or chest and interior components. An example is shown in Table F. More sophisticated dimensions may be required for more detailed occupant studies. Fleet distributions are available from many sources such as fuel economy data for projected fleets, Polk Data, and accident data sources such as NCSS (National Crash Severity Study) and NASS (National Accident Sampling System). One compilation of 1985 weight projections is shown in Figure 5 while overall NCSS passenger car weight distribution is shown in Figure 6 (3,4). Frequency of closing velocity distributions and accident types is obtained also from NCSS and NASS data along with occupant injury relationships. It is anticipated that exposure data as currently obtained will not significantly be altered in future fleets, except weight-frequency distribution changes. Other data being compiled for possible input to the analytical accounting model are interior data necessary to exercise an analytical 2-D or 3-D occupant model. These data may include input for intrusion in the model, various occupant sizes, various seating positions, etc. It is anticipated that the more complex approach to occupant modeling will not, however, be a part of the initial research effort.

ASSESSMENT OF RISK FACTORS

The primary factors which are related to risk and are practical to control by vehicle designs are vehicle structures and occupant protection countermeasures. Since nu-

Table F. Occupant spacing frequency distribution.

X_n (INCHES)	F (%)
6	34
12	50
18	8
24	8

X_n=MINIMUM SPACING BETWEEN OCCUPANT AND INTERIOR SURFACE

F=FREQUENCY OF OCCURRENCE OF A GIVEN OCCUPANT SPACING

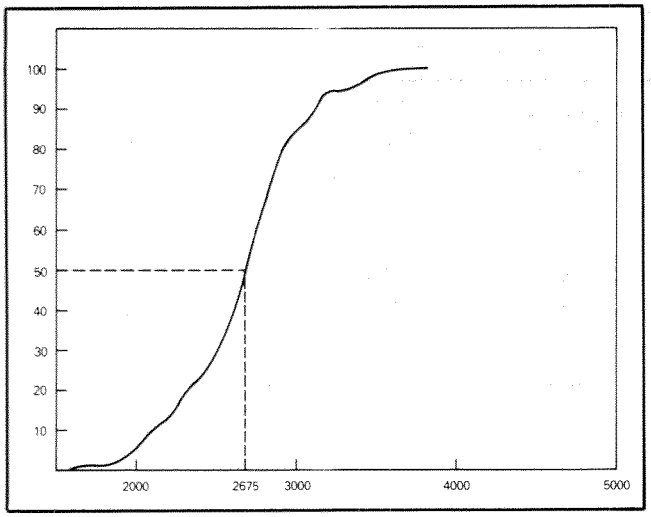


Figure 5. 1985 passenger car weight distribution by sales.

merous other studies have addressed occupant protection countermeasures in the vehicle interior, this paper will concentrate on assessing factors relating to vehicle frontal structures for design optimization purposes. Assessment of occupant risk requires understanding of general effects on the occupant due to changed structural parameters. A simple occupant model will be employed.

The direction for assessment of structures/occupant response is to adequately predict trends of occupant protection by varying structural parameters. For instance, predictions of occupant harm for unrestrained occupants will be based on the difference between the velocity of a free flying single mass object representing an occupant and the compartment velocity at the time the one-mass occupant contacts with interior. Time of interior contact is determined based on the difference between the integration of the occupant velocity and the compartment

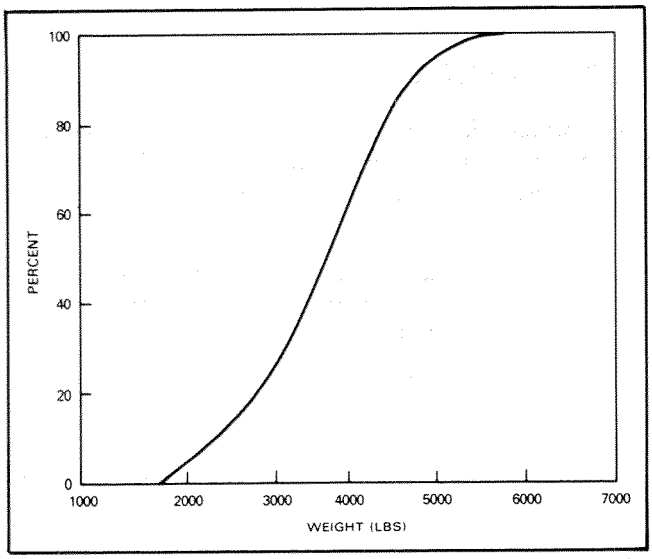


Figure 6. NCSS passenger car weight distribution.

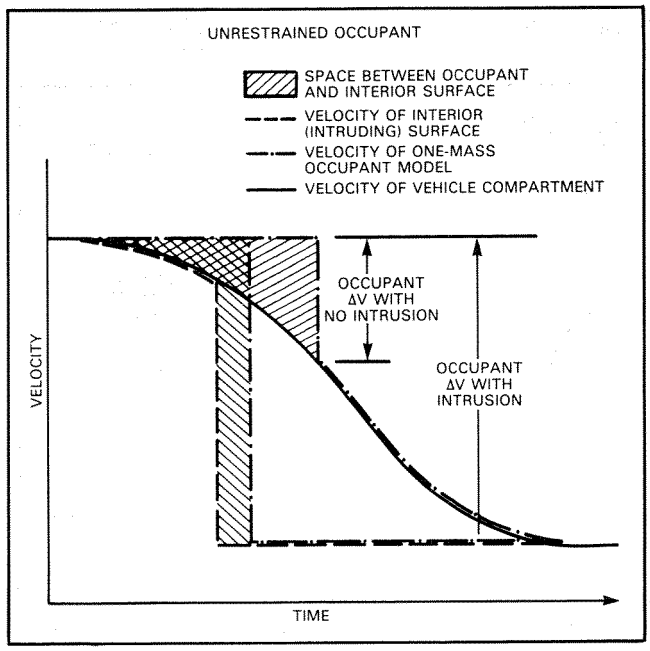


Figure 7. Unrestrained occupant velocity-time relationships.

velocity. Figure 5 shows the various occupant velocities which will be used to assess occupant harm. Likewise determination of contact speed is determined (if it occurs) for a restrained occupant as shown in Figure 6. Additionally, intrusion is considered very simply as a rigid coupling between the front bumper and the intruding surface (dash, steering assembly, etc.). Therefore, when intrusion begins it is assumed the intruding surface immediately undergoes the entire delta V of that crash event as shown by the theoretical representation of the interior intruding surface velocity profile in Figures 7 and 8. Furthermore it has been experimentally shown from crash test data that intrusion begins at approximately the time the crush reaches 80% of the value of the measured

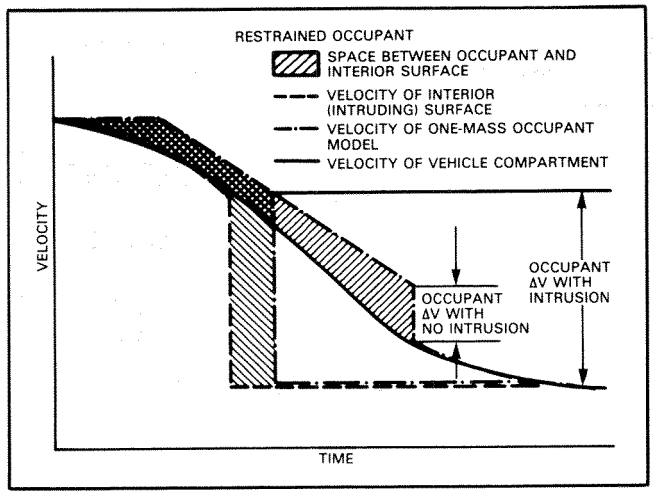


Figure 8. Restrained occupant velocity-time relationships.

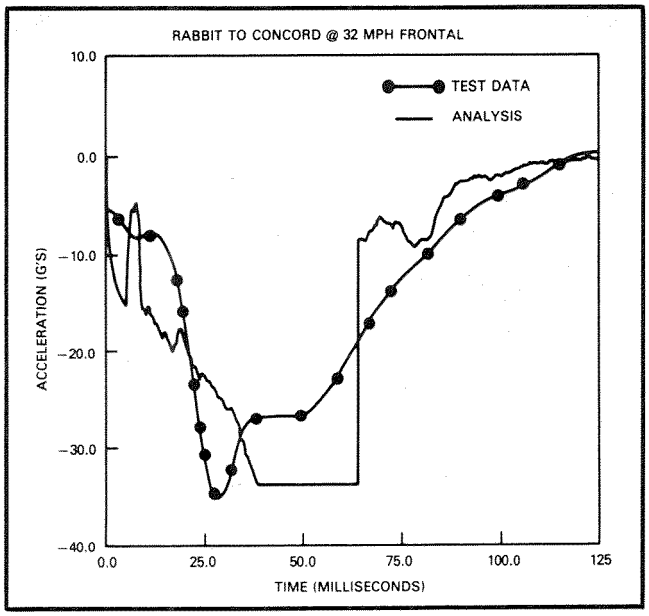


Figure 9. Acceleration time history for Rabbit from Rabbit-to-Concord crash test and from analytical prediction.

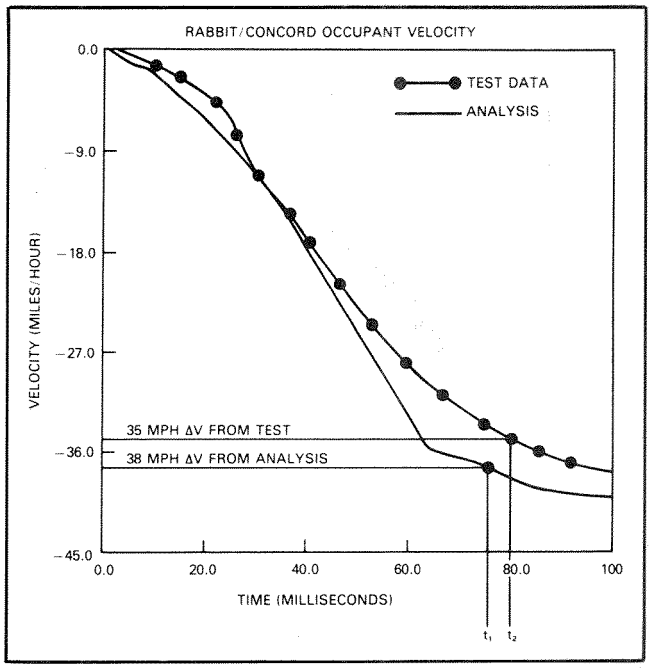


Figure 10. Velocity-time history of theoretical one-mass occupant, test vs. prediction.

distance between the engine and the front bumper. These distances on existing cars in the crash test data base may be obtained and assessed relative to occupant safety.

While these occupant injury relationships are simply conceived and are not expected to accurately predict crash protection potential of an individual vehicle in the fleet, it is expected that general "good" and "bad" structural characteristics (crash pulse, stiffness, engine placement) of individual vehicles and vehicle fleets can be identified.

To produce the multitude of crash pulses that can be generated from various car-to-car, object, etc., collisions an analytical crash model was developed. This analytical tool is used to predict occupant compartment response. By using this method, vehicle crush as well as time occurrence of crush is predicted. Therefore, all of the simplified occupant parameters as previously described can be defined. An example output is compared to actual crash data for a car-to-car collision in Figures 9 to 12. Note this shows the most difficult prediction in which two cars of incompatible structures collide head on. Particularly encouraging is the reasonable accuracy of the dynamic crush, see Figure 12. Compared parameters are presented in Table G. Note from Figures 11 and 12, intrusion begins substantially before the occupant would have contacted the interior surface (without intrusion). Therefore, as can be seen by referring to previous Figure 7, the occupant undergoes the total vehicle delta V as reported in the table.

The basis of this crash analysis is a comparative method by which structural crushing forces generated in two-car crash tests are compared at each time increment of the crash event to determine how each car is crushing due to its lower force level and to predict the resulting crash pulse. Part of the computational software assumes a constant force crush of the "weaker" car when its peak crush is reached. This plateau can be seen in Figure 9. Adjustments are then made to the duration of impact to obtain a theoretical impulse/momentum balance. Refinement of this methodology is still ongoing to validate results against crash data in all impact conditions. Also consideration is being given to the question of whether

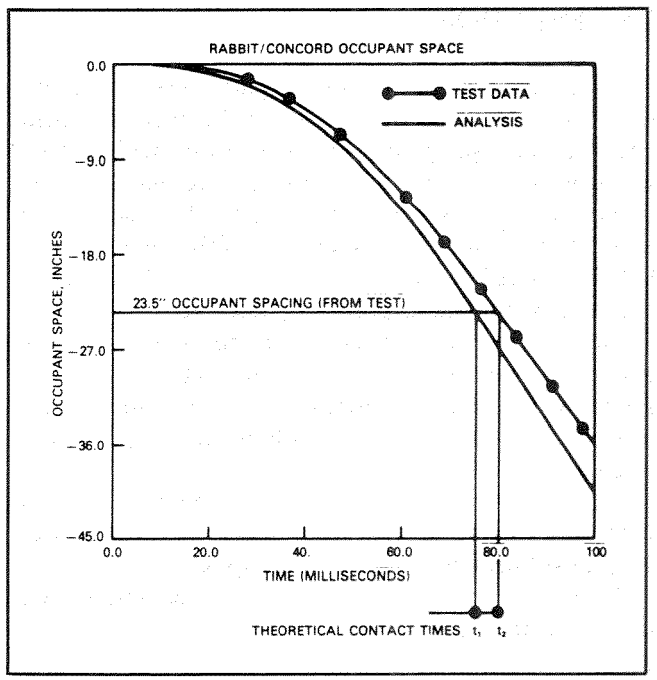


Figure 11. Rabbit unrestrained occupant spacing vs. contact time, test vs. prediction.

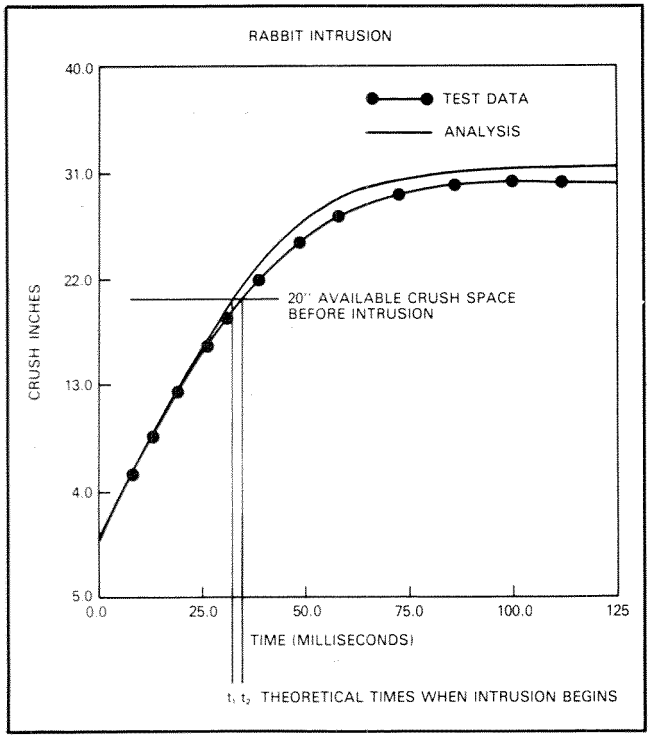


Figure 12. Rabbit displacement-time history to predict intrusion, test vs. prediction.

accelerometer generated force data can be used rather than currently used load cell data which have restricted availability.

PARAMETER STUDIES AND OPTIMIZATION

A methodology is currently being developed to account for all of the above parameters and predict their combined effect on occupant harm. The basis of this methodology was developed by Dr. A. C. Malliaris. A sample of the output generated was shown in Figure 1. Results were encouraging from the initial exercise of the methodology, but several refinements are required to include "best" available input data as previously discussed.

One of the major refinements to the model replaces empirically derived equations to predict occupant response and separate equations to predict crush and intrusion with the structural crash model as previously discussed.

Other refinements to the accounting methodology will include the ability to analyze a nonhomogeneous fleet of varying stiffness and crash pulse shapes.

As far as input refinements, all input parameters are being validated and changed as necessary using latest and best available data. One of the major refinements is in the area of structural data, which includes stiffness properties and crash pulse shapes. Other areas include weight, crash velocity, and occupant injury data as previously discussed.

EXPERIMENTAL APPROACH

Once an analytical method successfully predicts trends for improved structural crash performance, an experimental technique needs to be developed to verify results of this prediction. Currently the accepted method of evaluating crashworthiness is by flat rigid barrier. While this method has proven valuable in advancing state-of-the art in crashworthiness, particularly with regards to restraint development, it has done very little to advance improvements in compatibility as evidenced by extreme variations in stiffness (Table A). Shortcomings in assessment of crashworthiness and compatibility using the flat rigid barrier are twofold. First of all the intrusion aspect of crashworthiness is not evaluated on a comparable scale. This assessment can be readily visualized when one considers that in barrier crash testing, intrusion is proportional only to kinetic energy, meaning intrusion could be just as severe for large and small cars alike. In the accident environment, however, it is recognized that intrusion is typically a greater problem for small car occupants. Also, accident data show greater intrusion than crash test data at comparable delta V's. This latter observation is due to the crash environment of usually less than full frontal engagement resulting in lower acceleration (force) and greater extent of crush. The second shortcoming of the rigid barrier is the assumption that actual objects crashed into by a car will have the same force-crush properties as the car or will be non-yielding.

This assumption, while reasonable if stiffness of the car is "average," may result in ineffective restraint designs if the structural properties of the car versus those of the fleet are not considered. Note that car-to-car force inter-

Table G. Comparison of Rabbit data from Rabbit-to-Concord test and analysis.

	TEST DATA	ANALYTICAL SIMULATION
PEAK ACCELERATION	35 g's	34 g's
VELOCITY CHANGE OF OF VEHICLE	42 MPH	42 MPH
MAXIMUM CRUSH, RESIDUAL	28.6 INCHES	28 INCHES
VELOCITY WHEN OCCUPANT HITS INTRUDING SURFACE	42 MPH* (CALCULATED)	42 MPH*
VELOCITY WHEN OCCUPANT HITS NON-INTRUDING SURFACE	35 MPH (CALCULATED)	38 MPH

* SAME AS ΔV

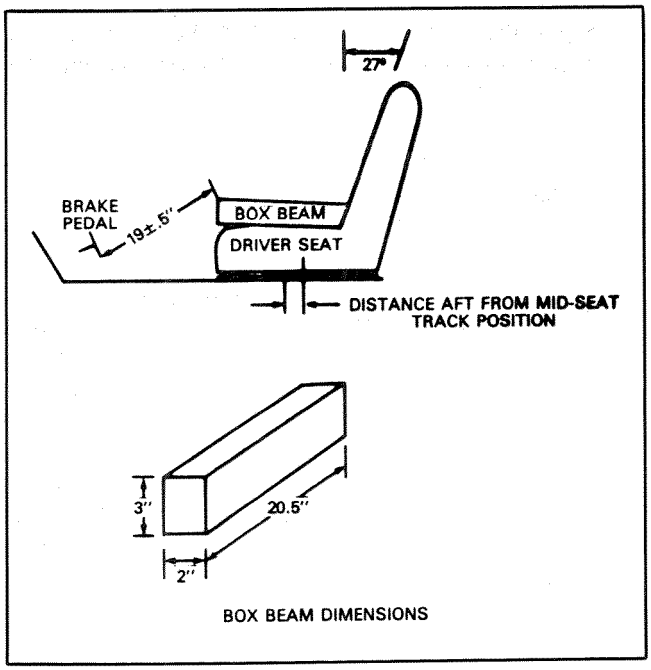


Figure 13. Seat positioning method used in deformable moving barrier testing.

actions are emphasized here because only 40% of the AIS $\geq$ 3 injuries are associated with fixed object collisions with a very small percentage of that number being a truly rigid, flat surface. The remaining 60% frontal AIS $\geq$ 3 injuries result from car-to-car collisions with a relatively large share, especially the more severe crashes, associated with front-to-front collisions. Thus the largest percentage of accidents, in which peak accelerations approach the peak dynamic force capability of the structure (divided by the mass), are accidents involving reasonably symmetric front-to-front collisions.

Therefore the crash environment initially chosen for experimental structure crashworthiness and compatibility evaluation, is one that creates maximum acceleration and maximum intrusion under a delta V environment which is inversely proportional to test car weight. Intrusion is also intended to be inversely proportional to structural stiffness of the test car, unlike the rigid barrier environment, in which intrusion is proportional to kinetic energy or energy dissipated by the cars structural collapse.

The means of testing cars in this crash environment is performed with a deformable moving barrier. Incidentally, load cells are mounted behind the deforming element to enhance knowledge of the structural behavior of the test car. This barrier is constructed of aluminum honeycomb and is the same barrier developed for side impact testing (5). It is designed to absorb energy roughly equivalent to that of a 1600 pound car impacting a rigid barrier at 35 mph. The purpose of this design is to force larger cars to absorb more energy for compatibility assessment and intrusion assessment.

Results of dummy response parameters using Part 572 dummies are shown in Table H. To eliminate variability in these tests the restraints were fixed at the "D" ring, thus eliminating restraint spool-out. Also for comparative analysis the seats were placed identically, as shown in Figure 13, to represent an intuitively average seating position. One more deformable barrier test is planned in the near future using a Fiat Strada. Analysis of the data has not been completed and will be presented at a later date.

CONCLUSIONS

This study is based on the premise that occupant risk is dependent not just on the singular properties of a vehicle but on the properties of the entire fleet. Research studies have shown that occupant response is indeed related to crash pulse shapes. It may also be rationalized that crash pulse shapes are dependent upon stiffness and on the combination of stiffness in car-to-car events. Therefore occupant response is also dependent on stiffness as it indirectly affects the crash pulse shape. Stiffness also affects the occupant harm environment directly by either preventing or allowing intrusion, particularly in car-to-car collisions.

NHTSA research will continue to quantify the effects

Table H. Dummy response using frontal deformable moving barrier.

CAR	TEST TYPE	HIC		CHEST G's 3 MSEC		FEMUR LOADS			
						DRIVER		PASSENGER	
		DRIVER	PASSENGER	DRIVER	PASSENGER	LEFT	RIGHT	LEFT	RIGHT
CITATION	DMB	483	418	40	30	255	750	1700	300
VOLVO	DMB	352	361	29	35	500	2000	200	750
MARQUIS	DMB	313	269	27	28	800	600	600	600
CONCORD	DMB	806	523	58	38	1825	1100	675	525
CUTLASS	DMB	1101	751	48	35	520	225	1585	1800
RABBIT	DMB	2250	707	59	39	550	400	650	400

of these and other parameters that affect occupant response. Finally, this research is intended to identify the structural properties which are optimal for occupants protection in the real world environment. Initially the effort will consist of a simplified analytical approach. Follow up studies may employ more sophisticated techniques such as the Fiat Methodology (6) or the Safety System Optimization Model.

REFERENCES

1. Cohen, D.S., Jettner, E. and Smith, W.E., "Light Vehicle Frontal Impact Protection," SAE Paper No. 820243, Warrendale, Pennsylvania, February, 1982.
2. Dimasi, P., "Generic Crash Pulse Study and Preliminary Data on Characterization of Generically Similar Kinematic Response in X vs X Plane," (A Progress Report) Transportation Systems Center, September 1982.
3. Segal, D.J. and Miller, P.M., "Methodology for Recommending Side Impact Moving Barrier Weight," October 1979, Progress Report, MGA Report No. 69-003-V-1
4. Jatras, K. and Carlson, W., "Frequency Distributions of Passenger Cars by Weight and Wheelbase by State—July 7, 1976," Report No. DOT-HS-803-382, June 1978.
5. Davis, S. and Ragland, C., "Development of a Deformable Side Impact Moving Barrier," Eighth International Technical Conference on Experimental Safety Vehicles, October 1980, Wolfsburg, Germany.
6. Shaw, L. M. and Ragland, C., "Application of the Fiat Methodology for Characterizing Vehicle Structural Responses in Side Impacts" to be published in the proceedings of the Ninth International Technical Conference on Experimental Safety Vehicles, November 1982, Kyoto, Japan.

Frontal Crash Protection in a Modern Car Concept

RUNE ALMQVIST, HUGO MELLANDER, MAGNUS KOCH

Volvo Automotive Safety Centre Volvo Car Corporation

ABSTRACT

Volvo's Safety Engineering Philosophy is described in detail starting with Volvo traffic accident investigations as one of the most important inputs to the safety characteristics specified for a new Volvo car. How the safety characteristics are transformed to measurable properties in laboratory environment is then explained and exemplified. The car specification is further broken down to system and subsystem specifications suitable and understandable to the engineer at the drawing board. The engineering follow-up procedure, including Crashworthiness Design Review Meetings and at the end certification tests and production control tests, is discussed.

How variations in test results affect the engineering procedure and methods to set engineering limits to be used during the different design phases are discussed.

How this Safety Engineering Philosophy is implemented into the development of a new Volvo car is then described step by step and exemplified by different technical solutions and test results.

INTRODUCTION

With the Volvo Safety Engineering Philosophy as a background this paper describes how the crashworthiness characteristics at the very first beginning of a project are built into a new car and how this is controlled through the total development programme.

VOLVO SAFETY ENGINEERING PHILOSOPHY

One of the primary characteristics of a Volvo car has for a long time been safety and with the safety characteristics Volvo has always meant safe transportation in the real traffic environment.

Volvo Safety Engineering Philosophy can be explained by a circle as in Figure 1.

As safety in the traffic environment is the primary goal, it is important to know the real performance of our cars in actual accidents.

Accident Analysis

Since 1965 Volvo has carried out traffic accident research on Volvo cars and the knowledge from this research is used to set up our own safety requirements.

Volvo's Traffic Accident Research consists of two main parts

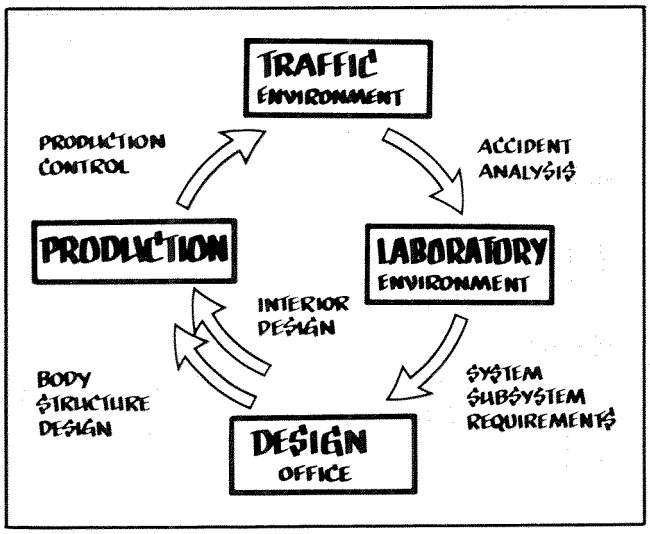


Figure 1. Volvo Safety Engineering Philosophy.

—multidisciplinary accident investigations
—data collection and statistical analysis

The multidisciplinary accident team is on call round the clock, seven days a week. All accidents with occupant injuries in a Volvo car, truck or bus are investigated. On the scene of the accident, the investigator looks for all information which can be of importance during his later analysis. This analysis consists of finding the cause of the accident and the consequences to the occupants and the vehicle. The medical expert of Volvo's investigation team gets in touch with his colleagues at the hospital to which the injured persons have been taken. With the help of data from the vehicle and information concerning the sustained injuries, it is possible to relate the pattern of injuries to the type of impact which caused them.

To get a material large enough to be used in a statistical analysis Volvo's unique insurance system has for a long time been used. All Volvo cars sold in Sweden are covered by a three-year motor vehicle damage warranty. This damage warranty is administrated by Volvo's insurance company. Through this motor vehicle warranty system Volvo has access to all data concerning the accidents. Each year, about 45,000 such accidents are reported to the warranty department. About 5,000 of the more seriously damaged vehicles are inspected by Volvo's staff of 12 damage assessors who are placed throughout the country. The basic information for our statistical accident research comes from this group of serious accidents.

Our own data in combination with data from different accident data files from all over the world are the basic background for setting our priorities.

Laboratory Requirement

The first step in the engineering procedure is to transform the accident scene to a controlled laboratory environment. The complex accident has to be transformed to a test which is repeatable and reproducible. Examples of these tests are frontal impacts into a rigid barrier, movable deformable barrier for side collisions and rollover simulations.

The occupants in the car have to be simulated with test dummies. These dummies are of course not in every detail copies of the human being but they are anthropometric and anthropomorphic. Dummies of different sizes are available (such as 5th percentile female, 50th percentile male, 95th percentile male and many different sizes of child dummies). Several different injury criteria are connected to the dummies, e.g., head injury criterion, chest injury criterion, femur injury criterion. These criteria have been found through biomechanical research. Within our function analysis staff Volvo has an expert in biomechanics who monitors this research in detail.

Engineering Requirements

Having the functional laboratory requirements on the complete car is not enough. The car must be divided into various systems and the system into various subsystems. With this technique the complete car requirement for different collisions could be broken down into a set of system and subsystem requirements which can be checked in laboratories and which are understandable to the draftmen and engineers.

The requirements on systems and subsystems form the basis for our development technique within the safety engineering procedure. The two major systems are the body structure system and the interior system. The body structure system covers the "body in white" and drive line (engine-transmission) and the interior system covers all the interior of the car such as instrument panel, steering wheel, seats and safety belts.

The requirements for the structure system are built up around a measuring technique using barrier tests, "body tests" and component tests. During the entire development procedure analytical tools such as structural mass/spring models and finite-element calculations are used to further optimize the mechanical engineering.

Two very important requirements for the structural system are intrusion and deceleration characteristics in the different crash tests. The reason is that these characteristics form the inputs to the interior system. The basic development technique for the interior system is a crash simulator in which the intrusion and deceleration can be reproduced. In this way the development of the interior is not depending on the possibilities to crashtest complete cars. As for the structure system the interior system uses several subsystem tests and in parallel calculations in mathematical models are made.

After a couple of loops between the structure and interior engineering departments in which an optimization of performance, weight and cost is done, the complete

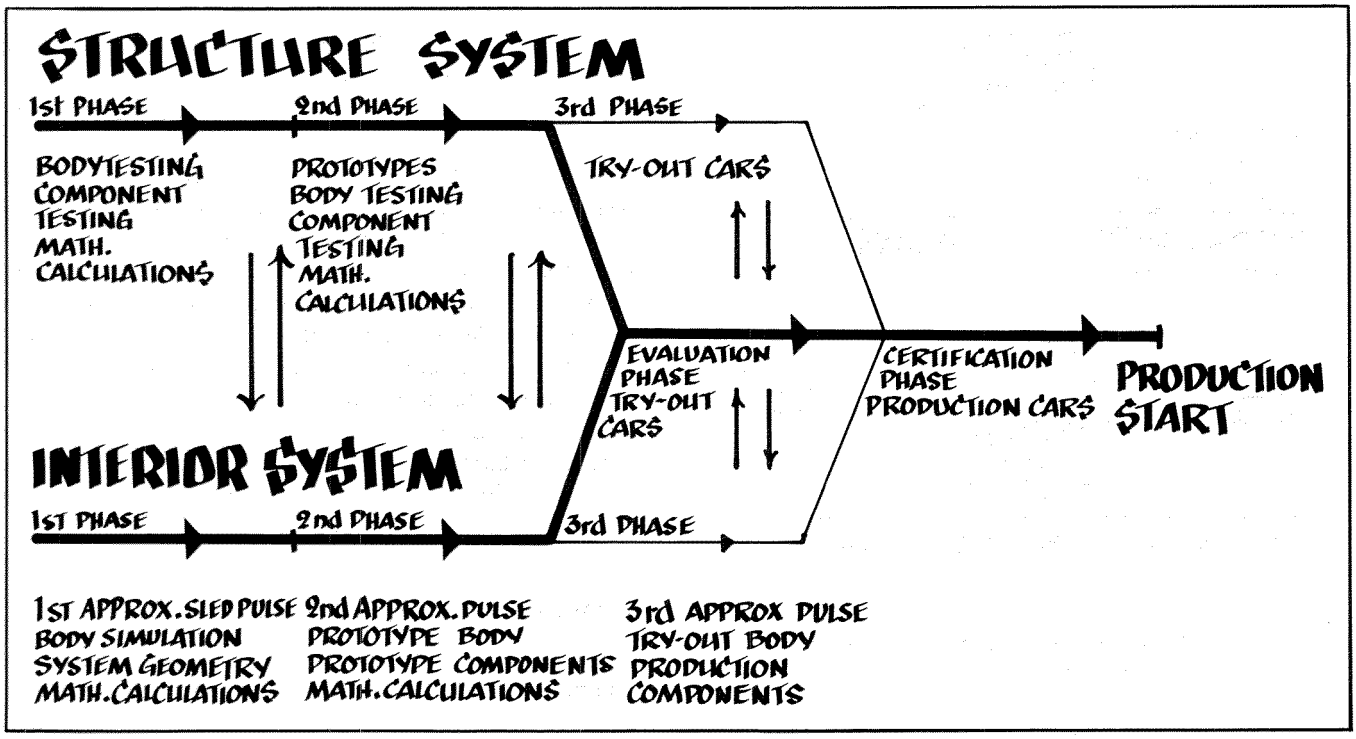


Figure 2. Development cycle for a new car.

car is ready for the evaluation and certification phase. In this phase complete cars (try-out and preproduction cars) are tested with the specified test methods and controlled against the specified criteria. A few extra loops back to structure and interior system may be necessary during the evaluation phase. Certification tests against legal requirements are then made, sometimes with representatives from the authorities witnessing the actual tests. Figure 2 shows a typical development cycle for a new car.

Production Control

During the development many different types of documentation are produced to ensure the production quality. A special documentation system for Vital Safety Parts (VSP) is used to

- —guide product engineering, manufacturing and assembly in accordance with government requirements
- —demonstrate compliance with government requirements
- —limit the number of vehicles affected by recall action in case of non-compliance or safety defect
- —limit product liability exposure and demonstrate that due care has been exercised

During production control many systems and subsystems (e.g. safety belts, windshields, seats, sunvisor) are tested and complete cars are taken as samples for crash tests.

The circle (see Figure 1) is closed and the new car is ready for the actual traffic environment. The Volvo Traffic Accident Research can start its investigations to evaluate the safety performance and to gain more knowledge for further improvements.

FRONTAL COLLISION PERFORMANCE FOR THE NEW VOLVO 760

The above described engineering philosophy will now be repeated and the special considerations during the development of the new Volvo 760 will be accounted for.

From all international traffic accident statistics as well as our own (refs 1, 2) it is obvious that frontal collisions are the type of collision with the highest number of accidents as well as the highest total cost for the society.

This has since a long time been recognized by Volvo and since the early fifties Volvo has gradually introduced different kinds of technical solutions to improve frontal crash protection (ref 3). When the work to specify a new Volvo for the eighties started, one of the highest priorities was to engineer a car with outstanding performance in frontal collision.

Test Method

The first step in our safety engineering procedure was to transform the overall specifications to functional requirements measurable in laboratory environment. Different safety regulations have since a long time used impacts against fixed barriers as their test procedures. Of course these test procedures are very simple simulations

of actual accidents and must be combined with careful analysis by experienced test engineers as well as by accident investigators. To limit development cost it was nevertheless decided to use these procedures (impact against a fixed barrier 0°, ± 30°) as the main laboratory tests as they must be used in the certification phase. It was decided to test at 35 mph.

Test Dummies

What type of dummies to use was the next decision to be taken. During the development of the Volvo 240/260 most of the tests were made with the Part 572 (50 percentile) male dummy. From our own experiences (ref 4) as well as others (ref 5) it is obvious that the total measurement chain with a dummy as "sensor" is a very complicated one and large variations in test results are to be expected. Careful analysis of test signals together with studies of the behaviour of the dummy during the test must be used to overcome the shortcomings of the dummy. As no other well documented dummies were available the Part 572 dummy was chosen.

Injury Criteria

The conventional measurements to be taken in the dummies are head and chest acceleration and femur forces. From these readings special injury criteria such as HIC, SI, Max Chest acceleration etc. can be derived.

In spite of heavy criticism the criteria stipulated in FMVSS 208, namely HIC, peak chest acceleration (3 ms) and maximum femur forces, are frequently used.

The protection levels of these criteria, HIC 1000, 60 g and 2250 lbf (10 kN) respectively have also been questioned, in particular the level of the HIC value. Patrick et al. (ref 6) suggested in 1974 that HIC of 3000 was below the acceptable limit and Walfish et al. (ref 7) recommends a tolerance limit of 1500.

To have consistency with all our previous experimental work it was nevertheless decided to use HIC 1000, chest acceleration 60 g and femur force 10 kN as protection levels.

During later years the problem of detecting submarining or penetration of lap belt into the abdomen has been focused. Our experience is that an optimal restraint system is heavily depending on the performance of the seat. One way to evaluate this performance is to measure submarining or submarininglike behaviour. Even if submarining is not a great problem in real life the benefits of a good support from the seat cushion in experimental work have been documented by several authors (refs 8–10).

Transducers on the iliac crest were therefore used in combination with high speed film analysis to evaluate the performance of the belt system.

Vehicle Related Criteria

Vehicle criteria were also set up, such as FMVSS 212 Windshield Retention, FMVSS 219 Windshield Zone Intrusion, and FMVSS 301 Fuel System Integrity.

ENGINEERING METHODOLOGY

System and Subsystem Requirements

Having the functional requirements on the complete car was not enough. The draftsman at the drawing table cannot design for example a front side member only knowing that certain injury criteria in a dummy should be below a specified level. The car must be divided into various main systems and the main systems into various subsystems. For the frontal collision two main systems are body structure system and interior system (Figure 3).

The body structure system covers the "body in white" and driveline and the interior system covers all the interior such as instrument panel, steering wheel, seats and safety belts.

By using mathematical modelling technique, structural mass/spring models, finite element calculations as well as different models of occupant simulations, the complete car functional requirements were broken down into requirements for the two main systems.

Body Structure System

The body structure system was specified for example by body deceleration curves for 0° and 30° barrier tests, intrusion limits for different parts of the body such as floor pan, instrument panel and steering wheel intrusion and vertical movement. These requirements formed an

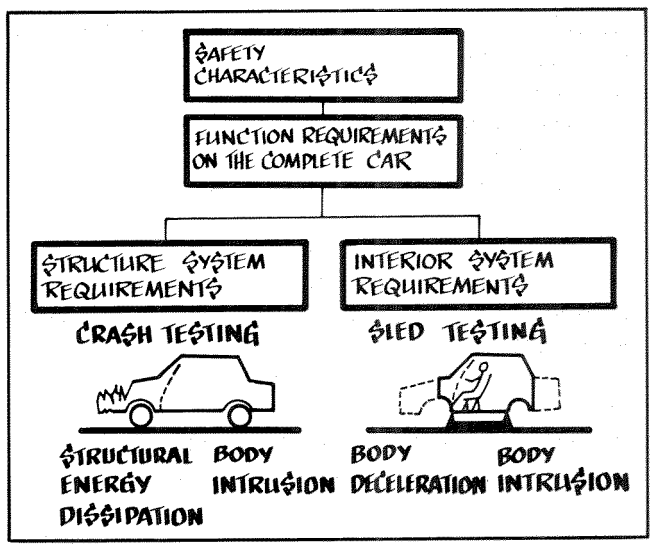


Figure 3. Body structure and interior system engineering methodology.

input to the body engineers for a further procedure broken down into subsystem requirements.

These systems and subsystems requirements were then controlled with test techniques such as component testing, subsystem testing, "body tests" and prototype tests. The "body test" is a technique used during early stages of development when no prototypes are available. By taking an existing car body and replacing specific parts in front of the A-pillar with prototype body concepts early test results such as force/deflection curves can be obtained. Our experiences from these body tests are that they are very useful both when different body concepts are to be evaluated as well as during the process of optimization between the structure design and material selection (ref 11).

Interior System

For the interior system the barrier test requirements are broken down to a sled test deceleration curve (the same as the body deceleration curve) and intrusion limits for body and interior parts such as the instrument panel and the steering wheel.

These requirements are the inputs to the interior engineering process which uses a HYGE crash simulation sled as an evaluation tool. From our early experiences of the use of the HYGE sled a good correlation between barrier tests and their simulations on the sled can be achieved at test speeds up to 30 mph (ref 12). Testing at higher velocities has however shown the need of further development of the simulation technique. Due to the higher test speed the body deceleration characteristics also in the vertical direction (pitch) and dynamic intrusions of body and interior panel including the steering wheel play an important role for the results in the dummies. Different techniques are used (max intrusion, intrusion at contact between dummy and interior, pitch simulations) but still much development has to be done to get an optimal simulation at speeds higher than 30 mph. In the meantime careful evaluation of test results from sled tests and a detailed comparison with results from barrier tests must be done during the development process. The importance of not being lost in these highly simplified simulations of actual traffic accident is obvious. For that reason our traffic accident analysis experts are involved also in the test evaluation process to ensure that not only good test results but also good performance in accidents will be achieved.

During both the structure and the interior engineering process mathematical calculations are used to back up the engineering and test work. Mathematical calculations have proven to be very helpful in concept evaluations and parameter optimizations.

The body structure and interior systems are developed in parallel during the early phases of a complete car project (see Figure 2). Several loops between the two systems are done in which performance, weight and cost are optimized. During the complete car evaluation phase tryout and preproduction cars are tested with specified test methods and controlled against specified criteria. A few extra loops back to the structure and interior systems may be necessary.

The number of complete cars crashed during the development of the Volvo 760 have been 50 and added to that around 70 body and component tests and 150 sled tests.

Crashworthiness Design Review Meeting

The safety characteristics influence more or less all the systems and subsystems in the car and consequently all departments in the organization have to be involved. Therefore a special steering committee meeting "Crashworthiness Design Review Meeting" was formed to control the implementation of the Volvo Safety Engineering Philosophy into the design process.

The responsibility to chair these meetings was given to the Crashworthiness Functional Analyst. The Functional Analyst is a person in the organization responsible for converting the crashworthiness characteristics set by the Product Planning Department into Functional Requirements of the complete vehicle.

In the case of crashworthiness the Functional Analyst is also responsible for the Volvo Automotive Safety Test Centre including Volvo Traffic Accident Research which ensures that neither test result nor actual traffic accident results are neglected during the development process.

The meetings have taken place every month and participants have been all of the managers in the line organization including representatives for Engine and Transmission Engineering, heads of different safety test departments, traffic accident experts and also representatives from Legal Requirement and Product Liability department.

The Crashworthiness Design Review Meeting was proven to be a very effective way to follow and control the development of the car safety characteristics during all stages of development. Optimization problems between different engineering areas have been possible to solve at the earliest possible time in the project.

ENGINEERING LIMITS

The various national and international requirements on safety characteristics are usually expressed as a maximum limit that no cars are allowed to exceed.

This implies that the average performance of the manufactured cars must be engineered with a margin to the limits.

The margin must include allowance for a number of factors. Some of these are

—uncertainty in the parameters that are used by the engineer in his work

—inaccuracies in the measurement techniques and data evaluation in the crash test
—unrepeatability of nominally identical crash test executions
—difference between prototype cars and production cars
—difficulties in making statistical inference from a small number of laboratory tests

Note that a single test outcome above the limit does not imply that the actual car value is outside the limit. It might equally well have been random fluctuations in the laboratory test procedures that have given this result.

A thorough treatment of the statistical consequences of some of these factors is given by Versace (ref 13). He has illustrated how the engineering limit can be related to the regulatory limit, by paying attention to all the above factors.

As input during the early stages of a new car project experience data from crash tests of previous models, data from the accident research and predictions on future technologies are used. If there is a larger technological step, say for instance a proposed change from belt restraints to airbag systems, due respect must be paid to the uncertainty concerning the behaviour of the new system. Based upon this, requirements are formulated which require the first tests with the prototype to exhibit values well below a limit. As the development continues and the test data accumulates for the new concept, the confidence increases in the soundness of the new product. This increased confidence makes it possible to revise the requirements so that the average performance is closer to the requirement than first permitted, even while the risk of having one car exceeding the limit is kept low.

It must be noted here that the requirement during development work is not, as some technicians may think, a more severe requirement than the requirement on the production cars. It is only an augmented and reformulated requirement on the engineers' work that must be achieved in order to get just the performance of the final car that the customers expect and the regulations require (ref 14).

TECHNICAL SOLUTIONS

The overall dimension and weight requirements for the 760 car were as such a challenge. The length from bumper to A-pillar was to be decreased some 10 cm as compared with the 240/260 car. The kerb weight should also be lowered some 50 kg. As a high crash performance was to be designed into the 760 car these goals demanded a thorough optimization between structure and interior engineering.

Structure

The 760 concept is a front engine, rear wheel drive, five-seat passenger car.

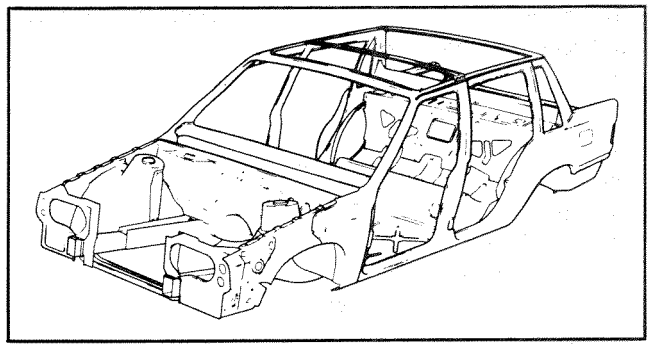


Figure 4. Structure design concept 760.

To optimize the stiffness and weight relationship, member design, sectional properties, welded joints and other joints have, for the monocoque body, been carefully calculated, analyzed and compared with experiences gained from previous designs (Figure 4).

The front side members (Figure 5) are designed as closed sections and from the front and backwards they form a continuously increasing cross section. The side members run under the floor with an outward angle and are connected to the doorsills with a cross member in order to distribute forces.

The front wheel housing and the suspension strut form together with the side member an integrated structure welded to the compartment.

The system is able to effectively absorb the kinetic energy in a frontal crash. The side members are at the front provided with "trigger swages" to initiate and control the buckling during deformation.

The aim has been to construct a body which, despite a large body area, weighs less than its predecessor. High strength steel (HSLA) has therefore been used in the front section of the front side members and sheet metal thickness has in different parts of the body been varied in order to optimize strength and weight.

Interior

The interior restraint systems are engineered not only to meet the overall safety requirements but also to improve the systems performance in the following areas: belt comfort, webbing guidance to eliminate problems with pi-

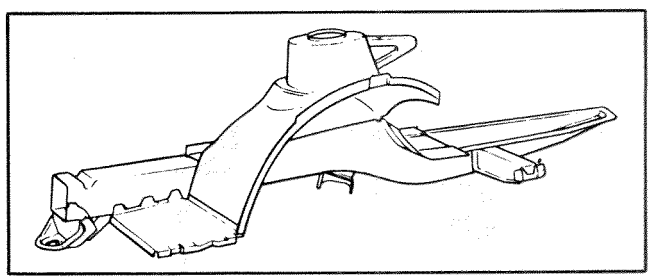


Figure 5. Front member system.

voting webbing guides, seat cushion yieldingness for front and rear seats optimizing the balance of the forces acting on the restrained occupant in a crash.

For the front seats a three-point manual belt with lower anchorage points in the seat frame was chosen. The system incorporates one reel and webbing guide fully covered behind a panel. The webbing guide in the B-pillar is inclined "aligned" and bolted to the pillar hereby giving consistent performance in crash testing.

The lower belt anchorages are located in the seat structure giving constant belt geometry of the lap belt independent of the seat position. The dynamic forces in a crash are transmitted through the rails which are engineered to withstand this extra loading.

The seat structure shown in Figure 6 has a special tube under the frontal part of the cushion which limits the vertical movement of the occupant during a crash.

To minimize steering wheel intrusion during a crash the system has at two locations a collapsible shaft, one for bending moments and one for axial loadings, in combination with a, for rearward forces, strong mounting of the upper shaft bearing.

Forces generated by chest impacts of unbelted occupants in a crash will be absorbed at a tolerable force level by deforming the steering wheel and the bracket for the upper shaft bearing.

The steering wheel with its four spokes, padded rim and hub is designed to mitigate head and face injuries on belted occupants in case of contact with the steering wheel during a crash.

The primary goal has been to keep the instrument panel away from the belted occupant during a crash. This has put special demands on the fire-wall and scuttle area as well as the attachments of the instrument panel.

At the same time efforts have been made to design an instrument panel without protruding parts, projecting a "clean" surface towards the occupant.

Sheet metal structure and padding characteristics have been combined to give tolerable forces if, in spite of all, a head contact would occur.

The three-point belt in the rear seat has the same fixed, inclined webbing guide as described above. The floor under the seat cushion has a special ridge which prevents excessive vertical movement and submarining during a crash. This design was built on the experience from the Volvo Concept Car (ref 12).

All belt geometries have within the limits of existing regulations been elaborated to give good protection and comfort for occupants spanning from 5th female to 95th male percentile.

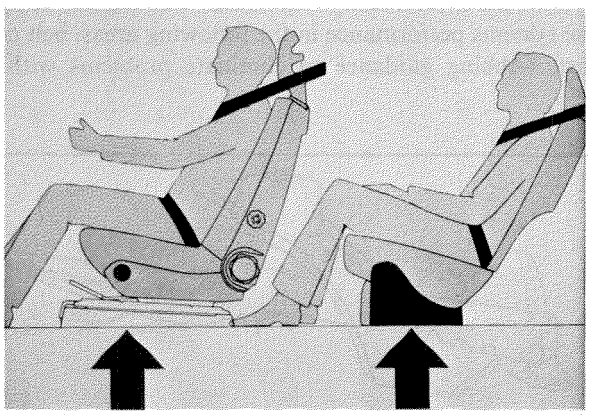


Figure 6. The interior design concept in the Volvo 760.

TEST RESULTS

During the complete development procedure (see Figure 2) a lot of testing was done at component, subsystem, system and complete car level.

At the end of the development it was decided to run three identical frontal barrier tests at 35 mph. The number of tests was chosen as a compromise between cost and the need to cover the repeatability and reproducibility problem. These three tests were run at MIRA (Motor Industry Research Association, England). They are identified by the numbers 227-229 in the following result presentation.

For comparison two previous tests done at the Volvo crash test laboratory are presented. The Volvo tests are taken from some early test series and the cars are prototypes not completely identical with the MIRA cars. The test numbers are 225 and 226. The test results are shown to illustrate the variation in test results during development.

TEST PROCEDURES

The tests were run according to the test procedure specified in FMVSS 208. Both MIRA and Volvo crash test laboratories have a long experience with this test procedure and fullfill all instrument requirements including a well organized dummy calibration procedure. The main difference between the two laboratories is the propulsion system used. MIRA uses an electrical linear motor directly connected to the car and Volvo uses a tyristor controlled electrical rotational motor and an endless wire connected to the car.

The test cars were Volvo 760 GLE with automatic transmission (see Figure 7).

Test weight was as specified in FMVSS 208 (unloaded vehicle weight plus its rated cargo and luggage capacity weight plus two Part 572 dummies) which for the Volvo 760 means 1630 kg (3590 lb).

A total of 50 signals cover both the dummies and different car related measurements as well as a segmented force measuring barrier. The tests were covered by eight high speed cameras.

The dummies were calibrated before every single test.

Table 1 shows some test parameters.

Figure 7. The Volvo 760 GLE.

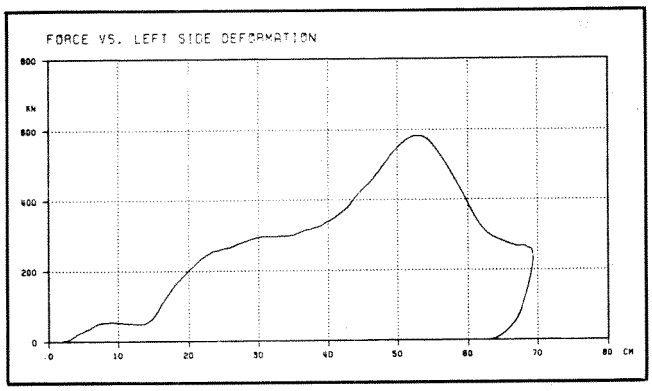


Figure 8. Body deceleration pulse.

Structure Related Test Results

A typical body deceleration pulse is shown in Figure 8.

A typical force/deflection curve is shown in Figure 9.

The following structure related regulations were checked: FMVSS 212 Windshield Retention, FMVSS 219 Windshield Zone Intrusion and FMVSS 301 Fuel System Integrity.

Table 2 shows results of the test.

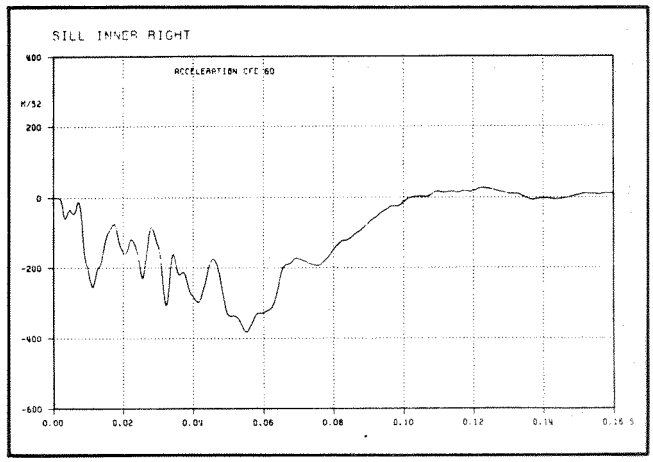


Figure 9. Dynamic Force/Deflection Curve during 35 mph barrier test.

Table 1. Test parameters.

	MIRA 227	MIRA 228	MIRA 229	Mean Value	SD*)	Volvo 225	Volvo 226
Test Weight kg	1630	1630	1630	1630	0.0	1630	1630
Test Speed mph	35.3	35.3	35.2	35.27	0.006	35.2	35.4
Test Temp °C	22.0	22.0	22.0	22.0	0.0	19	20

*) SD = standard deviation defined as $SD = \sqrt{\frac{\Sigma xi2 - n\bar{x}^2}{n-1}}$

Table 2. FMVSS 212, 219 and 301 test results.

Regulation	MIRA 227	MIRA 228	MIRA 229	Volvo 225	Volvo 226
FMVSS 212 % Retention	100	100	100	100	100
FMVSS 219 Penetration	OK	OK	OK	OK	OK
FMVSS 301 Leakage gram	0	0	0	0	0

Interior Related Test Results

The occupant crash protection was evaluated by measuring dummy signals as required in FMVSS 208.

Chest Injury Criteria

In Table 3 two chest injury criteria are shown.—Resultant chest acceleration duration longer than 3 ms, g_{3ms} and Chest Severity Index, CSI, (weighted time integral of chest resultant during crash).

Head Injury Criteria

Table 4 shows the Head Injury Criteria calculated as defined in FMVSS 208 (HIC) and also the same calculation but during head contact (HIC_c).

Femur Injury Criteria

In Table 5 femur injury criteria as defined in FMVSS 208 are presented.

Seat Belt Loads

Seat belt loads in the lap belt and shoulder belt were also measured and are listed in Table 6.

30° Barrier Test Results

Two tests were also done to evaluate the 30° barrier performance. One test 30° right—first contact passenger side and one test 30° left—first contact driver side and both tests at a velocity of 35 mph.

Requirements in FMVSS 212 Windshield Retention, FMVSS 219 Windshield Zone Intrusion and FMVSS 301 Fuel System Integrity were all met.

Dummy test results as for FMVSS 208 can be seen in Table 7.

CONCLUSIONS

This work has demonstrated that by integrating the desired safety properties from the very beginning of a new

Table 3. Dummy results—Chest injury criteria.

Chest Injury Criteria	MIRA 227	MIRA 228	MIRA 229	Mean Value	SD	Volvo 225	Volvo 226
Driver							
g_{3ms}	46.4	50.0	47.0	47.8	1.9	54.0	49.2
CSI	370	427	417	405	30	455	428
Passenger							
g_{3ms}	41.6	45.0	45.0	43.9	2.0	45.8	41.4
CSI	283	311	323	306	21	345	372

Table 4. Dummy results—Head injury criteria.

Head Injury Criteria	MIRA 227	MIRA 228	MIRA 229	Mean Value	SD	Volvo 225	Volvo 226
Driver							
HIC	945	697	820	821	124	898	825
HIC_c	645	676	820	714	93	898	825
Passenger							
HIC	729	890	990	870	132	1030	1290
HIC_c	27	209	87	108	93	349	686

Table 5. Dummy results—Femur injury criteria.

Femur Force kN	MIRA 227	MIRA 228	MIRA 229	Mean Value	SD	Volvo 225	Volvo 226
Driver							
F_L (Left)	4.96	4.74	4.24	4.65	0.37	5.8	4.4
F_R (Right)	0.61	1.76	1.07	1.15	0.58	2.0	1.3
Passenger							
F_L (Left)	3.91	5.52	3.36	4.26	1.12	3.6	3.1
F_R (Right)	1.31	2.98	0.87	1.72	1.11	1.0	2.3

Computer Modeling of Occupant Dynamics in Very Severe Frontal Crashes

SHERMAN E. HENSON
Ford Motor Company

ABSTRACT

Computer simulations of occupant dynamics in frontal crashes have pretty much been done like sled tests, in that crash-induced deformation of the interior—which may be significant for the occupant—has usually not been accounted for. The object of occupant dynamics simulation studies is often to assess the effect of changes in vehicle front-end parameters on occupant response. But these parameter variations may influence the amount of interior deformation. In order to simulate more accurately occupant dynamics in very severe crashes, the interior deformation caused by engine intrusion should concurrently be simulated. Crash test results over a range of speeds were used in a computer simulation study of occupant compartment intrusion in high speed barrier crash tests. It was found that intrusion has a significant effect on occupant response and where appropriate should be included in crash simulations. For the crash conditions simulated, intrusion increased the restrained occupant's head and chest accelerations while no clear trend emerged for the unrestrained occupant.

INTRODUCTION

This paper describes the use of a computer model to simulate dummy dynamics in very severe frontal car crashes—crashes that are similar to running a car into a wall at speeds ranging from 35 to 50 mph. Figures 1 and 2 are photographs of vehicles which were in real accidents of approximately the range of severity of the simulations discussed in this paper. These high speed crashes tend to use up all of the energy-absorbing capability built into the front structure of the car and so the front of the passenger compartment gets pushed closer to the occupant. The effect of this passenger compartment deformation on the loads imposed on the occupant in severe crashes is not very well understood. Computer simulations of occupant dynamics in frontal crashes have usually been done like sled tests, in that crash-induced deformation of the interior—which may be significant for the occupant—has not been accounted for. The object of such simulation studies is often to assess the effect of changes in vehicle front-end parameters on occupant response. But these parameter variations may influence the amount of interior deformation. In order to simulate more accurately occupant dynamics in very severe crashes, interior deformation caused by engine intrusion should concurrently be simulated.

In the study reported here, results of high speed barrier crash tests run by NHTSA were used to estimate occupant compartment intrusion as a function of time for input to a computer simulation model of occupant dynamics. Simulations were run both with and without intrusion to study the effect of intrusion isolated from other crash variables.

METHODOLOGY

The study utilized a computer model called MVMA-2D that was developed by the University of Michigan Highway Safety Research Institute with funding from the Motor Vehicle Manufacturers Association. The model is a lumped mass multi-degree-of-freedom dynamics model which represents an occupant, his restraint system, and the vehicle interior, as shown in Figure 3. The windshield, steering column, instrument panel, and floor pan are represented by line segments. In order to simulate the effects of occupant compartment intrusion, the movement of these components as a function of time relative to the occupant's seating position was needed as an input to the model.

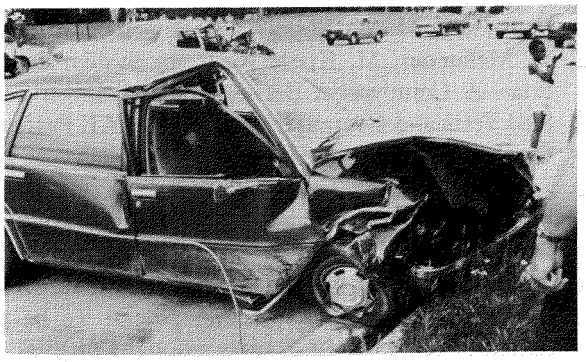


Figure 1. Actual severe crash.

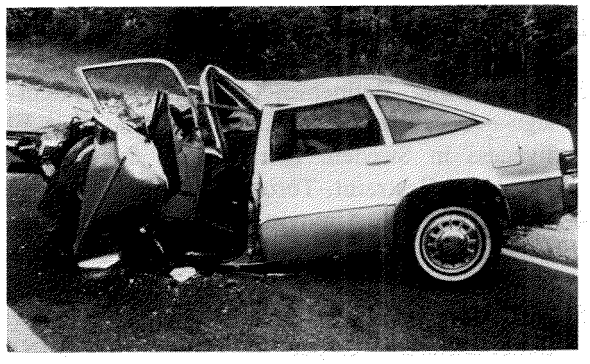


Figure 2. Actual severe crash.

Table 6. Dummy results—seat belt loads.

Belt load kN	MIRA 227	MIRA 228	MIRA 229	Mean Value	SD	Volvo 225	Volvo 226
Driver							
Lap	6.3	7.9	7.5	7.2	0.8	7.0	6.1
Shoulder	7.4	8.2	7.5	7.7	0.4	5.2	7.7
Passenger							
Lap	7.3	7.0	7.9	7.4	0.5	7.4	7.5
Shoulder	7.6	6.8	6.7	7.0	0.5	7.8	7.7

Table 7. Dummy results—30° barrier.

Test Parameters				
Velocity: 36.5 mph Right; 36.2 mph Left Weight: 1630 kg.				
	30° Right/MIRA		30° Left/MIRA	
	Driver	Passenger	Driver	Passenger
Chest g_{3ms}	35.0	31.0	47.0	44.0
CSI	216	227	388	315
HIC	418	517	762	570
HIC_c	285	258	361	73
Femur Forces			3.2	1.4
F_L kN	1.4	2.8		
F_R kN	2.8	2.4	2.6	0.8
Belt Loads			4.2	8.9
Lap kN	5.9	2.2		
Shoulder kN	6.9	5.1	6.8	7.6

car project and by continuously following up the engineering process it is possible to achieve an increased level of safety.

It has pointed out the inherent complexity of crash testing and the need to use statistical methods in order to make qualified judgments during a car development process.

Emphasis has also been placed on the necessity to use experience from field accidents in order to complement the laboratory simulation.

REFERENCES

1. H. Norin et al. Injury reducing effect of seat belts on rear seat passengers. ESV-Conference Wolfsburg 1980.
2. Fatal Accident Reporting System 1979. United States Department of Transportation.
3. N. J. Bohlin. Refinements of Restraint System Design—A Primary Contribution to Seat Belt Effectiveness in Sweden. International Symposium on Occupant Restraint. Toronto June 1981.
4. G. O'Connel, R. Almqvist. A Survey Concerning the Quality of Part 572 Hybrid II Dummies as measuring instruments for crash testing. SAE 770263.
5. V. Seiffert, H. Leyer. Dynamic Dummy Behaviour under Different Temperature Influence. SAE 760804.
6. L. M. Patrick, A. Andersson, N. J. Bohlin. Three-point Harness Accident and Laboratory Data Comparison. 18th STAPP Car Crash Conference 1974.
7. G. Walfisch et al. Human Head Tolerance to Impact: Influence of the Jerk on the Occurrence of Brain Injuries. IRCOBI 1981.
8. L. G. Svensson. Means for Effective Improvement of the Three-Point Seat Belt in Frontal Crashes. 22th STAPP Car Crash Conference 1978.
9. D. Adomeit, H. Appel. Influence of Seat Design on the Kinematics and Loadings of the Belted Dummy. IRCOBI 1979.
10. B. Lundell et al. Safety Performance of a Rear Seat Belt System with Optimized Seat Cushion Design. SAE Passenger Car Meeting 1981, SAE 810796.
11. S. Runberger. Dynamic Test Method for Crash Testing of Front Structures. To be presented at Open University, Milton Keynes UK November 1982.
12. H. Mellander, M. Koch. Restraint System Evaluation—A Comparison Between Barrier Crash Tests, Sled Tests and Computer Simulation. SAE Passenger Car Meeting 1978. SAE 780605.
13. J. Versace. Safety Test Performance Level. 6th Experimental Safety Vehicle Conference. Washington DC 1976.
14. M. Koch, A. Nilsson-Ehle. Setting Realistic Design Limits in Vehicle Safety Development. To be presented at the 1983 SAE International Congress and Exposition, Detroit February/March 1983.

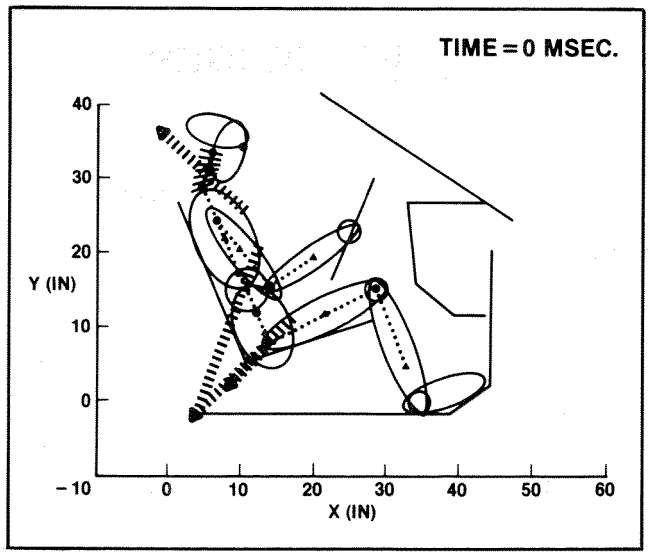


Figure 3. MVMA-2D computer model.

To estimate the movement of the intruding components into the passenger compartment, films of crash tests run by the NHTSA on Chevrolet Citations at 35, 40, and 48 mph were analyzed. The availability of test data at these high speeds was the main reason for choosing the Citation for this simulation study. High speed film analysis was used to determine the relative engine movement as a function of time in these three crashes because the engine, in effect, forced the intruding components rearward into the passenger compartment. Figure 4 shows the results of the film analysis, the average dynamic engine intrusion in inches as a function of time in milliseconds at the three speeds. The maximum intrusion varies from about 3 in. at 35 mph to about 22 in. at 48 mph and reaches the maximum at about 90 to 120 ms.

Knowing the engine movement as a function of time, and the Chevrolet Citation interior dimensions, the vehicle interior deformation was estimated for these crashes. The maximum rearward movement of the windshield, A-pillar, and upper instrument panel were gotten from post-crash vehicle photographs and from post-crash measurements included in the crash reports. The above components were assumed to begin relative movement at the time when engine intrusion began and to reach maximum deformation at the time of maximum vehicle crush. Displacement of each component between these two times was assumed to increase linearly with time. It had to be assumed that the lower instrument panel, dash panel, steering wheel, and floor pan displacement-time relationships were identical to that of the engine intrusion since the data were not available from the test to establish the intrusion precisely as a function of time and the area was hidden from the high speed camera coverage. It is recognized that the lower instrument panel rearward movement may not be identical to that of the engine, but the assumption was necessary in this case and the error introduced by this assumption is believed to be small. During model validation at 48 mph, the maximum rearward displacement of the steering wheel was adjusted somewhat to improve simulation fidelity. Figure 5 shows an outline of the maximum deformation of the passenger-side windshield and instrument panel at the three speeds as well as the undeformed location. The windshield position at 35 mph is the same as the undeformed position. A line drawing of the seat is shown for reference. Notice how the instrument panel and windshield move back and rotate as the crash speed is increased. Figure 6 shows the same thing for the driver side, except the steering wheel maximum deformation is included. As in Figure 5, the

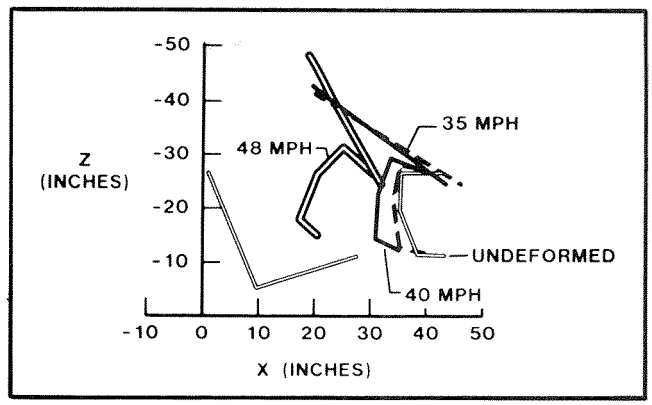


Figure 5. Passenger side interior deformation.

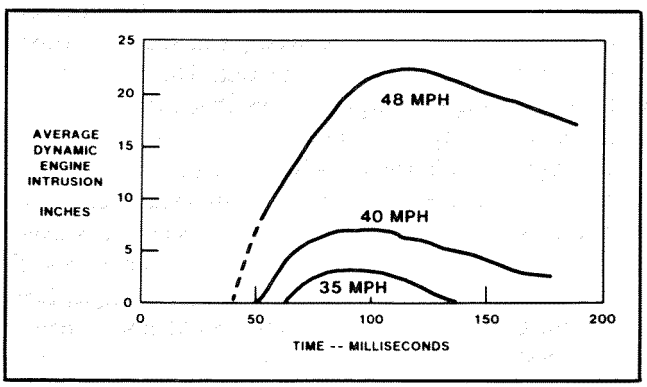


Figure 4. Average dynamic engine intrusion *vs.* time.

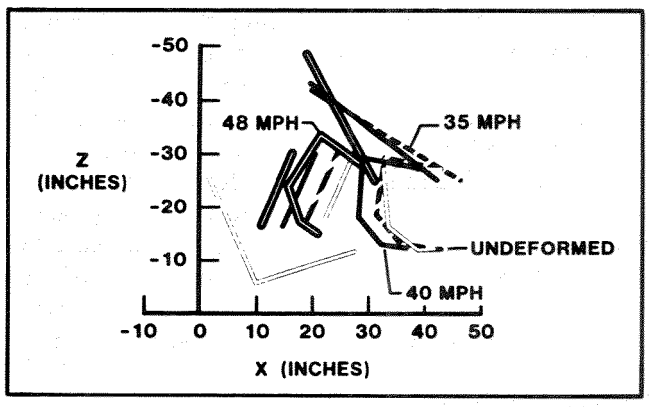


Figure 6. Driver side interior deformation.

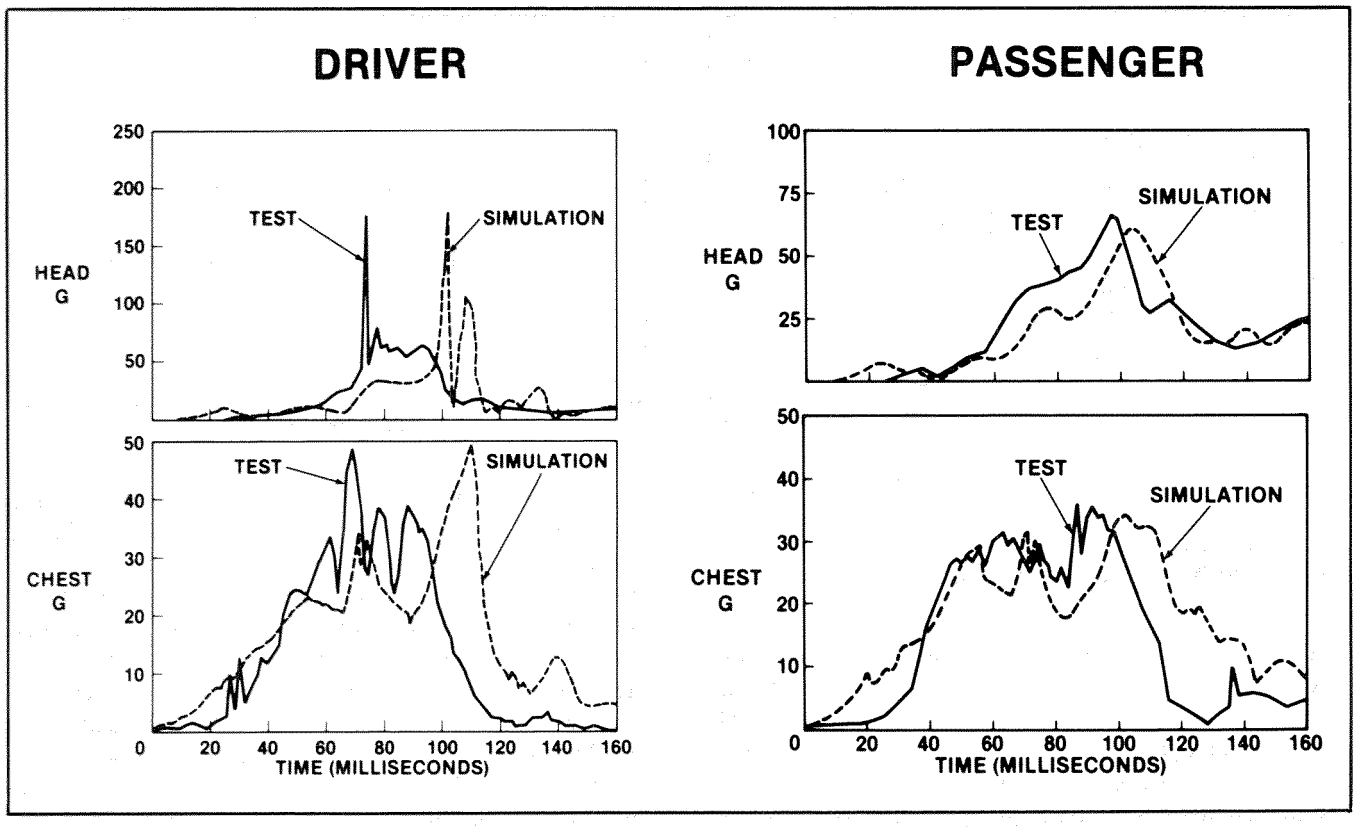


Figure 7. Model validation at 35 mph.

windshield is not deformed at 35 mph. The steering wheel position shown is the expected position without occupant loading. Figures 5 and 6 show the *maximum* deformation of the components, but for input into the model, the positions as a function of time for not only these components but the floor pan and toe board were required. To get the component positions as a function of time, functional relationships for the movement of all of these components were derived from the test results and the functions were inputted into the model as tables of surface displacement as a function of time.

The MVMA-2D model was set up to represent a 50th percentile male in a Citation package. The belt-restrained occupant is shown in Figure 3, but an unrestrained occupant was also simulated. Exercising these models is a very complex and time-consuming procedure, since hundreds of input variables are required to describe the occupant and vehicle interior. For each of the panels that can be contacted by the occupant such as the windshield, instrument panel, and seat, force-deflection characteristics are inputted into the model in either tabular or polynomial format. Belt restraint material properties have to be inputted as well as the acceleration-time pulse of the occupant compartment. Once all the input data were gathered and put into the computer correctly, several runs were made and the results were compared to those of the Citation tests to see if the model was a reasonable simulation of the event. The following section describes the model validation.

VALIDATION

Figure 7 shows a comparison of the dummy head and chest acceleration as a function of time for a driver and right front passenger in a 35 mph barrier crash. The solid lines are the test values from the Chevrolet Citation tests and the dashed lines are the simulation results. The results of the simulations compare reasonably to the test results especially when the large test-to-test variability of barrier crashes is considered. The same comparison at 40 mph is shown in Figure 8. The match again is reasonable except that, as in Figure 7, the peak head g's in the simulation occur somewhat later than in the test. The comparison at 48 mph in Figure 9 again shows that the simulation peaks occur later than the test.

Although there is room for improvement in the simulation, overall, the results were considered acceptable for the present study. Matching peak accelerations over the wide range of crash severity represented here proved to be more difficult than tuning a model to a single, less severe crash. The model predictions could not be compared to test results for the unrestrained occupant because a comparable set of tests has not been run.

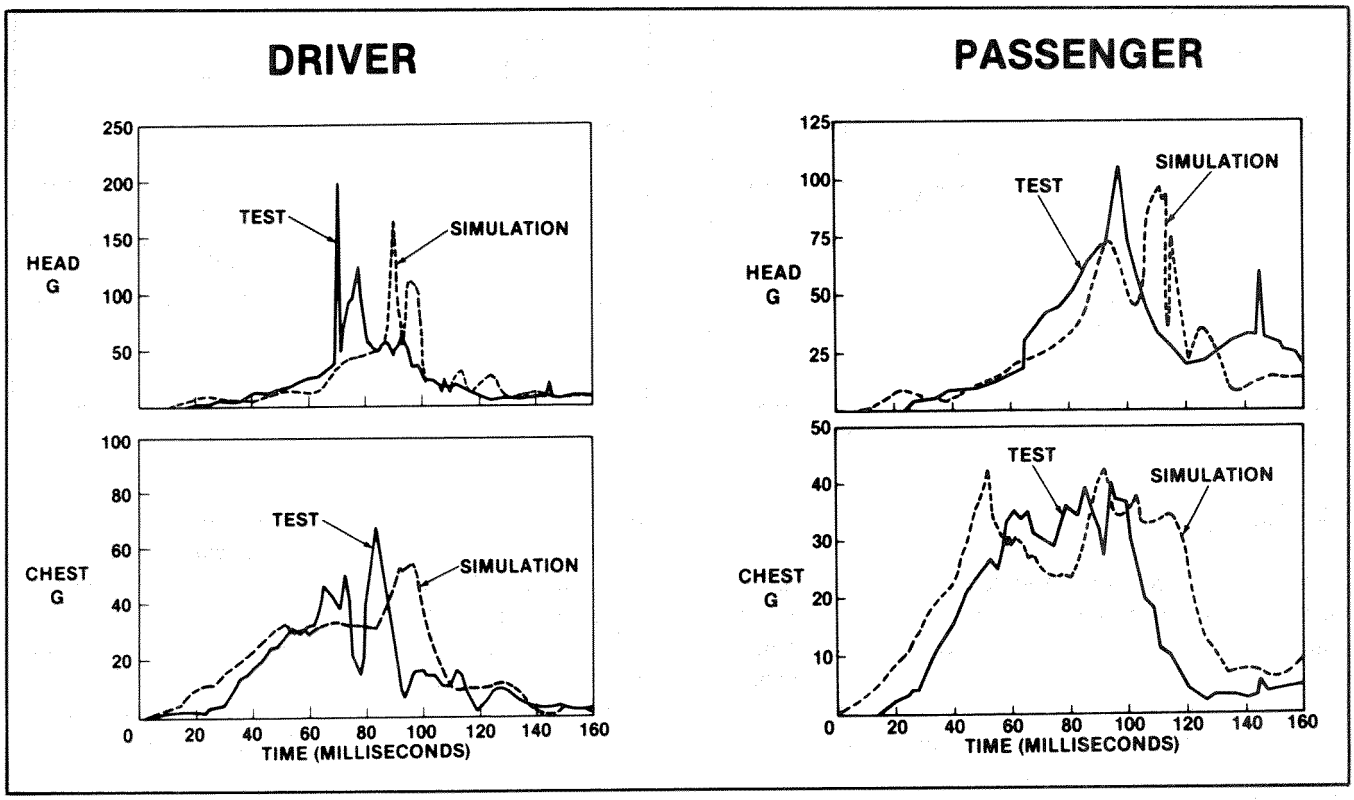


Figure 8. Model validation at 40 mph.

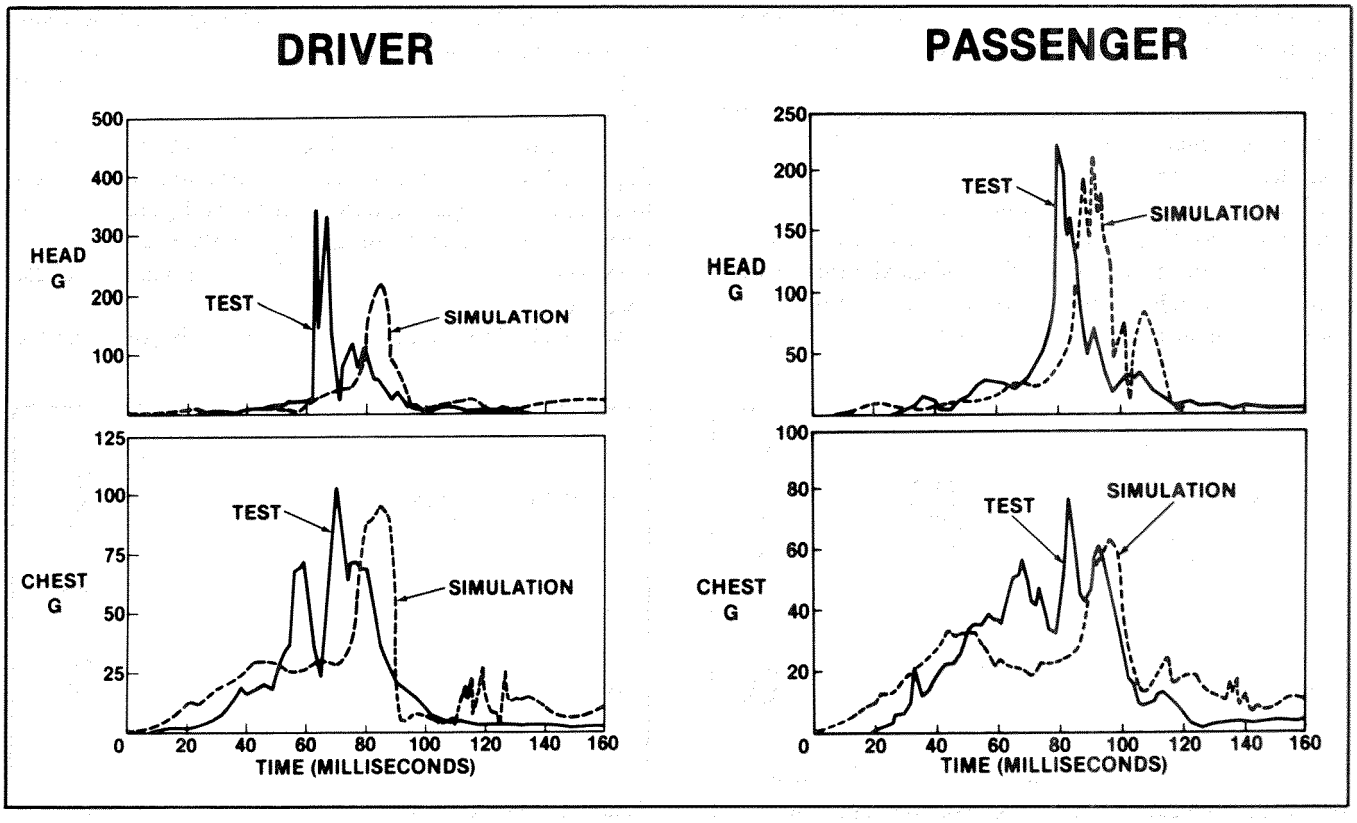


Figure 9. Model validation at 48 mph.

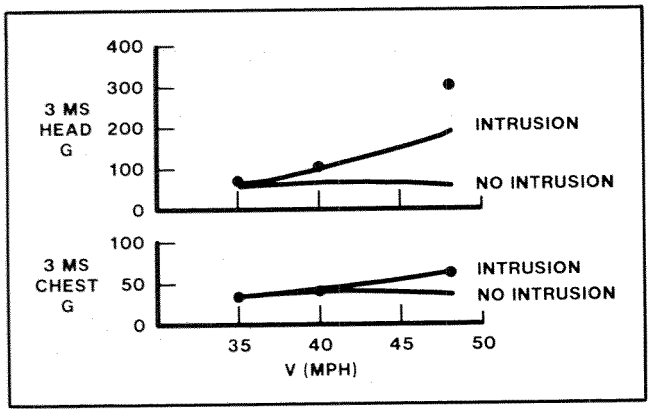


Figure 10. Intrusion effects on restrained passenger.

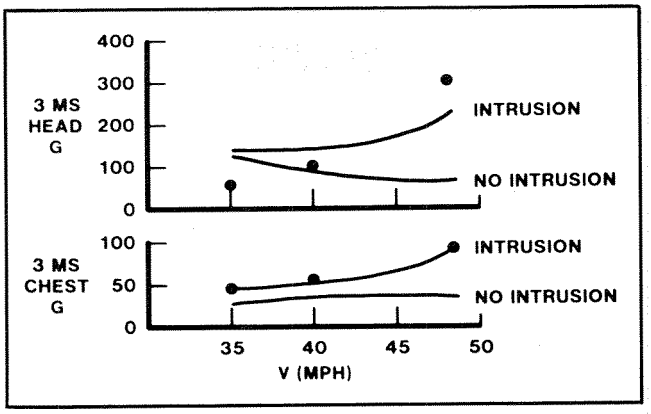


Figure 12. Intrusion effects on restrained driver.

PRELIMINARY RESULTS

Once the model was validated, computer runs were made to explore the effect of intrusion on dummy dynamics. This was done by simply repeating the simulations of the Citation barrier crash tests at the three speeds without the occupant compartment deformation. Figure 10 shows the maximum head acceleration of the restrained right front dummy for the three crash speeds with intrusion and with no intrusion. The dots on the graph are the values from the Citation tests. It is apparent that eliminating the intrusion for the restrained occupant has little effect at 35 mph where the intrusion is small, but the effect increases with speed and the head acceleration is much larger at 48 mph. Without intrusion, the dummy responses are nearly constant as speed increases. The constant response occurs because at these large values of structural crush, the crush resistance is nearly constant and so the vehicle average deceleration is nearly constant over the range from 35 to 48 mph.

Figure 11 shows the occupant kinematics for the same simulations as Figure 10. The upper set shows the occupant position at about the time of maximum forward movement, which is about 100 ms, for the three crash speeds when intrusion was included in the simulations.

It can be seen in the upper figures, the ones where intrusion was simulated, that the occupant strikes the instrument panel more forcefully as the crash speed is increased because the instrument panel and floor pan are moving closer to him. It was shown in Figure 4 that maximum engine intrusion occurs at about the same time, 100 ms. In the lower set of figures, the case with no intrusion, the occupant moves nearly the same distance forward even as speed increases and never hits the instrument panel because the panel remains in the same relative position.

The peak head and chest accelerations for the restrained driver are shown in Figure 12. As in the case of the restrained passenger, head and chest accelerations are lower when there is no intrusion. The apparent decrease in head acceleration is an artifact due to the 3 ms cutoff; the absolute peak acceleration actually increases slightly with speed.

The restrained driver position at 100 ms is shown in Figure 13 for the simulations with intrusion and with no intrusion. It is again apparent from the figures that the occupant loads the intruding components more forcefully when there is intrusion, resulting in higher head and chest accelerations.

While eliminating intrusion appears to be an attractive

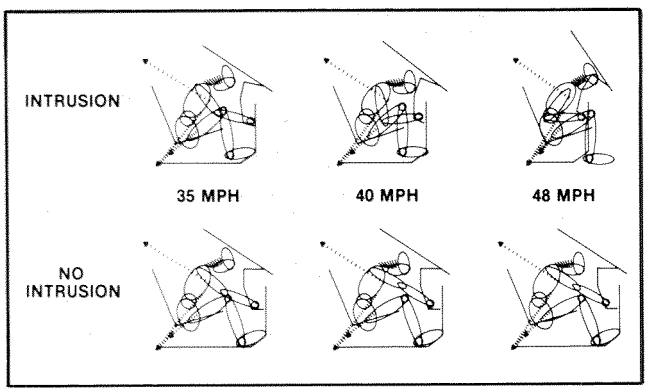


Figure 11. Intrusion effects on restrained passenger at 100 milliseconds.

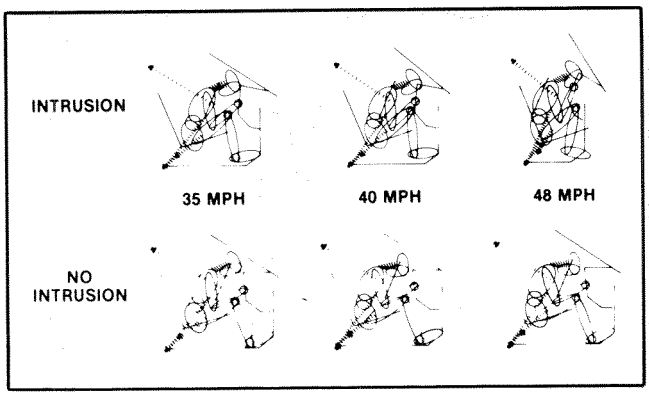


Figure 13. Intrusion effects on restrained driver at 100 milliseconds.

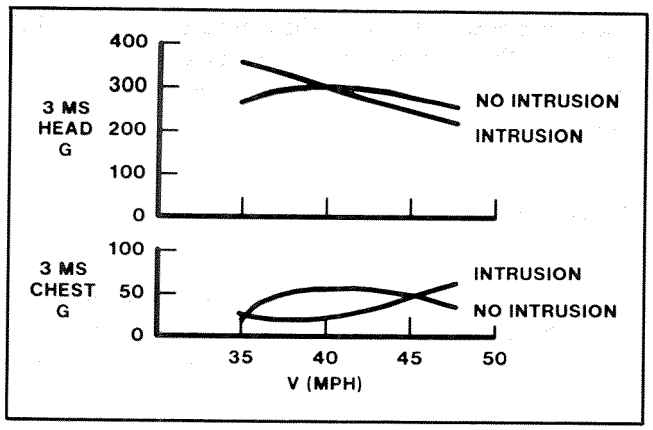


Figure 14. Intrusion effects on unrestrained passenger.

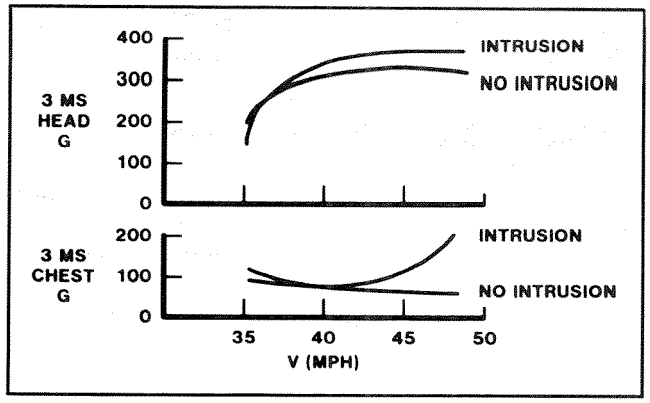


Figure 16. Intrusion effects on unrestrained driver.

way to reduce occupant loads for both driver and passenger, it is difficult in practice. In order to eliminate intrusion in these very severe crashes, the front structure would have to be made either very stiff, or the front of the car would have to be made very long. If the structure were stiffened, the vehicle acceleration would increase and the occupant in the bottom set of pictures in Figures 11 and 13 would move farther forward and probably strike the instrument panel like the occupant in the upper pictures where intrusion is included. Increasing the length, on the other hand, of the front of the car by the large amount necessary to eliminate intrusion in these very severe collisions would be impractical.

Figure 14 is similar to Figure 10 except the results are for the unrestrained passenger. The unrestrained model is identical to the validated restrained model except the belts were removed. There is no clear difference between the simulations with intrusion and those with no intrusion either for head or chest accelerations. There is an interesting effect, however, for the head acceleration in the case of intrusion. The head acceleration decreases somewhat as the crash speed increases. This is probably due to an effect known as ride-down, where the relative speed that the head contacts the windshield decreases at higher impact speeds because the windshield is moving closer to the occupant.

Figure 15 shows the kinematics for the unrestrained occupant. Notice that the occupant kinematics confirm the conclusion drawn from Figure 14, that there is very little difference in the unrestrained occupant response whether or not there is intrusion. The final occupant position in the simulations with intrusion shown in the upper figures looks almost like the bottom row of figures where no intrusion was included.

The head and chest acceleration results for the unrestrained driver are shown in Figure 16. Head acceleration is somewhat lower for the case with no intrusion, but is quite high in both cases. There is little difference in chest acceleration for intrusion compared to no intrusion except in the extremely severe 48 mph collision where the simulated steering column bottoms out. The validity of the simulation in this region is not known since test results for unrestrained occupants were not available. The high chest acceleration is determined by the assumed force-deflection characteristic of the steering system in the region beyond the normal collapse zone. Because force-deflection characteristics for the steering column were not available under these severe conditions, the simulation

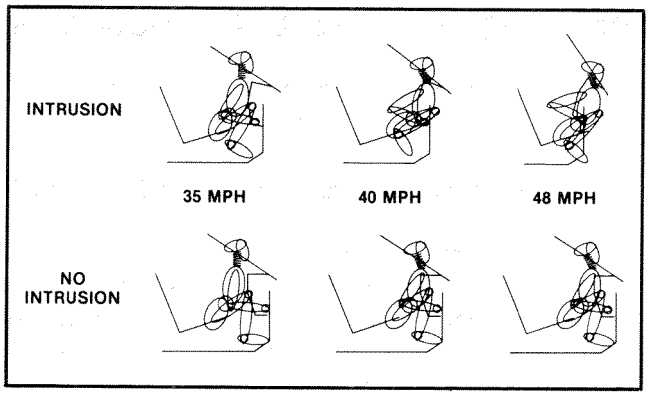


Figure 15. Intrusion effects on unrestrained passenger at 100 milliseconds.

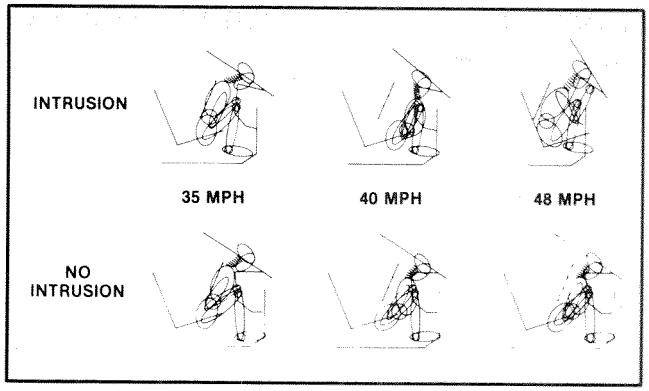


Figure 17. Intrusion effects on unrestrained driver at 100 milliseconds.

results could be considerably in error. The kinematics of the unrestrained driver are shown in Figure 17.

DISCUSSION AND CONCLUSIONS

The results of the computer simulation study indicate that simulations, whether by mathematical model or by impact sled, of severe collisions should take intrusion into account. Including intrusion is most important for the restrained occupant where intrusion may make the difference between contacting or not contacting the instrument panel or windshield, or where intrusion may have a large influence on the force generated by the contact.

In all the restrained occupant simulations, the effect of intrusion was to increase occupant acceleration. The effect of intrusion on the unrestrained dummy was not as clear as for the restrained dummy. In some cases intrusion reduced accelerations while in other simulations, accelerations were increased by intrusion.

The results of the simulations discussed above should not be generalized and applied to all accidents. Only a small fraction of frontal collisions were simulated in this study. Offset and angular collisions with other size occupants could produce different results. Also, while it is easy to eliminate intrusion in mathematical models, it is not so simple in practice. Using today's technology, major structural changes would be required (particularly for the higher speed crashes) which, even if possible, would greatly increase weight, cost, and fuel consumption and could adversely affect the safety of vehicles now on the road through increased aggressiveness in car-to-car collisions. A major challenge for the future is to determine through systems analysis tradeoff studies, the optimal balance of vehicle structure characteristics.

ACKNOWLEDGEMENT

The simulations described in this paper were set up and run by John Dueweke. Matthew Huang developed the program which created the computer graphics of the MVMA-2D occupant. Assistance and consultation by other MVMA-2D users at Ford is gratefully acknowledged.

REFERENCES

1. Bowman, B. M., Bennett, R. O., and Robbins, D. H., "MVMA Two-Dimensional Crash Victim Simulation, Version 4," Volume 1 (UM-HSRI-79-5-1) and Volume 2 (UM-HSRI-79-5-2), Highway Safety Research Institute, The University of Michigan, June 29, 1979.
2. Bowman, B. M., Bennett, R. O., Robbins, D. H., and Becker, J. M., "MVMA Two-Dimensional Crash Victim Simulation, Version 4," Volume 3 (UM-HSRI-79-5-3), Highway Safety Research Institute, The University of Michigan, June 29, 1979.
3. Levan, W. E., and Alianello, D. A., *"New Car Assessment and Standards Enforcement Indicant Testing*—FMVSS Nos. 212, 219, and 301-75, General Motors Corporation 1980 Chevrolet Citation 5-Door Hatchback, NHTSA 308-T1-430," Report No. 6525-V-1, (39.93 Mph), Calspan Corporation, Buffalo, N.Y., June 6, 1979.
4. Levan, W. E., and Alianello, D. A., *"New Car Assessment and Standards Enforcement Indicant Testing*—FMVSS Nos. 212, 219, and 301-75, General Motors Corporation 1980 Chevrolet Citation 5-Door Hatchback, NHTSA 308-T2-431," Report No. 6525-V-2, (48.0 Mph), Calspan Corporation, Buffalo, N.Y., June 7, 1979.
5. Levan, W. E., and Alianello, D. A., *"New Car Assessment and Standards Enforcement Indicant Testing*—FMVSS Nos. 212, 219, and 301-75, General Motors Corporation 1980 Chevrolet Citation 5-Door Hatchback, NHTSA 308-T3-432," Report No. 6525-V-3, (35.0 Mph), Calspan Corporation, Buffalo, N.Y., June 12, 1979.

Possible Future Trends Towards Increasing Occupant Protection in Frontal Impacts

G. JONES
Austin Rover Group Ltd.

ABSTRACT

Over the past decade or so of ESV/RSV activity it has been a priority to improve occupant protection in frontal impacts and there is evidently a need to continue research towards establishing maximum protection in this mode of impact.

In the ESV program we have seen developments aimed at making larger heavier cars more accommodating to the smaller lightweight cars in collision situations. We have also seen that there are big problems in reducing the aggressiveness of the larger heavier vehicles.

Future developments, particularly for lightweight cars, may therefore have to be based on the assumption that

it is not always possible to achieve the ideal of little or no intrusion matched to a restraint system which ideally attenuates the vehicle deceleration.

In these circumstances there appears to be considerable merit in the concept that the occupant be held much more rigidly in the seating position by seat belts considerably stiffer than those currently used.

Recent tests using a typical 30 mph barrier crash pulse show that reduced injury levels and much reduced forward displacement to avoid or reduce the effects of secondary impact, are obtained when adopting this concept.

With a more severe pulse the latter advantages are retained and injury levels, though higher, are still below accepted tolerable levels.

Bearing in mind the fact that a high proportion of frontal impacts are assymetric, producing relatively lower deceleration values but with more intrusion, the overall trade-off would appear to favour the system with reduced forward displacement.

INTRODUCTION

This paper concerns an investigation into the possibility of obtaining increased protection from seat belts in frontal impacts.

It is well known that belts as currently provided, and when correctly worn, do enable occupants to survive impacts of much greater severity than would be so if the occupants were unrestrained. However, there is evidently a need to continue the search for further improvements in restraint system performance particularly in view of the fact that initiatives towards producing a degree of compatibility between large and small vehicles in frontal impacts has proved to be much less fruitful than was expected at the start of the ESV program.

Accident data show that in some impacts the most serious injuries are as a result of the occupant striking forward interior components such as the steering wheel or facia partly because the restraint itself can allow considerable forward displacement and partly because of intrusion.

These injuries are generally more severe than those produced by the belts themselves.

The tests described in this paper were therefore carried out to determine the effect of having a restraint system which very much reduced the forward displacement of the occupant.

ACCIDENT DATA

The most recent data which indicate the general effectiveness of seat belts in the United Kingdom have been provided by the Transport and Road Research Laboratory and by the University of Birmingham Accident Research Unit.

One of the conclusions in a TRRL report by Hobbs (1) was that a seat belt wearing rate of 100% would give an estimated further saving of over 12,000 fatal and serious casualties per year. If only 85% wearing rate were achieved, which is a more realistic figure, the potential further saving would be 9,000. An estimate by the University of Birmingham Accident Research Unit, based on detailed studies of fatal accidents (2) suggests that in the United Kingdom about 800 people each year die needlessly in their cars simply because they do not use the seat belts available to them. These people represent 12% of all road accident fatalities, because car occupant fatalities comprise only about one-third of the total road deaths.

Note that the overall average seat belt wearing rate in Britain during the period covered by these statements has been about 30%.

Frontal impacts, even for those wearing seat belts, do however present the greatest risk of serious injury though this risk is much lower than for those not wearing belts.

One of the TRRL findings was that where injuries due to direct seat belt loading occurred they were mainly of minor severity.

It was also reported that the head was the most commonly injured region of the body and, because of the presence of the steering wheel, there were more drivers with serious injures (AIS3–6) than there were front seat passengers within the same injury range.

However, the difference was not statistically significant. Similar general statements on the TRRL findings were reported by Hobbs in a more recent paper (3).

In-depth investigations have also been carried out by the University of Birmingham Accident Research Unit and findings (4) were similar to those of the TRRL with regard to belted drivers suffering more severe head injuries than belted front seat passengers in frontal impacts.

Using the University of Birmingham data it is calculated that for injuries AIS3–6 the difference between drivers and front seat passengers was not statistically significant in this study also. When moderate injuries are included so that the range is AIS2–6 the difference, as reported, is statistically significant.

For drivers, the head and face was the most frequently injured body area, followed by the legs and the chest. For front seat passengers the head and face was the most frequently injured body area but its importance was much reduced compared with drivers and the chest was almost as important followed by the legs.

As would be expected, head or facial contacts were much more frequent where there was headspace intrusion, there being severe head space intrusion in accidents involving under-run and significant intrusion compromising belt performance in partial overlap impact configurations.

Although chest injuries were almost as important as head and face injuries for front seat passengers, it is noted that in the absence of intrusion and additional loading

from rear seat passengers, or luggage, no occupant sustained a chest injury more severe than AIS3, that is they were non-life-threatening.

A later publication by the University of Birmingham Accident Research Unit (5) deals specifically with steering wheel induced head injuries amongst drivers restrained by seat belts and a paper by Mackay (6) has emphasised the fact that injury producing contacts with the steering wheel and other forward components are subjects for further investigation in the search for better protection in frontal impacts.

BASIC CONCEPTS AND PRACTICAL REALITIES

One currently popular concept for obtaining increased occupant protection is to assume that there is little significant intrusion into the passenger compartment and to provide a restraint system which attenuates the vehicle deceleration to produce minimum forces on the occupant. Such a concept relies on inelastic deformation of the restraint system and use of all available space.

In cases where intrusion is small it is natural to endeavour to produce the ideal by allowing the restraint system to make full use of the forward displacement available before the occupant contacts the facia or steering wheel, etc.

However, current safety belt systems are not sufficiently inelastic or in other words the displacement is not sufficiently plastic as to produce attenuation. In fact there is usually a degree of magnification as associated with the performance of a damped elastic system.

Whilst this may indicate that future developments towards providing a more plastic restraint system deformation would be beneficial, field experience shows that there is little intrusion only in a limited proportion of real crash events.

Therefore good energy absorption qualities need to be linked to the practical limitations of available space when intrusion occurs.

An alternative concept, based on acceptance of the fact that considerable intrusion does occur in a proportion of the more severe frontal impacts, is to restrain the occupant so that he or she experiences little displacement within the passenger compartment and is subject to substantially the same deceleration pulse as the vehicle itself, virtually all of the energy-absorption being exterior to the occupant compartment.

In theory even when there is no intrusion the occupant should at least be better off than with an elastic restraint system in that there should be no magnification of deceleration.

The Battelle Memorial Institute proposed such a system as a near-term recommendation in their 1970 report 'The Evaluation of Phase I Reports on the Experimental Safety Vehicle Program' (7)—the recommendation being based mainly on reducing occupant mass sensitivity problems associated with elastic restraint systems, and concerned with vehicles in which there would be little intrusion.

In the context of the present study there are obvious advantages when considerable intrusion occurs.

TEST PROGRAMME

To obtain some facts related to this concept a series of tests was carried out on the 'Hyge' sled at the Motor Industry Research Association. These were to compare the performance of a typical inertia reel belt system with a belt system broadly in accordance with the Battelle recommendations, i.e., an elongation rate 10 to 20 percent of current belts under comparable loading.

This stiffer belt system consisted of a laminate of four thicknesses of current webbing for the lap and diagonal section, and for test purposes it was a static system with the shoulder belt terminating the 'B' post anchorage, to also minimise the effective belt length.

We estimate that at comparable loading the elongation of this system was in the order of 5 to 10 percent of that for the inertia reel system.

FIRST TEST SERIES

Figure 1 shows the 'Hyge' pulse used for the initial series of tests,—it is similar to the crash signatures from some medium size UK cars subjected to 30 mph barrier tests.

In this initial series of tests the Part 572 manikin was installed on the sled in a rigid seat as normally used for ECE 16 type seat belt tests.

Comparative forward displacements and injury criteria for the Part 572 manikin are shown in Table 1.

With standard inertia reel belts the mean maximum forward displacement of the head was 460 mm and with the stiff belts the figure was 300 mm.

The mean chest 'g' value exceeded for a cumulative

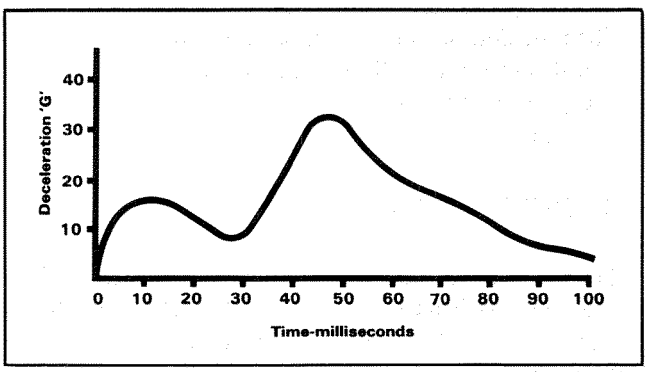


Figure 1. 'HYGE' test pulse-first series of tests.

Table 1. Results from part 572 manikin-first series.

Injury Criteria	Mean Test Results	
	Standard inertia reel belt	Special stiff belt system
Maximum Forward Displacement of Head—mm	460	300
Chest 'G' Exceeded for Cumulative 3 milliseconds	36.2	32.6
Chest Peak Resultant Deceleration 'G'	40.0	35.0
Head Injury Criteria	635	424
Head 'G' Exceeded for Cumulative 3 milliseconds	55.0	47.0
Head Peak Resultant Deceleration 'G'	57.6	50.0

3 m sec period was 36.2 for the standard inertia reel belt system and 32.6 with the stiff belt system.

Although many regard measured head injury criteria as being of no consequence when there is no contact between the head and any vehicle component, it is of interest to note that in these tests, in which there were no components to contact, the mean HIC was 635 with the standard belts and 424 with the stiff belt system.

It will be noted that with the stiff belt system the maximum forward displacement—that is, at the head—is approximately 65 percent of that which occurs with the standard belt system and at the same time the numerical injury values are less.

A further point noted was the tendency for the torso of the manikin to roll out of the diagonal section of the standard inertia reel belts.

This tendency was less evident with the stiff belts.

SECOND TEST SERIES

A further series of tests was carried out using a 'Hyge' pulse which lies within the ECE 16 envelope and which is shown in Figure 2.

This series of tests was carried out to determine the effect of using a differently shaped pulse, i.e., one having a more rapid build-up to peak 'g'.

As in the initial test series the ECE 16 seat and the Part 572 manikin were used.

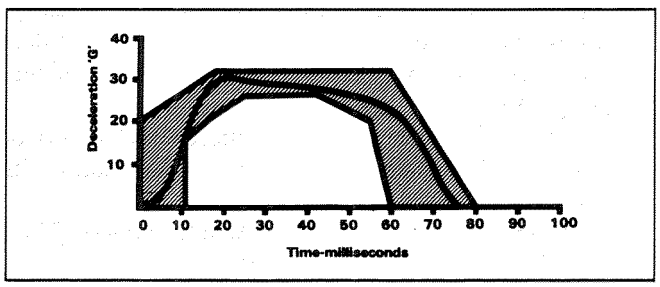


Figure 2. 'HYGE' test pulse-second series of tests.

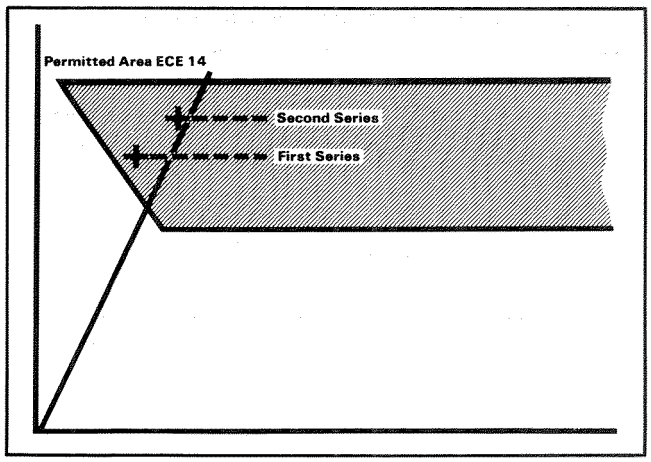


Figure 3. Shoulder anchorage point positions.

For this further series of tests the shoulder anchorage point was also raised in an endeavour to reduce the torso roll-out which had occurred particularly when standard inertia reel belts were used in the initial series. The respective anchorage points are shown in Figure 3.

The raised anchorage point still complies with the requirements of Regulation ECE 14 but the belt fit was more suited to the Part 572 manikin and there was no tendency to roll out.

Figure 4 shows comparative forward displacements of the manikin.

In this case with standard inertia reel belts the maximum forward displacement of the head was 530 mm and with the stiff belts the figure was 310 mm, i.e., less than 60 percent of the amount with standard belts.

Table 2 shows forward displacements relative to the ECE regulation requirements, this time at chest level. Head displacement is also shown for comparison.

Compared with the ECE 16 range of between 100 and 300 mm, measurements at chest level were 310 and 135 mm respectively for standard inertia reel and stiff belt system.

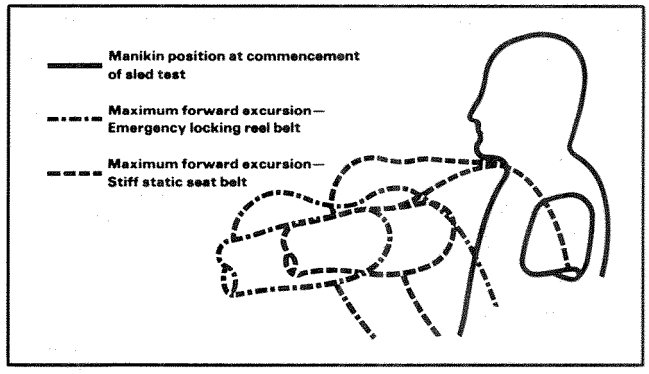


Figure 4. Forward movement of manikin restrained by emergency locking reel belt and by stiff static seat belt.

Table 2. Forward displacement of manikin-second series.

	ECE 16 Requirement	Mean Test Results mm: Standard inertia reel belt	Special stiff belt system
Head Displacement	None	530	310
Torso Displacement	Between 100 & 300	310	135
Pelvis Displacement	Between 80 & 200	170	95

It is of interest to note that although the Part 572 manikin is quite different from that used in testing belts to Regulation ECE 16 the forward displacements with standard reel belts are in the region of the higher ECE 16 values whereas with stiff belts they are near the lower values.

The comparative mean measured injury values from the Part 572 manikin are shown in Table 3. In this test series the mean chest 'g' value exceeded for a cumulative 3 m sec period was 44.5 for the standard reel belt system and 54.3 for the stiff system.

Comparable peak resultant chest values were 48.8 and 59.6 'g' respectively.

Note that whereas in the initial series of tests the values for the stiff system were lower, the values in this second series are higher.

However the results from these tests, using a pulse which some regard as being excessively severe, do show that even the peak resultant chest value does not exceed the 60 'g' which is accepted as being tolerable for a cumulative period of no more than 3 m sec.

With regard to head injuries it may again be pointed out that the quoted values may be of no consequence in the absence of head contact.

Even if they were considered to be of consequence the slightly higher results from the stiff belt system are not significant.

Table 3. Results from part 572 manikin-second series.

Injury Criteria	Mean Test Results: Standard inertia reel belt	Special stiff belt system
Chest 'G' Exceeded for Cumulative 3 milliseconds	44.5	54.3
Chest Peak Resultant Deceleration 'G'	48.8	59.6
Head Injury Criteria	521	582
Head 'G' Exceeded for Cumulative 3 milliseconds	60.2	63.5
Head Peak Resultant Deceleration 'G'	62.2	66.2

CONCLUSIONS

The results of the tests indicate that the forward movement of the occupant in an impact can be significantly reduced by the use of seat belts which at a comparable loading have much less elongation than current reel belt systems. This is particularly significant in the case of the driver whose space available for forward movement is limited by the steering wheel and also when in more severe impacts there is intrusion into the passenger compartment.

Though there is some trade-off in chest injury when the more severe test pulse is used, it must be noted that no special attention was paid to damping properties and it is possible that an increased amount would be an advantage.

Belt tensioning and webbing clamping devices are known developments towards the objective of reducing forward movement of the occupant. Low elongation webbing of minimum length, possibly in combination with a suitably developed webbing clamping system may be the most practical means of producing further improvements in reel belt systems. Any future developments along these lines must however run in parallel with developments towards providing maximum possible levels of comfort and convenience.

ACKNOWLEDGEMENTS

The writer would like to thank colleagues in the Austin Rover Group of BL Cars for assistance in preparing this paper.

Management are also thanked for permission to publish this paper.

REFERENCES

1. Hobbs C. A. The Effectiveness of Seat Belts in Reducing Injuries to Car Occupants. Department of Transport TRRL Report LR811. Crowthorne, 1978 (Transport and Road Research Laboratory).
2. Mackay G. M. University of Birmingham Accident Research Unit—Press Statement, May 1981.
3. Hobbs C. A. Car Occupant Injury Patterns and Mechanisms. Transport and Road Research Laboratory. Crowthorne, paper at Eighth International Technical Conference on Experimental Safety Vehicles—Wolfsburg, 1980.
4. Rattenbury S. J. et al.: The Biomechanical Limits of Seat Belt Protection. The American Association for Automotive Medicine. Kentucky, 1979.
5. Gloynes P. F. et al.: Steering Wheel Induced Head and Facial Injuries Amongst Drivers Restrained by Seat Belts. Sixth IRCOBI Conference, France, 1981.

6. Mackay G. M. Seat Belts In Europe—Their Use and Performance in Collisions. International Symposium on Occupant Restraint. Ontario, Canada, June 1981.

7. The Evaluation of Phase 1 Reports on the Experimental Safety Vehicles Program. Battelle Memorial Institute—Columbus Laboratories, Ohio, 1970.

Occupant Protection from Impact with the Steering Assembly

JOHN B. MORRIS, LEE STUCKI,
RICHARD M. MORGAN and NANCY BONDY
National Highway Traffic Safety Administration

ABSTRACT

This paper will discuss areas of NHTSA research relating to the accident environment of the driver impacting the steering assembly. These include:

- Accident analyses to define the problem.
- Development of biomechanical criteria for assessment of injury severity on test surrogates.
- Laboratory testing of steering assemblies to determine the safety performance.
- Computer modeling for reconstructing accidents and assessing the effects of changes to steering assembly characteristics on driver responses.

The accident analyses quantify the problem in terms of injuries and fatalities sustained by drivers as a result of impacting the steering assembly. Relationships will be developed between frequency and severity of injury and source of injury, affected body regions, crash direction and severity, and steering assembly response parameters.

Biomechanical injury criteria on blunt thoracic impact is available and may be applicable to chest impact with steering wheel hubs.

A program was recently completed which evaluated the safety performance of several production steering assemblies and, also, one improved steering assembly constructed from components with desirable safety attributes. The performance was evaluated via component tests and dynamic sled tests with instrumented Hybrid III dummies.

A computer program entitled "*S*teering *C*olumn and *O*ccupant *RE*sponse *S*imulation" (SCORES) has been developed to model the various interactions of a driver impacting a steering assembly in a frontal collision. The SCORES model is used to predict the occupant/steering assembly response when certain assembly characteristics are changed, i.e., column force deflection properties, and to reconstruct actual accident cases.

A joint effort by NHTSA and Transportation Systems Center (TSC) is being conducted to reconstruct the accident environment of occupants injured by the steering assembly. The SCORES model will be exercised for various make/model vehicles, occupant sizes, and accident configurations which essentially comprise this accident environment. Countermeasures will be introduced into the SCORES model and the effect on injury and fatality reduction will be assessed.

BACKGROUND

The steering column is responsible for producing more injuries and fatalities than any other vehicle component. In an effort to alleviate the harm caused by the steering assembly, the automobile industry started designing and developing energy absorbing steering assemblies in the late 1950's (1). Methods were also devised to prevent rearward intrusion of the steering column during the crash event. In 1965, the Society of Automotive Engineers (SAE), recognizing the need for a test procedure for this new device, issued Recommended Practice J944 (2). This practice describes the laboratory test procedure for evaluating the characteristics of steering control systems under simulated driver impact conditions. It consists of a body form weighing 75 pounds that impacts a steering assembly mounted in the production configuration. A load cell mounted between the wheel and column is used to measure the force imparted to the system.

In 1966, the General Services Administration (GSA) issued a steering assembly protection rule (GSA Standard 515/4a) which became effective in October 1967 (3)(4). All passenger cars purchased by GSA after the effective date were required to comply with this standard. The standard specified that the force imparted to the SAE J944 body form must not exceed 2,500 pounds when impacting the steering assembly at 15 mph. The intrusion prevention portion of the standard specified that the rearward horizontal displacement of the upper end of the column must not exceed 5 inches during a 30 mph frontal barrier test.

In 1967, NHTSA adopted the GSA standard but separated the energy absorption and rearward displacement requirements into two standards, FMVSS Nos. 203 and 204. These standards became effective on January 1, 1968 (5). Federal Motor Vehicle Safety Standard (FMVSS) No. 203, "Impact Protection for the Driver From the Steering Control System," specifies requirements for minimizing chest, neck, and facial injuries by providing steering systems that yield forward, cushioning the impact of the driver's chest by absorbing much of his impact energy in

frontal crashes. FMVSS No. 204, "Steering Control Rearward Displacement," specifies requirements limiting the rearward displacement of the steering control into the passenger compartment to reduce the likelihood of chest, neck, or head injuries.

Compliance with these standards has resulted in various designs for absorbing the energy of the occupant impacting the steering assembly, usually an energy absorbing device in the column (FMVSS No. 203). The prevention of column intrusion into the occupant compartment is usually accomplished by a shear capsule (FMVSS No. 204). The standards were subsequently extended to light trucks and vans effective September 1, 1981.

Many accident analyses have been conducted to assess the effect of post-1968 steering assemblies. Garrett (6), Huelke (7), Nahum (8), Levine (9), O'Day (10), and McLean (11) all reported a reduction in severe injuries as a result of the energy absorbing steering column. Two studies have been conducted by NHTSA to determine the effectiveness of post-1968 steering assemblies. One study was conducted by Kahane (4)(12), and the other which is included in the rulemaking support paper for FMVSS Nos. 201, 203, and 204 Extension to Light Trucks and Vans (13).

Kahane (4) reported that in pre-standard cars in the National Crash Severity Study (NCSS), 58 percent of the drivers who were killed or hospitalized in frontal crashes were seriously injured by contacts with the steering assembly. This is in agreement with a study by Nahum (8) based on 1960-1966 model cars. Kahane also reported that the pre-standard steering column entered into the passenger compartment in 3.5 percent of the towaway accidents. There also was column displacement in 20 percent of the cases involving steering assembly contact and 75 percent of the driver fatalities (14).

Using data from the Fatal Accident Reporting System (FARS), Kahane concluded that energy absorbing steering systems reduced the risk of driver fatalities in frontal crashes by 12 percent. Using NCSS data the study also concluded that energy absorbing systems reduced by 38 percent the risk of serious injury due to the steering assembly. Also observed was that post-standard steering system reduced the incidence of column intrusion into

Table 1. Harm to car occupant as a function of contact point.

	Contact	Body Region	Harm % of Total
1	Steering assembly	Chest	11.90
2	Steering assembly	Abdomen	9.41
3	Side interior surface	Chest	4.94
4	Windshield	Head and face	4.68
5	A-Pillars	Head and face	4.04
6	Instrument panel	Lower extremities	3.43
7	Steering assembly	Head and face	3.13
8	Roof edge	Head and face	3.02
9	Side interior surface	Abdomen	2.36
10	Instrument panel	Chest	2.06
11	Instrument panel	Abdomen	1.85
12	Roof	Head and face	1.80
13	Instrument panel	Head and face	1.65
14	Instrument panel	Upper extremities	1.40
15	Arm rests	Abdomen	1.25
16	Glove comp. area	Abdomen	1.23
17	Steering assembly	Upper extremities	1.16
18	Mirrors	Head and face	1.08
19	Glove comp. area	Chest	0.84
20	Window glass	Head and face	0.79
21	Window frame	Head and face	0.77
22	Front seat backs	Abdomen	0.76
23	Side interior surface	Lower extremities	0.71
24	Floor	Lower extremities	0.69
25	Roof edge	Neck	0.57
	All the above		65.52
	All other interior contacts		14.74
	All non-contact		7.91
	All exterior contacts		11.83
	All		100.0

Malliaris (15)

the passenger compartment by 68 percent. It should be noted that since it is difficult to separate the effects of FMVSS Nos. 203 and 204 on injury reduction, the above estimates are based on the combined effectiveness of the two standards.

Despite the apparent safety improvements of steering assemblies since 1968, the steering assembly remains the major source of injury. Using NCSS data, Malliaris (15) ranked source of injury (contact point) by percent of harm. Four of the top 17 most harmful body region/contact point interactions are produced by the steering assembly. Table 1 presents harm to the occupant as a function of contact point/body region.

Cohen (16) in analyzing NCSS data concluded that the steering assembly is responsible for 27 percent of all serious (AIS 3-6) injuries. The body areas involved and their percentage of total serious injury is shown in Table 2. As can be seen, steering assembly impacts with the chest and abdomen account for nearly 20 percent of all serious injuries. A tabulation of the distribution of steering assembly injury by body region is shown in Table 3. Serious to fatal injuries attributed to the steering assembly occur predominately to the chest (54%) and abdomen (25%). Cohen also investigated the effect of delta V on injury produced by the steering assembly. Figure 1 illustrates the results of this analysis. The mean delta V for serious chest injury is approximately 27 mph and 32 mph for the abdomen. Additional analysis of the accident data as it relates to the steering column will follow later.

Table 2. Percent of all AIS 3-6 injuries caused by steering assemblies.

Steering assembly/all body parts 27.3%		(698)
Steering assembly/chest	14.5	
Steering assembly/abdomen	6.6	
Steering assembly/upper extremity	1.8	
Steering assembly/head and face	1.7	
Steering assembly/pelvis	1.4	

Cohen (16)

Table 3. Distribution of steering assembly injuries (AIS 3-6) by body part and impact direction.

Body Part	Frontal	Non-Frontal
Chest	53.5%	51.8%
Head and face	6.6	5.5
Abdomen	24.9	22.1
Pelvis	5.8	4.5
Upper extremity	5.0	11.1
Lower extremity	2.2	2.5
Total AIS 3-6 Injuries	499	199

Cohen (16)

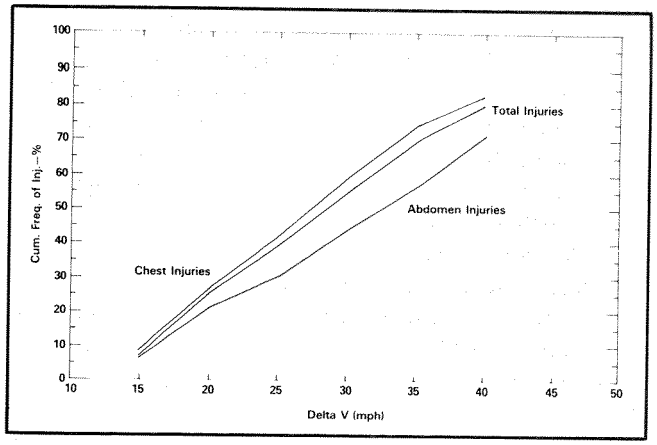


Figure 1. Distribution of steering assembly injuries—AIS 3-6 injuries—for drivers in frontal impacts by delta V.

As reported by Stucki (17) several issues have been raised regarding the adequacy of the FMVSS No. 203 test procedures. Key among these issues are:

- The test device does not physically simulate the driver impacting the steering assembly in actual crash simulations.
- The test device is not a good human surrogate and the performance criteria are not adequate indicators of injury severity.
- The inability of the test and/or performance criteria to distinguish "good" and "bad" design steering assemblies as a result of the previous inadequacies.

Observations of the inability of the current test procedure to address the effects of accident-induced steering column behavior were made by Gloyns (18) and Garrett (19).

Stucki also noted that the FMVSS No. 203 force criteria do not account for load distribution and that improvements to the safety of the steering assembly such as load distribution features are not rewarded by the performance criteria. Ways to realistically evaluate the safety performance of the steering assembly will be addressed later in this paper.

ACCIDENT ANALYSIS

The National Crash Severity Study (NCSS) contains 12,050 accidents in which a passenger car, light truck, or van had to be towed. Accidents were sampled from seven areas throughout the United States from January 1977 to March 1979. The NCSS file reports 67,559 weighted drivers in towaway passenger cars, of which 14,512 had a known contact source. Of the 14,512 drivers 5,902 or 40.7% had contact with the steering assembly of which 154 or 2.69% were fatally injured. The data presented in this section consist of only those drivers in passenger cars having contact with the steering assembly.

Table 4 shows the distribution of driver injury severity in terms of AIS, by crash mode. Crash mode is defined by the variable 'General Area of Deformation' which is the second component of the Collision Deformation Classification (CDC) and describes the general area of impact to the vehicle. The most severe impact to the vehicle was used to define crash mode.

Table 4 shows that 72% of the drivers having steering assembly contact were in frontal impacts. Almost 74% of the injuries caused by steering assembly contact were minor injuries (AIS 1). Note: in right and left impacts, there are almost the same number of drivers contacting the steering assembly.

Table 5 shows the distribution of AIS for drivers having contact with the steering assembly by delta V. Delta V is defined as the change in velocity which occurs during the collision.

Deleting the 'other' category, Table 5 shows that 76% of the drivers were occupants of passenger cars having a delta V between 1-20 miles per hour. Approximately 82% of the AIS 1 and 2 injuries occur at the delta V between 1-20 mph. The severe injuries AIS 3-6, increase proportionally as the delta V increases.

Table 6 describes the injuries sustained by drivers contacting the steering assembly in terms of body region and AIS.

Table 6 shows that over 60 percent of the injuries to drivers contacting the steering assembly are to the body regions face and chest, followed by upper extremities, head and abdomen. Note: the majority of these injuries are of low severity; however, over 40 percent of the injuries to the abdomen and one-fourth of the injuries to the chest are AIS 3 and above.

The National Accident Sampling System—Continuous Sampling Subsystem (NASS-CSS) is a random sample of police-reported accidents in 10 sites throughout the United States. These accidents when weighted produce national estimates. Because the potential error in many of the estimates is large, these numbers should be used as estimates, not as precise counts.

Table 4. AIS for drivers having contact with the steering assembly by crash mode (NCSS).

Frequency Percent Row % Column %							
AIS	Front	Right	Left	Back	Top	Other*	Total
1	3113 52.75 71.37 73.21	264 4.47 6.05 71.16	246 4.17 5.64 66.49	213 3.61 4.88 89.50	106 1.80 2.43 75.71	420 7.12 9.63 79.10	4362 73.91
2	558 9.45 73.81 13.12	53 0.90 7.01 14.29	60 1.02 7.94 16.22	11 0.19 1.46 4.62	9 0.15 1.19 6.43	65 1.10 8.60 12.24	756 12.81
3	325 5.51 71.43 7.64	33 0.56 7.25 8.89	32 0.54 7.03 8.65	13 0.22 2.86 5.46	19 0.32 4.18 13.57	33 0.56 7.25 6.21	455 7.71
4	99 1.68 74.44 2.33	7 0.12 5.26 1.89	17 0.29 12.78 4.59	0 0 0 0	2 0.03 1.50 1.43	8 0.14 6.02 1.51	133 2.25
5	90 1.53 79.65 2.11	8 0.14 7.08 2.16	9 0.15 7.96 2.43	1 0.02 0.88 0.42	3 0.05 2.65 2.14	2 0.03 1.77 0.38	113 1.91
6	16 0.27 80.00 0.38	2 0.03 10.00 0.54	2 0.03 10.00 0.54	0 0 0 0	0 0 0 0	0 0 0 0	20 0.34
Injured Severity Unknown	51 0.86 80.95 1.20	4 0.07 6.35 1.08	4 0.07 6.35 1.08	0 0 0 0	1 0.02 1.59 0.71	3 0.05 4.76 0.56	63 1.07
Total	4252 72.04	371 6.29	370 6.27	238 4.03	140 2.37	531 9.00	5902 100

*Other includes undercarriage, unclassifiable, and unknown.

Table 5. AIS for drivers having contact with the steering assembly by delta V (NCSS).

Frequency Percent Row % Column %	Delta V (miles per hour)								
AIS	1-10	11-20	21-30	31-40	41-50	51-60	61-99	Other*	Total
	823	1351	358	46	9	2	0	1773	4362
	13.94	22.89	6.07	0.78	0.15	0.03	0	30.04	73.91
1	18.87	30.97	8.21	1.05	0.21	0.05	0	40.65	
	88.59	75.35	60.58	25.56	18.37	14.29	0	75.80	
	80	275	89	37	6	1	0	268	756
	1.36	4.66	1.51	0.63	0.10	0.02	0	4.54	12.81
2	10.58	36.38	11.77	4.89	0.79	0.13	0	35.45	
	8.61	15.34	15.06	20.56	12.24	7.14	0	11.46	
	20	107	87	46	13	2	1	179	455
	0.34	1.81	1.47	0.78	0.22	0.03	0.02	3.03	7.71
	4.40	23.52	19.12	10.11	2.86	0.44	0.22	39.34	
3	2.15	5.97	14.72	25.56	26.53	14.29	14.29	7.65	
	1	28	27	19	7	1	1	49	133
	0.02	0.47	0.46	0.32	0.12	0.02	0.02	0.83	2.25
4	0.75	21.05	20.30	14.29	5.26	0.75	0.75	36.84	
	0.11	1.56	4.57	10.56	14.29	7.14	14.29	2.09	
	0	15	25	25	13	6	4	25	113
	0	0.25	0.42	0.42	0.22	0.10	0.07	0.42	1.91
5	0	13.27	22.12	22.12	11.50	5.31	3.54	22.12	
	0	0.84	4.23	13.89	26.53	42.86	57.14	1.07	
	0	1	0	4	1	1	1	12	20
	0	0.02	0	0.07	0.02	0.02	0.02	0.20	0.34
6	0	5.00	0	20.00	5.00	5.00	5.00	60.00	
	0	0.06	0	2.22	2.04	7.14	14.29	0.51	
Injured	5	16	5	3	0	1	0	33	63
Severity	0.08	0.27	0.08	0.05	0	0.02	0	0.56	1.07
Unknown	7.94	25.40	7.94	4.76	0	1.59	0	52.38	
	0.54	0.89	0.85	1.67	0	7.14	0	1.41	
Total	929	1793	591	180	49	14	7	2339	5902
	15.74	30.38	10.01	3.05	0.83	0.24	0.12	39.63	100
%AIS ≤ 3	2.3	8.5	23.7	53	69.4	77	100		

*Other includes unknown and not applicable.

Since the weighting factors assigned to actual accident cases are large in order to extrapolate to national estimates, this magnifies differences between cells with no actual cases and those with only a few cases. As more cases are collected by NASS, this discrepancy should be somewhat corrected.

The NASS-CSS file reports, for 1979 and 1980 combined, 17,703,387 drivers of passenger cars of which 821,732 or 4.6% had contact with the steering assembly. Of the 821,732 drivers 10,353 or 1.3% were fatally injured.

Table 7 shows the distribution of AIS for drivers contacting the steering assembly by crash mode.

Table 7 shows that 60% of the drivers having contact with the steering assembly were in frontal impacts. Almost 85% of the injuries to these drivers were minor injuries (AIS 1). These results are in agreement with the NCSS file.

Table 8 shows the distribution of AIS by delta V.

Excluding the 'other' category, Table 8 shows that 76.7% of the drivers contacting the steering assembly were occupants of passenger cars having a delta V between 1-20 mph. About 80% of the AIS 1 and 2 injuries occurs at delta V between 1-20 mph. The severe injuries, AIS 3-6, increase proportionally as the delta V increases with the exception of delta V '51-60.' The discrepancy is most likely due to the small number of actual cases that fall into the '51-60' category.

Table 9 describes the injuries to drivers in terms of body region and AIS.

Table 9 shows that half of the injuries to drivers are to the body regions, face and chest followed by upper extremities, abdomen, and head. The majority of the injuries are of low severity (AIS 1 and 2); however, almost one-fourth of the injuries to the abdomen and one-sixth of the injuries to the chest are AIS 3 and above. These

Table 6. AIS for drivers having steering assembly contact by body region (NCSS).

Frequency Percent Row % Column %	AIS							
Body Region	1	1	3	4	5	Injured Severity 6	Unknown	Total
*Upper Extremities	682 11.56 84.0 15.64	78 1.32 9.61 10.32	43 0.73 5.30 9.45	9 0.15 1.11 6.77	0 0 0 0	0 0 0 0	0 0 0 0	812 13.76
Chest	1046 17.72 65.62 23.98	144 2.44 9.03 19.05	276 4.68 17.31 60.66	41 0.69 2.57 30.83	60 1.02 3.76 53.09	17 0.20 1.07 85.00	10 0.17 0.63 15.87	1594 27.01
Face	1723 29.19 83.00 39.50	318 5.39 15.32 42.06	29 0.49 1.40 6.37	5 0.08 0.24 3.76	0 0 0 0	0 0 0 0	1 0.02 0.05 1.59	2076 35.17
Head	218 3.69 58.13 5.00	97 1.64 25.87 12.83	13 0.22 3.47 2.86	3 0.05 0.80 2.26	9 0.15 2.40 7.96	1 0.02 0.27 5.00	34 0.58 9.07 53.97	375 6.35
Knee	84 1.42 84.00 1.93	12 0.20 12.00 1.59	4 0.07 4.00 0.88	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	100 1.69
Abdomen	189 3.20 54.94 4.33	2 0.03 0.87 0.26	28 0.47 8.14 6.15	64 1.08 18.60 48.12	44 0.75 12.79 38.94	1 0.02 0.29 5.00	16 0.27 4.65 25.40	344 5.83
Pelvis	71 1.20 57.26 1.63	16 0.27 12.90 2.12	35 0.59 28.22 7.69	1 0.02 0.81 0.75	0 0 0 0	0 0 0 0	1 0.02 0.81 1.59	124 2.10
Shoulder	168 2.85 71.19 3.85	60 1.02 25.42 7.94	7 0.12 2.97 1.54	0 0 0 0	0 0 0 0	0 0 0 0	1 0.02 0.42 1.59	236 3.99
Thigh	88 1.49 73.95 2.02	12 0.20 10.08 1.59	14 0.23 11.76 3.08	5 0.08 4.20 3.76	0 0 0 0	0 0 0 0	0 0 0 0	119 2.02
Other Unknown	93 1.58 76.23 2.13	17 0.29 13.93 2.25	6 0.10 4.92 1.32	5 0.08 4.09 3.76	0 0 0 0	1 0.02 0.82 5.00	0 0 0 0	122 2.07
Total	4362 73.91	756 12.81	455 7.71	133 2.25	113 1.91	20 0.34	63 1.07	5902 100

*Includes arm, elbow, forearm, and wrist/hand.

Table 7. AIS for drivers contacting the steering assembly by crash mode (NASS).

Frequency Percent Row % Column %							
AIS	Front	Right	Left	Back	Top	Other*	Total
	413779	22080	39209	24459	12388	183047	694962
	50.35	2.69	4.77	2.98	1.51	22.28	84.57
	59.54	3.18	5.64	3.52	1.78	26.34	
1	83.12	75.64	70.46	78.99	82.68	94.78	
	45756	4850	6942	6015	999	8606	73168
	5.56	0.59	0.84	0.73	0.12	1.05	8.90
2	62.54	6.63	9.49	8.22	1.37	11.76	
	9.11	16.62	12.48	19.43	6.67	4.45	
	24110	1850	8749	491	1596	1485	38281
	2.93	0.23	1.06	0.05	0.19	0.18	4.66
3	62.98	4.83	22.85	1.28	4.17	3.88	
	4.84	6.34	15.72	1.59	10.65	0.77	
	6194	110	276	0	0	0	6580
	0.75	0.01	0.03	0	0	0	0.80
4	94.13	1.67	4.19	0	0	0	
	1.24	0.38	0.50	0	0	0	
	4514	0	0	0	0	0	4514
	0.55	0	0	0	0	0	0.55
5	100.00	0	0	0	0	0	
	0.91	0	0	0	0	0	
	1498	299	0	0	0	0	1797
	0.18	0.04	0	0	0	0	0.22
6	83.36	16.64	0	0	0	0	
	0.30	1.02	0	0	0	0	
Injured	1961	0	469	0	0	0	2430
Severity	0.24	0	0.07	0	0	0	0.30
Unknown	80.70	0	19.30	0	0	0	
	0.39	0	0.84	0	0	0	
Total	497812	29189	55645	30965	14983	193138	821732
	60.58	3.55	6.77	3.77	1.82	23.50	100

*Other includes undercarriage, unknown, and unclassified.

results are similar to those shown in Table 6 from the NCSS. Differences which appear are primarily due to the small number of actual cases sampled.

SUMMARY

The NCSS and NASS files both indicate that drivers are more likely to contact the steering assembly in frontal impacts than in any of the other impacts. The severity of the impact defined by delta V shows that the severity of the injuries (AIS 3-6) increases as the delta V increases. The common injuries sustained by drivers contacting the steering assembly primarily to the face and chest, followed by upper extremities, head, and abdomen. The majority of these injuries are AIS 1 and 2, however, the severe injuries, AIS 3-6 occur to the body regions, abdomen and chest.

INJURY CRITERIA

In order to assess the protective capability of a steering assembly a criterion for estimating injury is required. As noted previously the two most prevalent body regions injured by the steering assembly are the thorax and the abdomen. In the following section a review of previous studies addressing thoracic and abdominal injury tolerance is undertaken, and the most appropriate continuous injury criteria for frontal thoracic and abdominal impact are presented.

THORAX INJURY CRITERIA—A variety of kinematic parameters have been utilized in the literature for predicting the results of a blow to the thorax—thoracic acceleration, force, deflection, power, etc. The data bases for these approaches also vary extensively in type of subject tested—cadavers, porcine subjects, squirrel monkeys,

Table 8. AIS for drivers having contact with the steering assembly by delta V (NASS).

Frequency Percent Row % Column %								
	Delta V (miles per hour)							
AIS	1-10	11-20	21-30	31-40	41-50	51-60	Other*	Total
1	89174 10.85 12.83 92.35	126837 15.44 18.25 86.51	34646 4.22 4.99 67.59	7583 0.92 1.09 56.18	2175 0.26 0.31 40.28	2522 0.31 0.36 71.26	432022 52.58 62.17 85.57	694959 84.57
2	5275 0.64 7.21 5.46	15423 1.88 21.08 10.52	7355 0.90 10.05 14.35	3327 0.40 4.55 24.65	0 0 0 0	782 0.10 1.07 22.10	41009 4.99 56.04 8.12	73171 8.90
3	1204 0.15 3.15 1.25	1830 0.22 4.78 1.25	6688 0.81 17.48 13.05	551 0.07 1.44 4.08	2110 0.26 5.51 39.08	235 0.03 0.61 6.64	25653 3.12 67.03 5.08	38271 4.66
4	0 0 0 0	1418 0.17 21.55 0.97	1993 0.24 30.29 3.89	0 0 0 0	0 0 0 0	0 0 0 0	3169 0.39 48.16 0.63	6580 0.80
5	0 0 0 0	666 0.08 14.76 0.45	0 0 0 0	1801 0.22 39.91 13.34	635 0.08 14.07 11.76	0 0 0 0	1411 0.17 31.26 0.28	4513 0.55
6	0 0 0 0	440 0.05 24.47 0.30	399 0.05 22.19 0.78	235 0.03 13.07 1.74	0 0 0 0	0 0 0 0	724 0.09 40.27 0.14	1798 0.22
Injured Severity Unknown	911 0.11 37.47 0.94	0 0 0 0	180 0.02 7.40 0.35	0 0 0 0	479 0.06 19.70 8.87	0 0 0 0	861 0.10 35.42 0.17	2431 0.30
Total	96564 11.75	146614 17.84	51261 6.24	13497 1.64	5399 0.65	3539 0.43	504849 61.44	821723 100
%AIS ≤ 3	1.3	3.0	17.7	19.2	55.8	6.6		

*Other includes unknown and not applicable.

rhesus monkeys, baboon, etc. Each of these data bases has difficulties associated with its use. Using cadavers, the muscle tension and lung inflation (as compared to living subjects) must be considered. Animal tests must be scaled to account for size, shape, and anatomical differences.

The approach taken herein is based on two facets: [1] the injury criteria must be continuous and [2] only data sets composed of human cadavers or porcine subjects shall be utilized and other animal species shall be used only to guide the analysis. Porcine subjects are used based on the understanding that the circulatory, respiratory, and skeletal systems of the pig are important human analogues which establish the pig as structurally a very similar animal species to man (20).

The first body of experiments to be considered is the Kroell data (21, 22). These data are comprised of 24 cadavers which received frontal blunt thoracic impacts. The Kroell data (where the cadaver weights were 90-209 pounds) are shown in Figure 2. The numbers in the center of the figure are the associated injury (using the 1971 AIS scale). The ΔV term for the Kroell data should be the maximum change-of-velocity between the sternum and a point on the spine, say fourth thoracic vertebra. In actuality, that number is often not available and the ΔV of the impactor is substituted. This turns out to be a reasonable approximation for the Kroell data because the sternum pulse is over by the time the spine pulse begins (21). In Reference 23, the average ratio of first integral of the sternal spike pulse to the contact velocity of the impactor is 1:11.

Where this approximation breaks down is when the

Table 9. AIS for drivers having steering assembly contact by body region (NASS).

Frequency Percent Row % Column %	AIS							
Body Region	1	2	3	4	5	6	Injured Severity Unknown	Total
*Upper Extremities	103258 12.56 80.91 14.86	21818 2.66 17.10 29.82	1458 0.18 1.14 3.81	1087 0.13 0.85 16.52	0 0 0 0	0 0 0 0	0 0 0 0	127621 15.53
Chest	165235 20.11 78.04 23.78	11641 1.42 5.50 15.91	26981 3.28 12.74 70.48	3379 0.41 1.60 51.34	2097 0.26 0.99 46.46	1350 0.17 0.64 75.53	1050 0.13 0.50 43.21	211741 25.77
Face	267544 32.56 90.27 38.50	28082 3.42 9.48 38.38	746 0.09 0.25 1.95	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	296377 36.06
Head	25905 3.15 86.21 3.73	3721 0.45 12.38 5.08	424 0.05 1.41 1.11	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	30050 3.66
Knee	24165 2.94 97.15 3.48	709 0.09 2.85 0.96	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	24874 3.03
Abdomen	33057 4.02 73.92 4.76	511 0.06 1.14 0.70	6151 0.75 13.75 16.07	2115 0.26 4.73 32.14	2417 0.29 5.40 53.54	0 0 0 0	469 0.06 1.05 19.30	44720 5.44
Shoulder	31396 3.87 87.60 4.52	3533 0.43 9.86 4.83	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	911 0.11 2.54 37.49	35840 4.36
Thigh	27962 3.40 100.00 4.02	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	27962 3.40
Other	16440 2.00 72.89 2.37	3154 0.38 13.98 4.31	2522 0.31 11.18 6.59	0 0 0 0	0 0 0 0	440 0.05 1.95 24.47	0 0 0 0	22556 2.74
Total	694962 84.57	73169 8.90	38282 4.66	6581 0.80	4514 0.55	1798 0.22	2430 0.30	821736 100

*Includes arm, elbow, forearm, and wrist/hand.

impactor mass is very light which is the case for a handful of the Kroell data. (In those few cases, momentum calculations were made to better estimate the sternum ΔV.)

Two models—to define the dependent variable, AIS, as a function of the response parameters—were considered. These were:

$$AIS = f(\Delta V, P/D, Age)$$

and

$$AIS = g(P/D, Age)$$

where

ΔV = impact velocity (fps),
P = penetration,
D = depth of chest,
P/D = normalized total deflection,

and

AGE is in years.

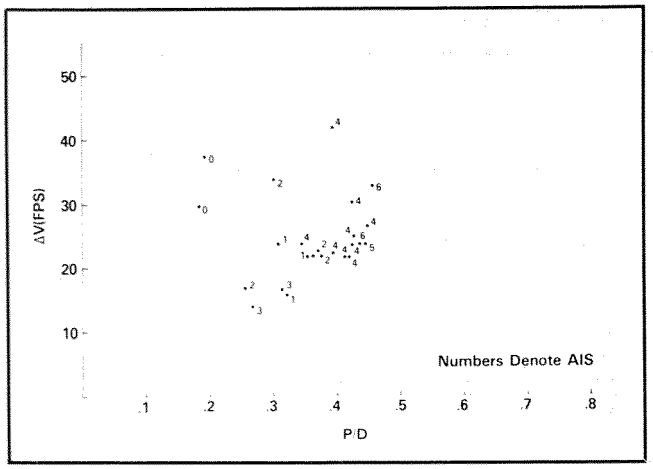


Figure 2. GM cadaver frontal impacts to the thorax.

The following equation is the AIS predictive expression as a function of P/D and AGE:

$$AIS = 17.4\ P/D + 0.0313\ AGE - 5.15 \quad (1)$$

where

R = multiple correlation coefficient = .87
SE = standard error of estimate = .87

This is Neathery's equation from Reference 22. Naturally, this regression equation is only good for values of P/D and AGE which lie within the region covered by the original data (24); e.g., this equation is not to be used for a 5-year-old child because children were not included in the original data set.

For the regression analysis on AIS = f (ΔV, P/D, AGE), the coefficient in front of the ΔV term is not significant. In other words, ΔV is not a good independent parameter for the GM cadaver tests. This point bears further consideration.

Recently, Eppinger (25) used a combination of digital convolution theory and least-squares approximation techniques to predict relative velocity and deflection based on accelerometer readings from side impacts of human cadavers. Eppinger found a relationship which suggests that the magnitude or severity of the resulting trauma is not only the result of the maximum deflection the thorax experiences but also a function of the rate at which the thoracic deflection is produced.

In 1975, Fayon et al. (26) investigated frontal crash simulations with 3 point seat belts. Results were presented for 31 cadavers in dynamic tests and 7 other in static tests. Fayon concluded that it is not possible to specify a tolerance level for thorax deflection without specifying the deflection speed which the thorax undergoes.

Jonsson (27) exposed anesthetized rabbits to controlled compression blunt impact on the right side. The results of this study suggest that velocity, as well as compression, might be a primary factor in nonpenetrating thoracic injury mechanisms. Predominantly fatal injuries were observed at velocities >39 fps and input compressions of 20-30%, whereas compression of 50-60% were required for a lethal outcome at velocities <39 fps.

The apparent injury mechanism was different for impact velocities above and below the 39 fps impact velocity region. In the higher velocity exposures the lung lesions resembled those found in blast injury.

Twenty-one living and post mortem porcine subjects were exposed to blunt thoracic impact by GM (20, 28). The impactor was a 46.3 pound mass with a flat contact surface traveling at 9.8 to 34.8 fps. The contacting interface was an unpadded, 6-inch-diameter wooden block with a half-inch edge radius to prevent localizing loading at the perimeter. The GM argued that a comprehensive review of comparative anatomy between the swine and man would indicate that the cardiovascular, respiratory, and thoracic skeletal systems of the pig are anatomically and functionally a good parallel of similar structures in man. During the impacts, the force was applied in the horizontal direction through the vertically aligned contact block and was centered midsagitally over the sternum.

In their most recent swine experiments (29), the GM team concluded that—while chest compression is clearly an important factor related to injury in severe blunt thoracic impact—there is a specific role for velocity as well. In other words, for a given level of thoracic compression, a higher average loading velocity represents a potentially more damaging exposure.

There is a possible reason ΔV is not a significant independent variable for the Kroell data. Figure 3 shows the GM swine data, or Viano data, for blunt thoracic impact. (The weight of the swine varied from 102-154 pounds). The Viano data have points of high ΔV and low P/D while the cadaver data do not.

The Viano data suggest that the magnitude of the resulting trauma is not only the result of the maximum deflection the thorax experiences but is also a function of the rate at which the thoracic deflection is produced.

Finally, chest deflection was used for a Highway Safety

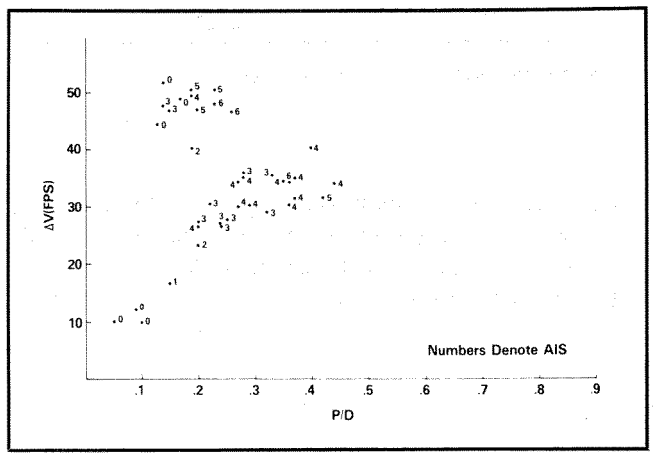


Figure 3. GM swine frontal impact to the thorax.

Research Institute (HSRI) study (30) as the indicator of injury.

The whole of the GM, HSRI, Fayon, Jonsson, and Eppinger work suggests that the most appropriate continuous injury criteria for frontal impact to the thorax should be based on at least two kinematic parameters: maximum deflection of the thorax and the rate at which the thoracic deflection is produced.

At this time, the *best continuous injury criteria* is:

(1) The Neathery equation

$$AIS = 17.4\ P/D + 0.0313\ AGE - 5.15$$

Plus (both parts are to be used together)

(2) The following restriction on the rate at which the thoracic deflection is produced as suggested by Figure 4 if

$\Delta V \leq 30$ fps, use Neathery equation

if 30 fps $\leq \Delta V \leq$ 40 fps,
use Greater of AIS = 3 or Neathery equation

if 40 fps $< \Delta V \leq$ 50 fps,
use Greater of AIS = 4 or Neathery equation

if 50 fps $< \Delta V$,
use Greater of AIS = 5 or Neathery equation

The duration over which the rate of thoracic deflection is calculated should not exceed 120 msec.

ABDOMEN INJURY CRITERIA—The mechanisms of injury to various abdominal organs are not well understood. Biomechanical studies by Stalnaker et al. (31) have defined tolerance values or injury severity as function of a dimensionless parameter involving force magnitude, duration of impact, mass of the impacted subject, and the area of contact. Melvin et al. (32) have established a loading rate sensitivity of the isolated liver and kidney to injury. In a recent study of closed blunt impacts delivered to anesthetized rabbits, Lau and Viano (33) also demonstrated that injury severity of the liver was velocity dependent.

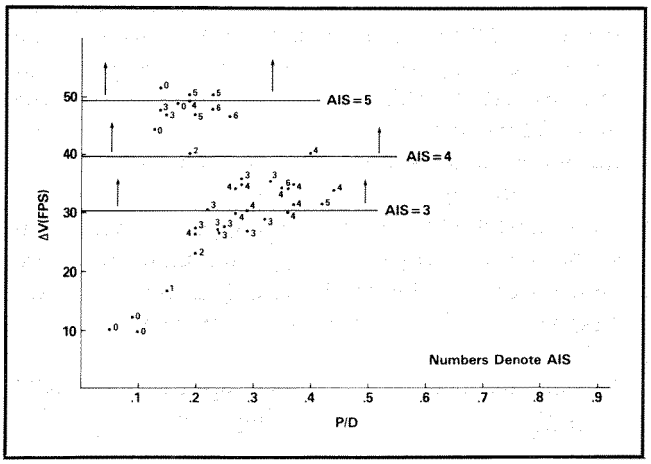


Figure 4. Velocity layers for frontal impact to the thorax.

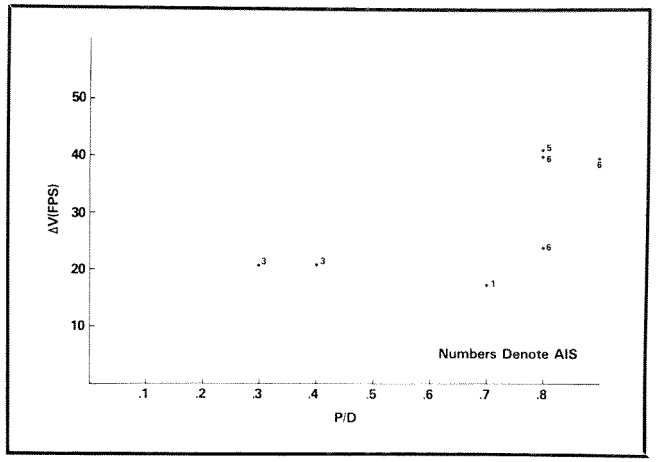


Figure 5. Winquist's swine frontal impact to the abdomen.

One of the earliest studies to try to relate kinematic parameters to abdominal injury level is a 1953 report by Winquist et al. (Discussed in Reference 34.). They employed upright seated swine to examine the effects of frontal abdominal impacts against objects that might be struck in an aircraft cockpit. These objects were a control wheel, a stick-like protrusion—struck end-on—and a large, flat surface similar to a radio box. The animals received impacts in both their midriff and lower abdominal regions at velocities of 20 and 40 fps. All of the high velocity exposures were fatal. These data are shown in Figure 5. These swine weighed from 95-187 pounds.

A regression analysis of these data results in a lower correlation coefficient for AIS as a function of P/D alone.

This lower correlation coefficient is probably due to the AIS = 1 at P/D = .7. The impactor in that event was the stick-like protrusion. What may have happened—as suggested by the second author of Reference (34) in personal communication—is that the rod went in at a lower speed and allowed the midriff organs to avoid the main thrust.

In Reference (35), 15 swine (43–65 pounds) were exposed to controlled frontal abdominal impact. The rigid impactor weighed 30 pounds and had a 3-inch-diameter circular impacting surface.

The swine test data are shown in Figure 6. Regression models for this data have a correlation coefficient of about 0.75.

The data for abdominal impact suggest a dependence of injury on normalized abdominal penetration and upon rate of change of the penetration. The data are not abundant enough to allow the exact understanding of these parameters (or of possible age effects).

The equation for abdominal impact to the HSRI swine (frontal) and Winquist swine (frontal) shows some similarity to the GM work for frontal impact to the thorax.

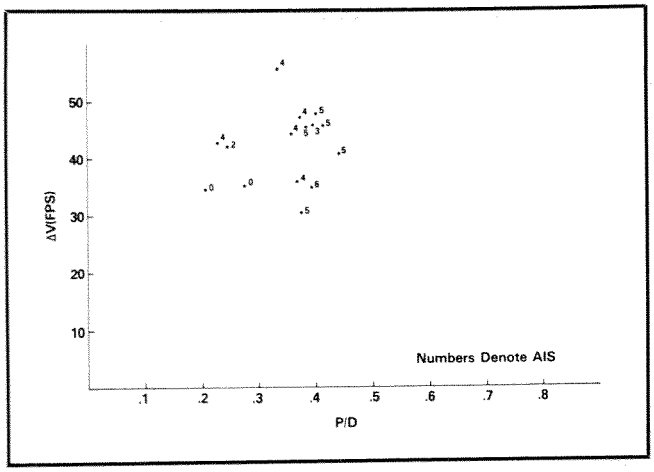


Figure 6. HSRI swine frontal impact to the abdomen.

If the assumption is made that severe injury begins to appear after 30 percent normalized total penetration (the same as in the thorax for frontal impact), then an injury criteria can be hypothesized.

The *most appropriate continuous injury criteria* for frontal abdominal impact are:

(1)

$P/D \leq .1$	$AIS = 0$
$.1 < P/D \leq .5$	$AIS = .15\ P/D - 1.5$
$.5 < P/D$	$AIS = 6$

plus (both parts are to be used together)

(2)

if $\Delta V \leq 30$ fps, use equation in (1) above
if 30 fps $< \Delta V \leq 40$ fps, use Greater of $AIS = 3$ or equation above
if 40 fps $< \Delta V \leq 50$ fps, use Greater of $AIS = 4$ or equation above
if 50 fps $< \Delta V$, use Greater of $AIS = 5$ or equation above

The duration over which the rate of thoracic deflection is calculated should not exceed 120 msec.

RECENT AND CURRENT RESEARCH

Several programs recently completed or currently in progress will advance our understanding of the role of the steering assembly in causing injury during an accident. A program which was the subject of an SAE paper entitled "Study of Steering Assemblies for Evaluation and Rating of Safety Performance" (17) investigated the performance of several production steering assemblies via static component and dynamic systems tests. The selection of steering assembly types was based on acquiring a cross section of production available types of energy absorbers as shown in Table 10. Since publication of this paper additional research was conducted in this same program. An improved dynamic systems test was developed where the complete Hybrid III dummy is impacted into a stationary assembly. Tests were conducted on four make's types of steering assemblies (Ford Fairmont, Chevy Citation, Volvo, and a hybrid type) in the frontal mode at 20 and 25 mph and 30° oblique at 25 mph.

The hybrid steering assembly was constructed from components which yielded the best results based on earlier testing: a Ford Fairmont column and energy absorber and Volvo steering wheel. Table 11 shows the results of the dynamic testing.

As discussed previously in the biomechanics section and in References 23, 26, and 29, it appears that chest deflection correlates better with injury than does spinal chest acceleration for blunt impact. If this is used as a performance criteria, the hybrid steering assembly would rank as the best of those tested.

Two other innovations were developed during this program. A device which uses electrical switches to give a rough estimate of the area in contact between the dummy and the impacted surface was developed and included in the later tests. An abdomen form which replaces the standard insert was constructed of Styrofoam and following impact will show the maximum penetration of the wheel rim, or other component into the abdomen. Both of these techniques will provide measurements which will be useful in determining the injury severity.

This device for measuring contact area was further refined under a NHTSA contract (36) to improve the accuracy. The switching array was expanded to 180 switches, monitored discretely, arranged on a 180 square inch area. The discrete method has numerous advantages over the parallel method originally used on the device, such as improved electronic accuracy and the potential to identify the specific location of each closed switch. The device was built into a vest which can be worn over the chest of a dummy. Since the area monitoring method used a discrete switching pattern of 1 inch squares, the accuracy of the device is very dependent on both size and shape of the contact surface. Based on geometric analysis and static and dynamic testing using common shapes (circles, squares, etc.), the accuracy appears to vary from 10% or less for larger areas (greater than 20 square inches) up to 30% for small areas (less than 4 square inches) when sufficient pressure is applied to close the switches.

A computer model has been developed to specifically address the unrestrained driver impacting the steering assembly in a frontal collision. This model entitled

Table 10. Steering column types.

Make/Model	EA Types	Other Features
Chevrolet Citation	Ball-tube	Cowl bracket guide
Volvo	Convoluted jacket	Self-aligned wheel
Ford Fairmont	Ring-tube	
Mercedes	Convoluted hub	EA unit in lower column
Honda	Hook bends plate	
Chrysler K-car	Mesh-Mandrel	

Table 11. Dynamic test results (phase II).

Column Test No. (inches)	Column	Mode	Speed (mph)	Peak Chest Acceleration (Gs)	Maximum Chest Deflection (inches)	Maximum Stroke
2251	Citation	Frontal	19.8	38.4	3.1	0.94
2254	Citation	Frontal	24.6	46.5	2.6	3.75
2282	Citation	Oblique	24.9	35.5	20.5	3.42
2260	Volvo	Frontal	19.0	28.7	1.6	3.50
2262	Volvo	Frontal	25.0	49.4	2.5	3.1
2278	Volvo	Oblique	24.9	40.5	1.92	2.2
2357	Fairmont	Frontal	20.0	39.7	1.6	3.05
2362	Fairmont	Frontal	25.0	61.1	2.9	3.8
2287	Fairmont	Oblique	25.0	50.6	2.7	1.8
2237	Hybrid	Frontal	19.7	34.0	1.6	2.5
2350	Hybrid	Frontal	25.0	47.9	1.95	4.5
2288	Hybrid	Oblique	25.1	36.6	1.76	1.2

SCORES (Steering Column and Occupant Response Simulation) was the subject of an SAE paper by Stucki and Fitzpatrick (37).

As noted in the report more work was needed to validate the model and to add the capability of modeling occupant impact with the windshield and/or header. As part of a larger computer modeling effort which was awarded in September 1982, the first task will be to incorporate the windshield and header into the current SCORES model and to validate these additions.

A program is currently being conducted at NHTSA's Safety Research Laboratory (SRL) to validate the SCORES model. Two passenger cars (Ford Fairmont and Chevrolet Citation) were selected for the study. All inputs for the modeling will be obtained from available sources such as vehicle and dummy specification, through direct measurement and from testing of dummies and steering assembly components. Frontal sled tests at 20 and 25 mph were conducted on both vehicles. The unrestrained driver dummy is the same Hybrid III which was used in the component tests to ensure consistent responses. These sled tests will be used as cases for the validation study, comparing dummy and steering assembly responses predicted by the SCORES model to the measured responses in the sled tests.

FUTURE PROJECTS

A project was recently started by the NHTSA to give a better understanding of harm resulting from steering assembly impact and methods of alleviating the problem. The following tasks, to be conducted, will contribute towards these objectives:

A. Establish relationship between injury and occupant and vehicle response measurements.
B. Extrapolate this analysis to a national representative accident environment such as that predicted by the NASS and/or NCSS files.
C. Propose countermeasures to reduce injuries and fatalities which will be applied to the predicted accident environment.
D. Analyze the effects of these countermeasures on injury and fatality, nationwide and select the most viable candidates for further development through sled and crash testing.

The spectrum of accidents will be those in which an injury to the occupant was caused from impact with the steering assembly. The form of the accident data will be a multi-element array of the following parameters:

(a) Body region injured.

(b) AIS level: 1 through 6.
(c) Vehicle Make/model, 1975 and later.
(d) Occupant size and sex: A maximum of 3 categories for each.
(e) Principle Direction of Force (PDOF): 11, 12, and 1 o'clock.
(f) Object contacted: Other vehicle or fixed object.
(g) Velocity change: Either 5 or 10 mph increments from 5 to 35 mph.

The SCORES computer model will be exercised for each cell of this matrix, i.e., for each make/model vehicle, occupant size, and sex, PDOF, object contacted, and velocity change SCORES will predict responses for each body region (for SCORES this is limited to head, chest, abdomen, and femurs). These responses will be converted to injury level (AIS) by the applicable biomechanical criteria for the particular body region. The outcome of this exercise will be an AIS level for each cell in the multi-element array. The frequency of occurrence can be applied to each cell and summed to give overall frequency of each AIS level for comparison with the actual accident file. If the AIS distributions are not similar between the SCORES prediction and the actual accident data, adjustments will be made to the SCORES inputs until good agreement is achieved.

One of the major efforts of this project is to acquire the inputs necessary to exercise SCORES on each cell of the matrix. The Transportation Systems Center (TSC) has responsibility for providing all vehicle dimensions for approximately 40 post-1974 passenger car lines which account for more than 90% of the passenger cars produced in this period (one car line will generally include several models). These measurements include dimensions such as steering column angle, wheel location, etc., and force-deflection properties of the wheel rim and energy absorber unit in the column.

TSC is also generating vehicle crash pulses for different velocity change, PDOFs, and object contacted. The final requirement for input is the anthropometric and biomechanical properties of the various occupant sizes for each sex. Much of this information currently exists for certain size occupants and may have to be extrapolated to other size occupants using engineering judgment.

The output of the SCORES model will be verified by checking against results of other models, such as the MVMA-2D, and sled and crash test results. The input parameters will continually be upgraded by this verification process and by the latest biomechanical criteria.

One of the primary injury risks to occupants involved in collisions is the relative velocity at which the occupant strikes interior contact surfaces. The SCORES output will provide the information, in terms of body part velocities and responses, needed to construct relationships between body part response (which can be converted to an injury level) and impact velocity. Figure 7 shows this relationship for the chest impacting the steering wheel hub, where the given responses are the most probable indicators of chest injury level. This is a preliminary analysis based on several SCORES runs with a 50th percentile male occupant and 1979 Volvo dimensions and properties. Once relationships such as these have been developed, countermeasures, which will lower the injury risk, in this case impact velocity, can be investigated using the SCORES Model.

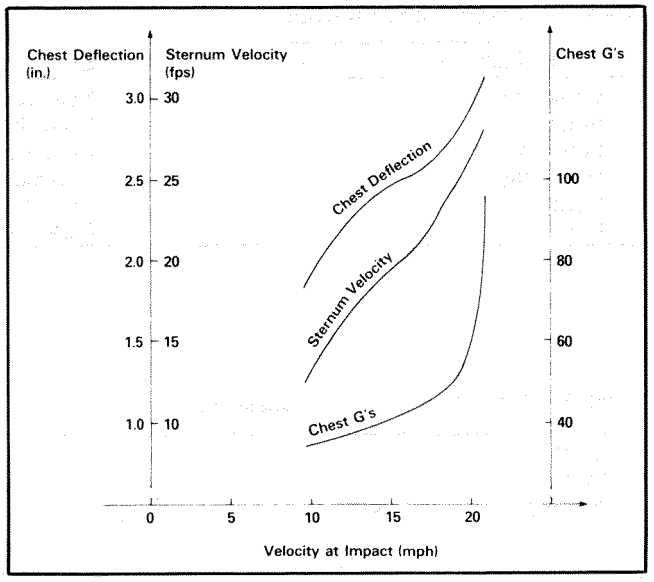


Figure 7. Chest/steering wheel hub impact.

SUMMARY

The steering column is responsible for producing more injuries and fatalities than any other vehicle component: 27% of all serious to fatal (AIS 3-6) injuries. Steering assembly impact with the chest and abdomen accounts for over 20% of all serious injuries.

The most appropriate continuous injury criteria for frontal impact to the thorax are based on maximum deflection and the rate at which the thorax deflection is produced. The most appropriate injury criteria for abdominal impact are abdominal penetration and rate of change of penetration.

An improved dynamic systems test has been developed and the performance of several steering assemblies evaluated.

A steering assembly computer model has been developed and is being validated.

We are establishing the relationship between injury and occupant and vehicle response measurements, investigating countermeasures, and analyzing the effects of these countermeasures on injury reduction.

REFERENCES

1. Marquis, D.P., "The General Motors Energy Absorbing Column" SAE Report 670039, Society of Automotive Engineers.
2. Recommended Practice J944, *1981 SAE Handbook*, Society of Automotive Engineers.
3. *Federal Register,* Vol. 31, National Archives, Washington, D.C., July 15, 1966, pg. 9631-2.
4. Kahane, C. J., "An Evaluation of Federal Motor Vehicle Safety Standards for Passenger Car Steering Assemblies; Standard No. 203—Impact Protection for the Driver, Standard No. 204—Rearward Column Displacement," DOT Report No. DOT-HS-805 705, 1981.
5. *Federal Register,* Vol. 32, National Archives, Washington, D.C., February 3, 1967, pg. 2414.
6. Garrett, J. W., "A First-Look-Differences in Injuries in 1968 and Pre-1968 Automobiles," Society of Automotive Engineers Report No. 680542, August 1968.
7. Huelke, D. F., and Chewning, W. A., "The Energy Absorbing Steering Column," Highway Safety Research Institute, Report B10-7, 1968, (DOT-HS-002 615).
8. Nahum, A. M., Siegal, A. W., and Brooks, S., "The Reduction of Collision Injuries; Past, Present, and Future," Society of Automotive Engineers, Report No. 700895, 1970.
9. Levine, D. N., and Cambell, B. J., "Effectiveness of Lap Belts and the Energy Absorbing Steering Systems in the Reduction of Injuries," Highway Safety Research Center, November 1971, (DOT-HS-011 537).
10. O'Day, J., and Creswell, J. S., "Can The Effect of Changes in Vehicle Design be Seen in Mass Accident Data?" *HIT LAB Reports,* University of Michigan, February 1971 (DOT-HS-009 811).
11. McLean, A. J., "Collection and Analysis of Collision Data for Determining the Effectiveness of Some Vehicle Systems" Motor Vehicle Manufacturers Association, 1974.
12. Kahane, C. J., "Evaluation of Current Energy Absorbing Steering Assemblies" Society of Automotive Engineers, Report No. 820473, 1982.
13. *Federal Register,* Vol. 44, No. 321, National Archives, Washington, D.C., November 29, 1979.
14. Huelke, D. F., and Gikas, P. W., "How Do They Die? Medical Engineering Data From On-Scene Investigation of Fatal Automobile Accidents" Highway Vehicle Safety, Society of Automotive Engineers, 1968.
15. Malliaris, A. C., Hitchcock, R., and Hedlund, J., "A Search For Priorities In Crash Protection", Society of Automotive Engineers, Report No. 820242, 1982.
16. Cohen, D. S., Jettner, E., and Smith, W. E., "Light Vehicle Frontal Impact Protection", Society of Automotive Engineers, Report No. 820243, 1982.
17. Stucki, S.L., and Hannemann, N., "Study of Steering Assemblies for Evaluation and Rating of Safety Performance", Society of Automotive Engineers, Report No. 820476, 1982.
18. Gloyns, P. F., and Mackay, G. M., "Impact Performance of Some Designs of Steering Assembly in Real Accidents and Under Test Conditions", SAE Paper 741176, Proceedings of the Eighteenth Stapp Car Crash Conference, 1974.
19. Garrett, J. W., and Hendricks, D. L., "Factors Influencing the Performance of the Energy Absorbing Steering Column in Accidents", 5th International Conference on Experimental Safety Vehicles, London, England, June 1974.
20. Viano, D. C., and Warner, C. Y., "Thoracic Impact Response of Live Porcine Subjects", 20th Stapp Car Crash Conference, October 1976.
21. Kroell, C. K., Schneider, D. C., and Nahum, A. M., "Impact Tolerance and Response of the Human Thorax II", 18th Stapp Car Crash Conference, December 4-5, 1974.
22. Neathery, R. F., Kroell, C. K., and Mertz, H. J., "Prediction of Thoracic Injury from Dummy Responses", 19th Stapp Car Crash Conference, November 17-19, 1975.
23. Nahum, A. M., Schneider, D. C., and Kroell, C. K., "Cadaver Skeletal Response to Blunt Thoracic Impact", 19th Stapp Car Crash Conference, November 17-19, 1975.
24. Draper, N. R., and Smith, H., "Applied Regression Analysis", Second Edition, John Wiley and Sons, Inc., New York, 1981, pg. 8.
25. Eppinger, R. H., and Chan, H. S., "Thoracic Injury Prediction via Digital Convolution Theory", 25th Stapp Car Crash Conference, October 1981.
26. Fayon, A., Tarriere, C., Walfisch, G., Got, C., and Patel, A., "Thorax of 3-Point Belt Wearers During a Crash (Experiments with Cadavers)", 19th Stapp Car Crash Conference, November 17-19, 1975.
27. Jonsson, A., Clemedson, C. J., Sundquist, A. B., and Arvebo, E., "Dynamic Factors Influencing the Production of Lung Injury in Rabbits Subjected to Blunt Chest Wall Impact", Aviation, Space, and Environment Medicine, Vol. 50, No. 4, April 1979, pp. 325–337.
28. Viano, D. C., Kroell, C. K., and Warner, C. Y., "Comparative Thoracic Impact Response of Living and Sacrificed Porcine Siblings", 21st Stapp Car Crash Conference, October 19–21, 1977.
29. Kroell, C. K., et al., "Interrelationship of Velocity and Chest Compression in Blunt Thoracic Impact to Swine", 25th Stapp Car Crash Conference, September 28–30, 1981.
30. Melvin, J. W., Mohan, D., and Stalnaker, R. L., "Occupant Injury Assessment Criteria", Warrendale, Pennsylvania, SAE Paper No. 750914, 1975.
31. Stalnaker, R. L., et al., "Door Crashworthiness Cri-

teria", Final Report for Contract No. DOT-HS-031-2-382, September 1973.
32. Melvin, J. W., et al., "Impact Injury Mechanisms in Abdominal Organs", 17th Stapp Car Crash Conference, November 1973.
33. Lau, V. K., and Viano, D. C., "Influence of Impact Velocity on the Severity of Nonpenetrating Hepatic Injury", *Journal of Trauma*, Vol. 21, November 2, 1981.
34. Mertz, H. J., and Kroell, C. K., "Tolerance of Thorax and Abdomen", *Impact Injury and Crash Protection*, Charles C. Thomas, Springfield, Illinois, 1970.
35. Beckman, D. L., et al., "Impact Tolerance—Abdominal Injury", Report No. DOT-HS-800 549, June 30, 1971.
36. Broadhead, W. G., Final Report, Contract No. DTNH22-82-P-07024, "Development of a Measuring Device for Chest Contact Area", June 30, 1982.
37. Stucki, S. L., and Fitzpatrick, M. U., "A Computer Model for Simulating an Unrestrained Driver in Frontal Collisions", Society of Automotive Engineers Report No. 820469, 1982.

A Study on the Ride-Down Evaluation

HIROSHI KATOH and RYOJI NAKAHAMA
Passenger Car Engineering Center
Mitsubishi Motors Co., Ltd.

ABSTRACT

The injury of occupants restrained by seat belt is dominantly affected by the vehicle crash characteristics and seat belt effectiveness. Matching both performances is essential in attaining occupant's safety with most reasonable weight and cost.

Hitherto the efficiency of occupant's energy disposal has been evaluated in terms of a concept of Ride-Down, a ratio of energy absorbed vicariously by the vehicle to the occupant's initial kinetic energy.

This long established idea, however, has a certain limit for further analysis. In this paper, a new method of assessing relative effectiveness of vehicle structure and seat belt system is proposed to enable to attain a balanced approach as a whole.

The Ride-Down efficiency is decomposed to one that concerns vehicle structure and the other that relates to restraint system. The former is determined as relative Ride-Down efficiency when the simulated system of the vehicle is subjected to collision with a standard restraint system. The latter is obtained in the relation of conventional and the newly obtained method.

The two-way Ride-Down approach paves the way to indicating straightforwardly the most effective direction in which occupant protection is harmoniously attained in each vehicle design.

INTRODUCTION

The trend toward smaller car and weight reduction of automobiles has progressed increasingly to save energy and material.

To make down-sizing and safety compatible, it is well known to be important to utilize Ride-Down phenomena effectively.

Many studies (Refs. 1-8) have been made regarding what kind of vehicle crash characteristics or seat belt one can decrease occupant injury with.

However, there seems no study to clarify the effect of seat belt and vehicle crash characteristics on Ride-Down efficiency. It is difficult to separate the effect of seat belt and that of vehicle body, since Ride-Down phenomena consist of a combined effect of vehicle crash characteristics and seat belt ones.

Here an idea, which we call "Ride-Down index," is introduced and utilizied for safety design to evaluate each effect of vehicle body and seat belt separately.

RELATIONSHIP BETWEEN RIDE-DOWN EFFICIENCY AND PASSENGER CHEST DECELERATION

Figure 1 shows the macrosocopic model of vehicle collision against fixed barrier. K is a spring which denotes seat belt and is assumed constant.

Passenger energy absorption is written in equation (1).

$$1/2M\ Vo^2 = M\ddot{X}_1 dX_2 + 1/2\ K\ (X_1 - X_2)^2 \quad (1)$$

where M : Passenger mass
Vo : Velocity at collision
$\ddot{X}_1$: Passenger deceleration
$\ddot{X}_1$: Passenger displacement
X_2 : Vehicle displacement
K : Spring constant of seat belt

The first term of right hand of equation (1) denotes the energy which vehicle body vicariously absorbs and is generally called Ride-Down energy. The rate of Ride-Down energy to initial passenger kinetic energy (1/2 M Vo^2) is called Ride-Down efficiency. That is

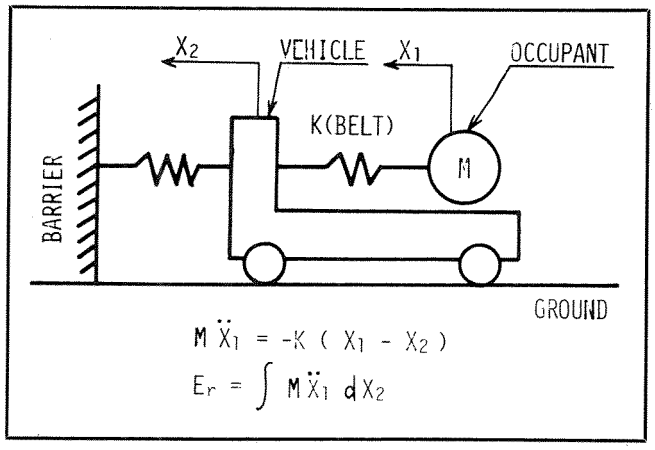


Figure 1. Macroscopic model of collision.

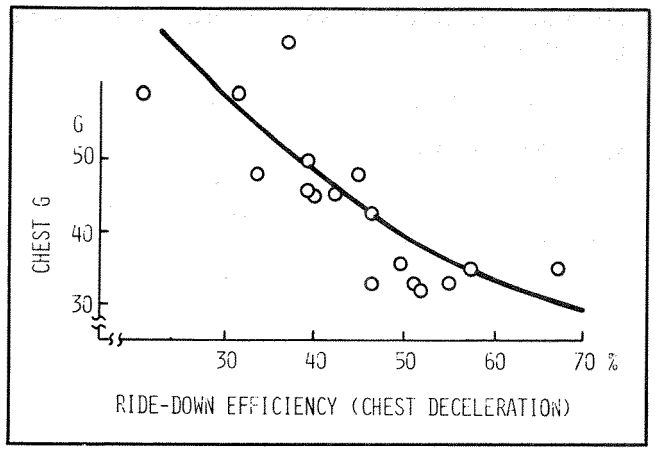


Figure 2. Passenger chest G and Ride-Down efficiency.

Ride-Down energy:

$$Er = \int_0^{X_2 max} M\ddot{X}_1 dX_2 \qquad (2)$$

Ride-Down efficiency:

$$n_t = \frac{\int_0^{X_2 max} M\ddot{X}_1 dX_2}{1/2\ M\ Vo^2}$$

where X_2max : Maximum vehicle displacement

Furthermore, it is well known that Ride-Down efficiency is closely related to occupant injury value. Figure 2 shows this relationship between Ride-Down efficiency and passenger chest deceleration of frontal collision tests at 35 mph. Here Ride-Down efficiency is calculated according to equation (2) where $\ddot{X}_1$ is replaced with fore and aft component of passenger chest deceleration. These data are based on 35 mph collision tests performed on various vehicles since 1978 as a part of NCAP (New Car Assessment Program) by NHTSA (National Highway Traffic Safety Administration) in U.S.A.

Figure 2 clearly indicates the relationship that passenger chest deceleration decreases as Ride-Down efficiency increases.

However, since Ride-Down efficiency, as shown in Figure 1 and equation (2), is the result of a combined effect of both vehicle body and seat belt, each effect cannot be estimated separately. But from the standpoint of safety design, if each effect of vehicle body and seat belt can be estimated independently, it is very useful.

INTRODUCTION OF "RIDE-DOWN INDEX"

Considering the collision model shown in Figure 1, we assume that seat belt has the characteristics shown in Figure 3(A), where spring rate K is constant and initial slack δ_0 is chosen as a parameter of seat belt characteristics. Besides vehicle crash characteristics are defined by sine wave deceleration time history shown in Figure 3(B), and maximum deceleration Gm is selected as a parameter of vehicle body characteristics. Because the collision velocity is constant (35 mph), Gm·Tt becomes constant.

In this simple model, Ride-Down efficiency ηt becomes a function of two variables (Gm, δ_0). In order to obtain each effect of vehicle body and seat belt, we keep either Gm or δ_0 constant and vary the other. Then "Ride-Down index of vehicle body" ηv is for convenience defined as a function of Gm (while δ_0 = const.). Similarly "Ride-

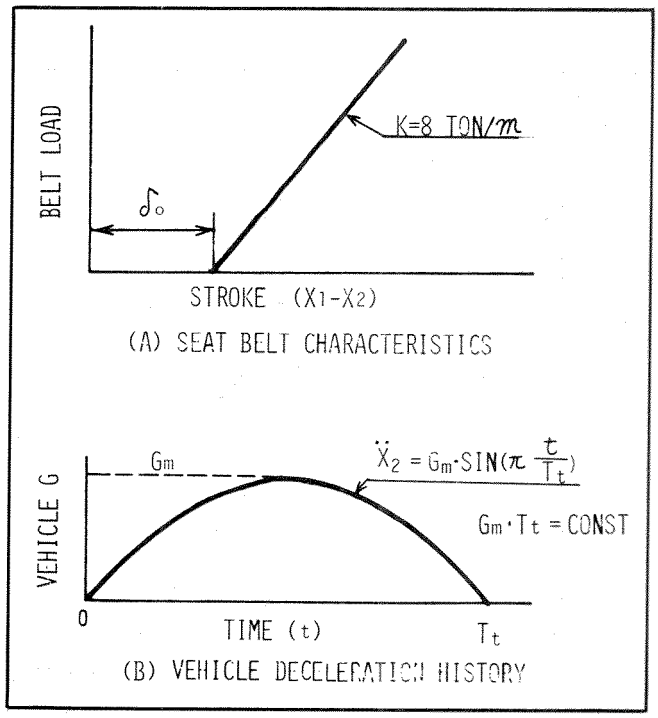


Figure 3. Conditions used for calculation.

Down index of seat belt" ηb is defined as a function of δ_0 (while Gm = const.). That is

$$\text{Ride-Down efficiency} \quad \eta t = f(\delta_0, \text{Gm})$$

$$\text{Ride-Down index of vehicle body} \quad \eta v = f(\delta_{0B}, \text{Gm}); \ \delta_{0B} = \text{const. (5 mm)} \qquad (3)$$

$$\text{Ride-Down index of seat belt} \quad \eta b = f(\delta_0, \text{Gm}_B); \ \text{Gm}_B = \text{const. (17G)}$$

where

δ_0 : seat belt slack

δ_{0B} : the slack of the standard seat belt (5 mm)

Gm : maximum vehicle deceleration

Gm_B: maximum vehicle deceleration of the standard vehicle (17 G)

The value of δ_{0B}, Gm_B is selected practically as the most optimum value after various attempts were made.

Then, simulation calculation results in the constant ηt curves shown in Figure 4. Now ηt is divided into ηb and ηv. Therefore we can estimate each effect of vehicle body and seat belt on the Ride-Down efficiency ηt, and the most cost-benefit direction on the improvement of ηt can be indicated. The change in ηt due to the variation in ηv or ηb can be respectively estimated using Figure 4. For example, in case of ηt = 30% and ηb = 40%, ηv is shown to be large, about 80%. Therefore to increase ηt, it seems more practical to improve ηb rather than ηv. On the other hand,in case of ηt = 30%, ηv = 40%, it seems better to improve ηv rather than ηb.

Figure 5 shows the flow chart of actual improvement method.

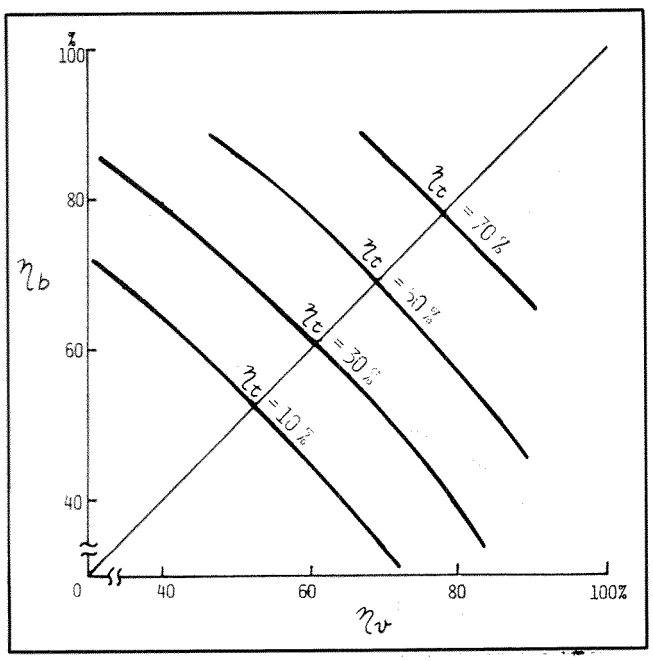


Figure 4. Constant value lines of ηt.

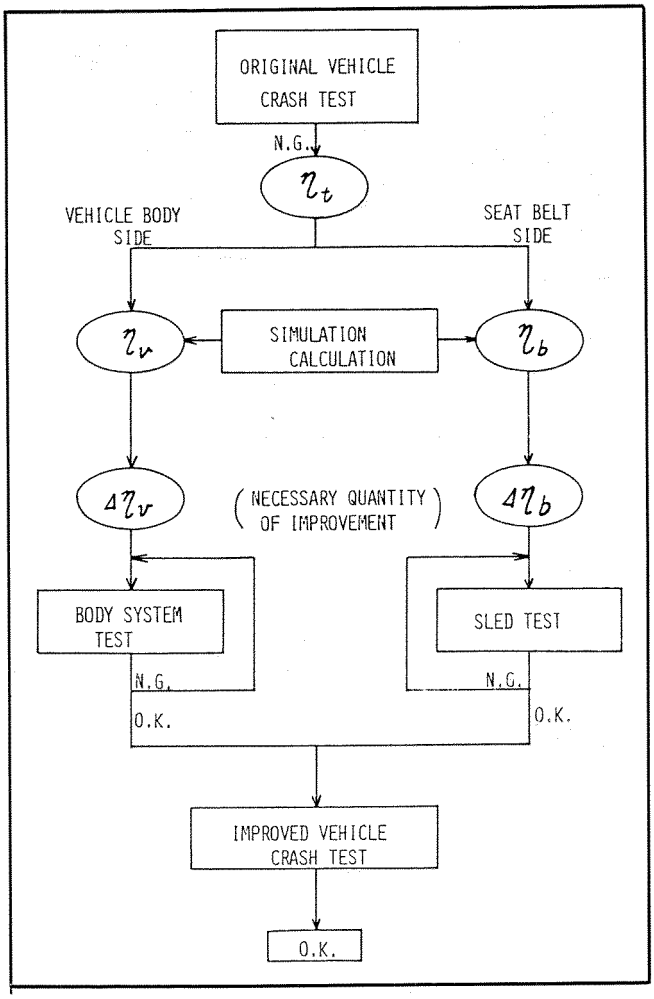


Figure 5. Flow chart of improvement method.

THE METHOD TO OBTAIN ηb AND ηv IN ACTUAL TEST

First, ηt is obtained from actual test data by substituting the fore and aft component of passenger chest deceleration as $\ddot{X}_1$ into equation (2).

In order to obtain ηv, two-dimensional simulation model shown in Figure 6 is used. Here seat belt characteristics shown in Figure 7 are applied for all vehicles, and for vehicle crash characteristics, vehicle deceleration time history of the actual test is used. Then ηv is obtained.

Two-dimensional simulation model is used here instead of one-dimensional model shown in Figure 1 because the chest deceleration can be calculated in two-dimensional model. Then ηv using the chest deceleration in two-dimensional simulation becomes comparable with ηt substituting the chest deceleration measured in actual test as described above.

Accordingly ηb can be known when ηt, ηv are plotted on Figure 4. Now the effect of vehicle crash characteristics and seat belt characteristics on Ride-Down efficiency in actual test can be obtained separately.

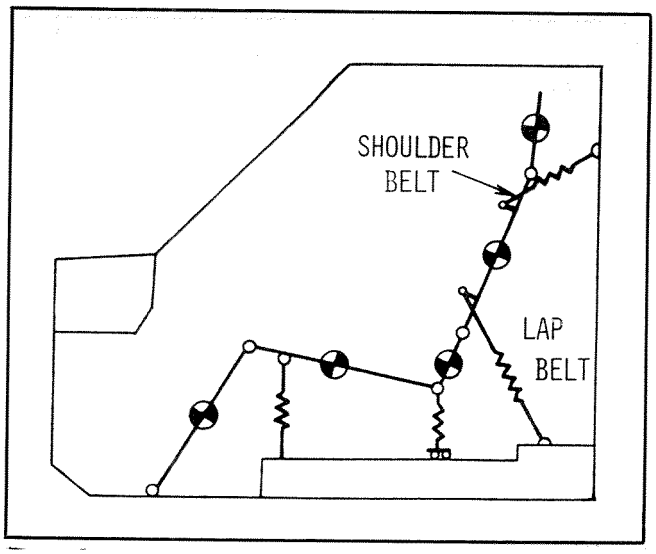


Figure 6. Two-dimensional simulation model.

Here a consideration must be given to the fact that ηv and ηb are not really independent, so evaluation by ηv and ηb are not absolute but relative. However, within the scope of actual vehicle collision, ηv and ηb are considered to be of practical significance in evaluating each functions of the various vehicles relatively.

ηb can be approximately obtained by the following simple method. As we take δ_0 as a parameter of seat belt characteristics, consider the seat belt slack δ_{100}, which indicates relative displacement between passenger and vehicle when shoulder belt load reaches 100 kg (220 lb.).

δ_{100}: relative displacement between passenger and vehicle when shoulder belt load reaches 100 kg (220 lb.).

Here δ_{100} is chosen instead of δ_0 in Figure 3(A), because it is difficult to obtain δ_0 in actual test.

Figure 8 shows the relationship between ηb and δ_{100}. It can be said that they are mutually related. From Figure 8, ηb can be approximately obtained if δ_{100} is known.

APPLICATION TO TEST DATA

Figure 9 shows the summary of ηv, ηb for various vehicles subjected to NCAP crash tests at 35 mph. The

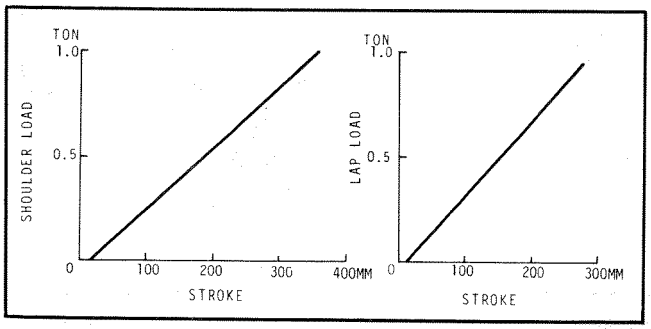


Figure 7. Seat belt characteristics used for calculation.

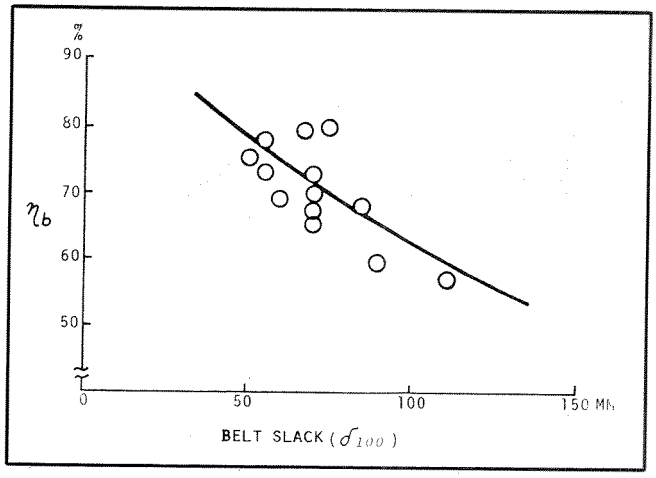


Figure 8. Seat belt slack and ηb.

data are classified based on whether the vehicle passed injury criteria of FMVSS 208 or not.

To pass injury criteria, $\eta t \geqq 50\%$ becomes a necessary condition.

Furthermore, improvement direction and quantity can be easily obtained from Figure 9. For example, ηv of vehicle A is almost the same as that of vehicle B, but ηb is considerably different and as a result vehicle B could not pass injury criteria. If vehicle B were equipped with the same seat belt as vehicle A, vehicle B could be expected to pass the criteria. Keeping ηb at the same value, and increasing ηv up to 83%, a similar result could be expected.

EXAMPLE OF ACTUAL IMPROVEMENT

Figure 10 shows a result of improvement on vehicle C_1 in Figure 9. As ηv of vehicle C_1 is relatively high, im-

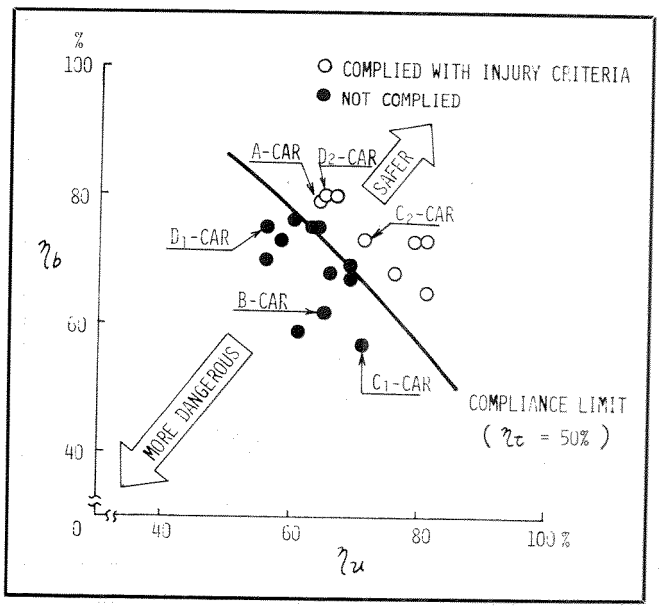


Figure 9. Test data arranged by ηv and ηb.

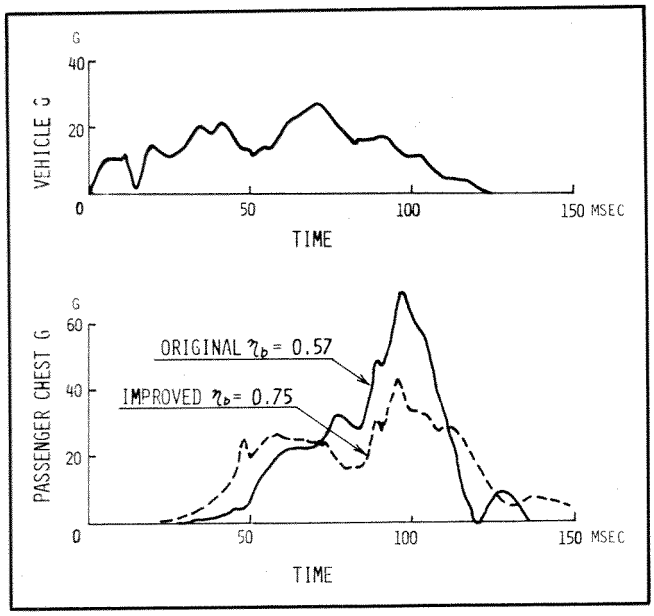


Figure 10. Example improved by increasing ηb (C_1 and C_2 car in Figure 9).

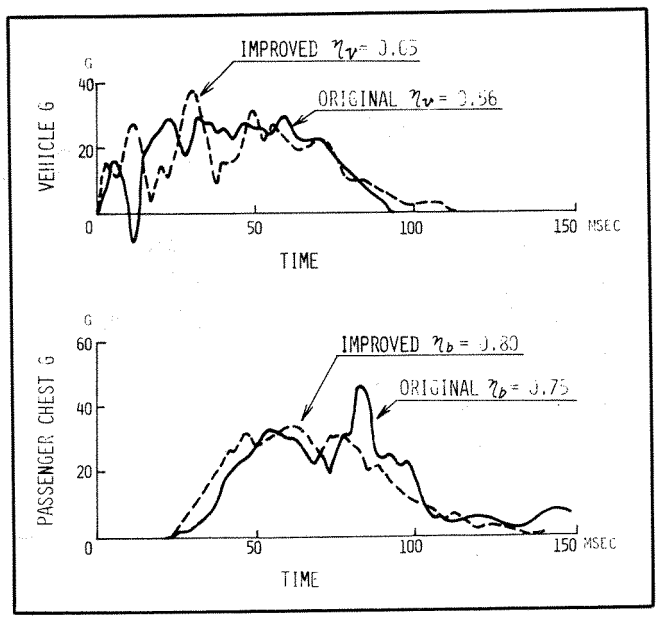


Figure 12. Example improved by increasing both ηv and ηb (D_1 and D_2—car in Figure 8).

provement of ηb was made. In original test (C_1) δ_{100} = 120 mm and ηb = 57%. To pass injury criteria, ηb must be increased up to 75% and seat belt slack δ_{100} must be shortened by about 60 mm from Figure 8. Therefore seat belt retractor was modified to minimize the spool-effect or spool-out due to squeezed winding around the spool, and the favorable result (C_2) is obtained.

Figure 11 also shows the example of seat belt improvement on another vehicle at 30mph collision.

Figure 12 shows the case of improvement made on both vehicle body and seat belt. This case is expressed as vehicle D_1 (original) and D_2 (improved) in Figure 9.

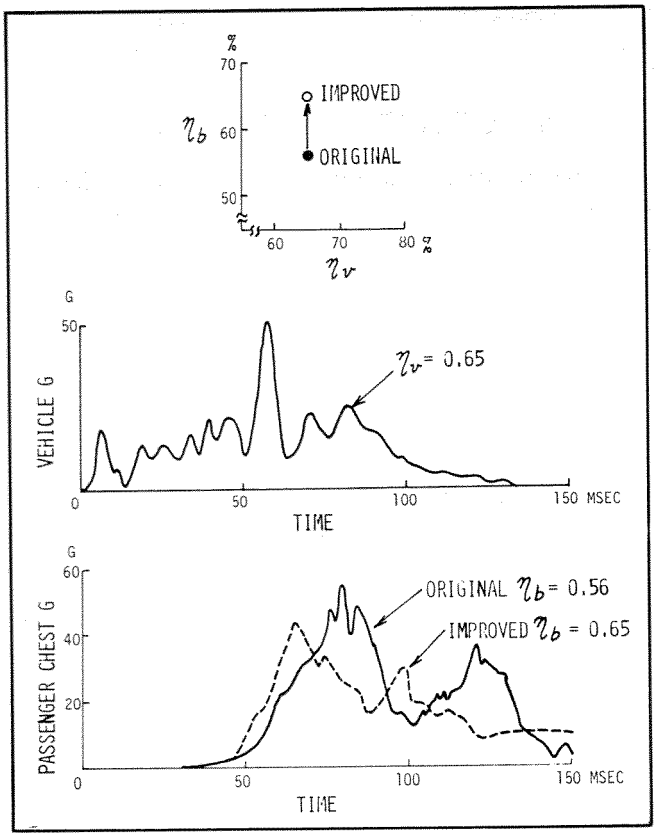


Figure 11. Example improved by increasing ηb (at 30 mph).

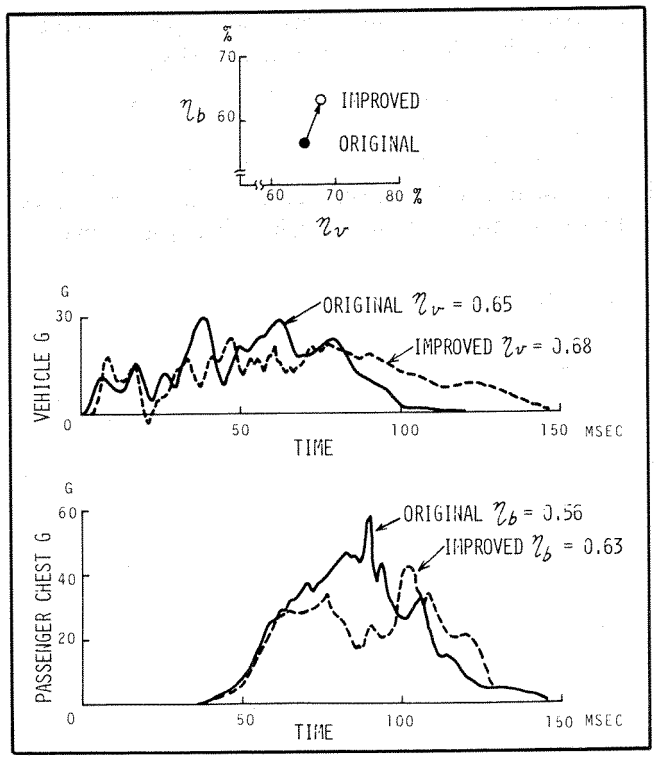


Figure 13. Example improved by increasing both ηv and ηb (at 30 mph).

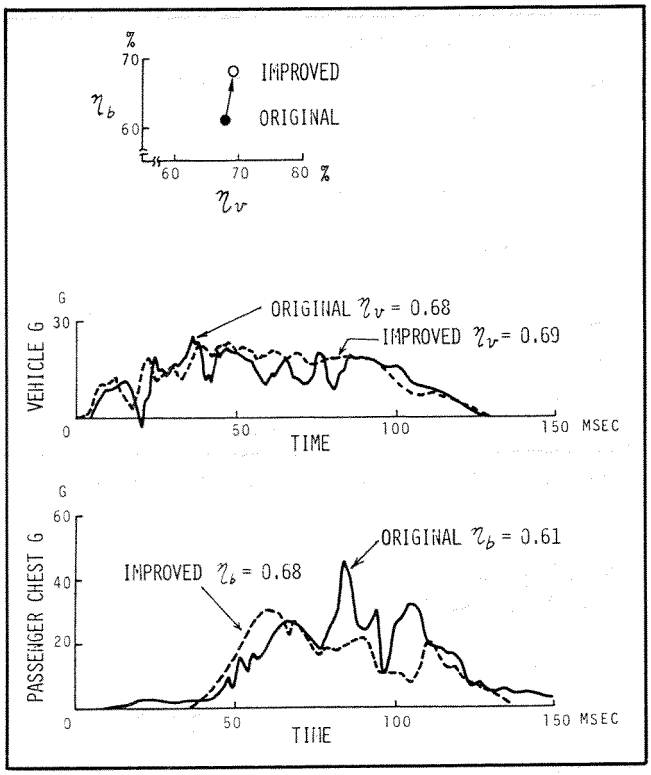


Figure 14. Example improved by increasing both ηv and ηb (at 30 mph).

Figures 13 and 14 also show the test results of the similar improvement made on both vehicle body and seat belt. Generally, if the base body structure is unchanged, it seems very hard to increase ηt without changing the front side member layout largely.

CONCLUSION

(1) Ride-Down efficiency ηt has a close relation to the occupant injury value in the vehicle frontal collision.
(2) The new idea to separate the effect of seat belt and vehicle body on the Ride-Down efficiency (ηt) is proposed.
(3) The vehicle crash characteristics can be evaluated by Ride-Down index of vehicle body (ηv) which is obtained by using the mathematical simulation with the standard seat belt.
(4) The seat belt characteristics can be evaluated by Ride-Down index of seat belt (ηb) which is obtained by using the mathematical simulation with the standard vehicle body.
(5) By using ηb and ηv, the problem of which side and how much improvement of vehicle body and seat belt should be made is easily clarified. This idea of Ride-Down index is practically useful for safety design.

REFERENCES

1. R. McHenry et al., "Computer Simulation of the Crash Victim—A Validation Study", SAE 660792.
2. H. Furusho, "Effect of Vehicle Body Crush Characteristics on Occupant Second Collision", JSAE VOL 22, No. 8, 1968.
3. D. F. Moore, "Minimization of Occupant Injury by Optimum Front-End Design", 1970 International Automobile Safety Conference Compendium.
4. R. McHenry, "Analysis of the Dynamics of Automobile Passenger-Restraint System", 7th Stapp Car Crash Conference.
5. K. Higuchi, "Characteristics of Body Energy Absorption and Restraint System", 5th International Technical Conference on E.S.V.
6. N. Aya, "A Method How to Estimate the Crashworthiness of Body Construction", 6th International Technical Conference on E.S.V.
7. N. Bohlin, "Safety and Comfort Factors in Volvo Occupant Compartment Packaging", SAE 780135.
8. H. Nakaya, "Collision Safety Design by Structural Analysis", JSAE VOL 34, No. 9, 1980.

Optimizing Knee Restraint Characteristics for Improved Air Bag System Performance of a Small Car

HIDEO TAKEDA and SABURO KOBAYASHI
Honda R & D Co., Ltd.

ABSTRACT

The two known systems for restraining vehicle occupants in a crash situation are the seat belt and the air bag. A series of head-on crash tests against a barrier indicated that these restraining devices present widely different G waveforms for the chest of a dummy seated behind the steering wheel as the crash pulse becomes more severe. The dummy chest, when restrained by a seat belt, showed a gentle G waveform, while with an air bag, it presented another waveform with unusual spikes.

An analysis of the test findings reveals that spikes in chest G are always accompanied by similar spikes in G for the pelvis. It was found that this is attributable to a substantial shock when the dummy's upper leg contacts the molded pelvic structure. This suggests that the existing dummy might have some structural deficiency. This con-

tact occurs when the restraining force for the upper torso of the dummy is much less than that for the pelvis.

An air bag was used to restrain the driver's upper torso and a knee restraint to hold the pelvis. The restraining force for the upper torso was limited by the characteristics of the bag. Therefore, use of a softer knee bolster appeared to be the only available alternative for keeping the upper and lower restraining forces well-balanced.

Another series of crash tests was conducted on an improved air bag system using softer knee bolsters. The findings indicate that the improved system can allow gentle G waveforms even with severe crash pulses despite the shortcoming of the existing dummy.

INTRODUCTION

A series of head-on crash tests against a barrier was conducted to develop a suitable air bag for small cars. When the vehicle crash speed was increased from 30mph to 35mph and the vehicle structure modified accordingly, unusual spikes began to appear frequently in chest G for the driver side dummy. Available data were analyzed by various methods to find why such spikes occur and how they could be precluded. This report discusses the research efforts that have successfully solved the chest G spike problem.

AIR BAG/SEAT BELT-RESTRAINED DRIVER CHEST G

Figures 1 and 2 present typical chest G for the driver dummy restrained by two alternative methods—an air bag and a seat belt—in 30mph and 35mph head-on crash tests against a barrier. The dummy chest, when restrained by a seat belt, continued to show a gentle G waveform with no appreciable change even if the crash speed was increased to 35mph, while with an air bag, it presented another waveform with unusual spikes at 35mph crash speed.

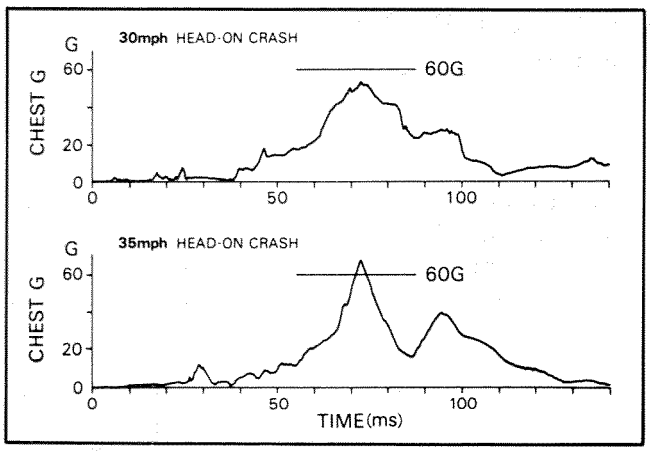


Figure 1. Air bag-restrained driver dummy chest G.

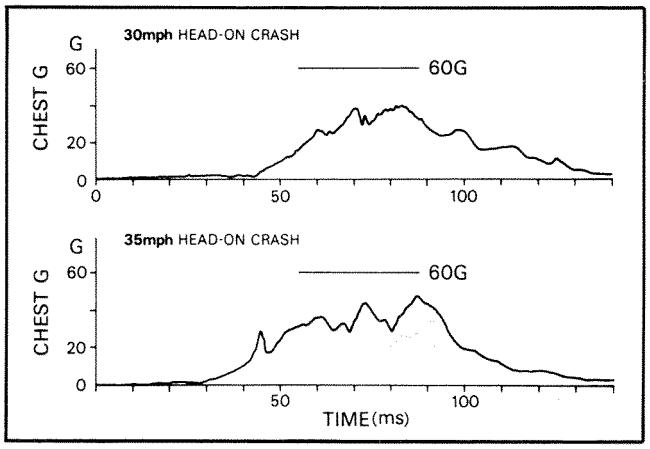


Figure 2. Seat belt-restrained driver dummy chest G.

CONCEIVABLE CAUSES OF UNUSUAL CHEST G SPIKES

Initially, we simply attributed the unusual spikes in chest G to inadequate energy-absorbing capability of the air bag system. Therefore a variety of techniques were developed to increase the energy-absorbing capability including the use of a larger air bag, increased gas generator capacity, and a longer stroke for the energy-absorbing column. None of them resulted in any appreciable improvement.

Longitudinal, vertical, and lateral G traces were separately analyzed in relation to the position of the dummy from high speed films. The analysis revealed that a vertical G spike always appeared immediately preceding a longitudinal G spike. The findings led to the assumption that unusual spikes in chest vertical G create big longitudinal G with high peaks and deep valleys. (See Fig. 3.) The dummy's behavior was carefully examined with particular attention given to the movement of its pelvis because this region is the only conceivable source of vertical G input.

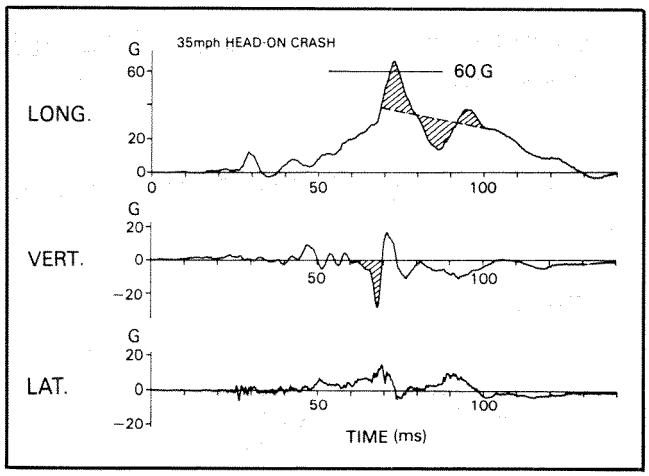


Figure 3. Typical measured chest G with unusual spike.

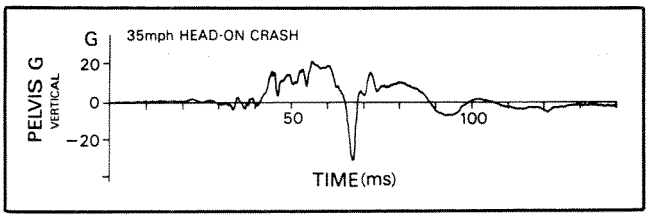


Figure 4. Typical measured pelvis G.

As shown in Figure 4, it was found that the vertical G for the pelvis has similar spikes as those in the chest vertical G.

Figure 5 shows another important finding: these spikes occur when the hip joints reach their maximum angle due to the upper leg segments firmly contacting the molded pelvic structure. Unlike the dummy, we can bend over until our thighs touch the abdomen. This suggests that the existing dummy might have some structural deficiency. The impact occurring under this condition is presumably transmitted to the chest through the steel cable which forms the central core of the lumbar spine as shown in Figure 5.

RESEARCH EFFORTS TO REDUCE CHEST G SPIKES

Chest G spikes might occur, as noted earlier, when the dummy's hip joints are bent to the utmost limit. It was assumed therefore that the spikes could be removed simply by reducing the extent to which the hip joints bend in a crash test.

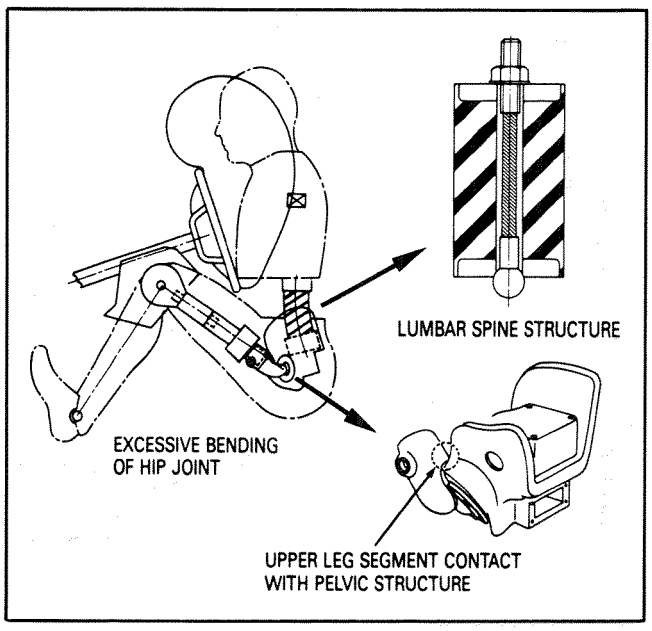


Figure 5. Excessive bending of hip joint.

Major Factors of Large Hip Joint Bending

In our crash tests on air bag systems, the dummy's upper torso was restrained by an air bag, while pelvis was held by a knee bolster. The sharp bending of the hip joints is attributable to a large difference between these two systems in developing restraining force. (See Fig. 6.)

The air bag cannot develop a restraining force as quickly as the knee bolster since the gas inside the bag has to be compressed by the dummy to some extent to produce a sufficient reaction force. The difference between these systems' initial restraining forces permits the upper torso of the dummy to move forward substantially more than the lower part in a crash situation. This is probably why the hip joints bend sharply.

As noted earlier, unusual spikes in chest G began to appear after the vehicle crash speed was increased to 35mph and the vehicle structure stiffened as required. In other words, a crash of a stiffer vehicle structure at a speed 5mph faster than the previous level reduced the crash pulse duration. As the crash pulse becomes more severe, the imbalance in restraining forces between the air bag and knee bolster systems becomes greater. This is a significant factor affecting hip joint bending.

System Improvements to Reduce Hip Joint Bending (Table 1)

The following paragraphs discuss the system improvements we made to reduce sharp hip joint bending and the problems we faced in working out such improvements.

Several attempts were made to improve the unfavorable characteristics of the air bag in developing a restraining force. These improvement efforts included the use of a larger bag and increased gas generator capacity for faster bag deployment. As discussed earlier, however, a series of tests revealed that none of these changes resulted in any appreciable improvement and at the same time tended to increase air bag deployment noise.

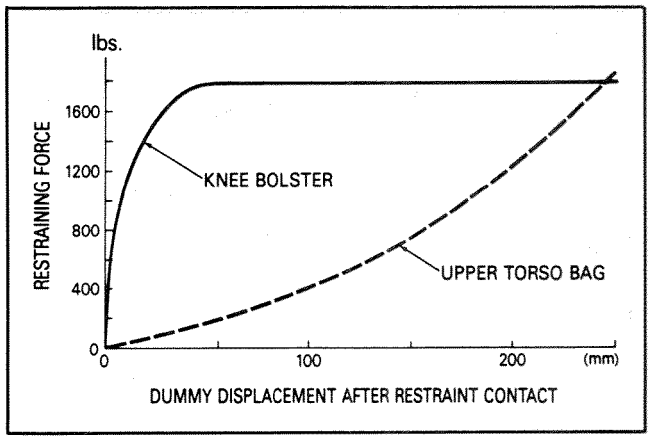


Figure 6. Typical restraining force of knee bolster and upper torso bag.

Table 1. Causes and remedies of sharp hip joint bending.

	Causes	Remedies	Problems
1	Inadequate air bag capability to quickly develop a restraining force	Use of a larger bag and faster deployment system	Larger noises during bag deployment
2	Greater restraining force of the knee bolster	Reduction of the knee bolster's restraining force by increasing its crush	Reduced passenger leg space in a small automobile

We concluded that the only available means to ensure well-balanced restraining forces for the upper and lower parts of the dummy would be to reduce the knee bolster's restraining force. Our improvement efforts were then concentrated on the development of a modified knee bolster.

KNEE BOLSTER MODIFICATION

A series of 35mph head-on crash tests against a barrier using a buck was conducted with knee bolsters of different hardness levels and sizes installed at different distances from the occupant. The findings may be summarized as follows: As shown in Figure 7, a greater forward displacement of the pelvis results in lower chest G. In other words, favorable results can be achieved if the knees sink deeper into the bolster. However, when a smaller, harder knee bolster is used to minimize the required space and is installed farther away from the occupant to allow a greater forward displacement of the pelvis, spikes in chest G still occur if the bolster's collapsing load exceeds a 1400 lb. level in femur load equivalent. A knee bolster installed closer to the occupant to immediately produce a restraining force also fails to preclude chest G spikes because it stops the forward movement of the dummy's pelvis too early and causes sharp hip bending. These findings suggest that a satisfactory solution to the chest G spike problem requires the use of a larger, softer knee bolster which has a much smaller collapsing load than the allowable femur load limit as specified in FMVSS 208. The knee bolster must be installed at a proper distance from the occupant to allow sufficient forward displacement of the pelvis.

Figure 8 shows typical examples of chest G curves recorded at average femur loads of 1720 lb., 1350 lb., and 1100 lb. As is apparent from the diagram, vertical chest G spikes become smaller, reducing the maximum resultant chest G, as femur load decreases.

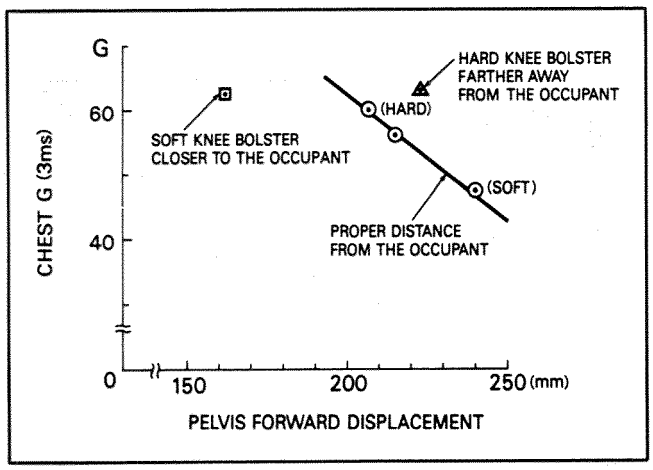


Figure 7. Pelvis forward displacement vs. chest G.

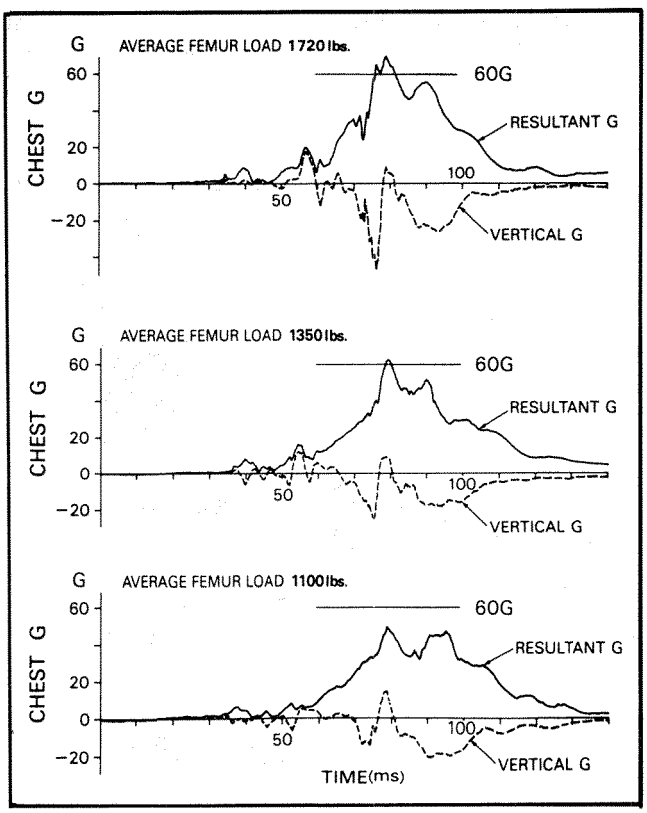


Figure 8. Typical chest G with different femur load.

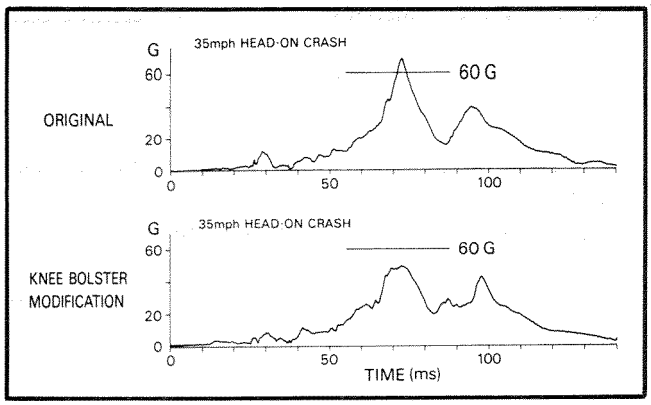


Figure 9. Effects of knee bolster modification on chest G.

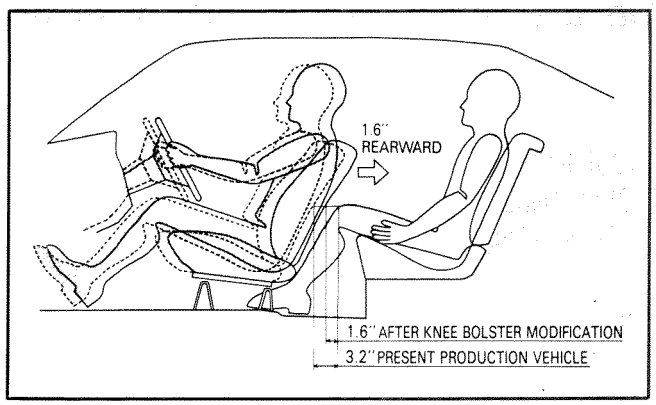


Figure 10. Required seat positioning.

FULL-SCALE CRASH TESTS

Some full-scale crash tests were performed to demonstrate the effects of the above remedies for chest G spikes. Figure 9 shows the chest G traces recorded before and after the improvements were made in the knee bolster. As expected, the results are similar to those of the buck tests; no unusual spikes appeared in chest G. The improved restraint system produced acceptable head and chest G and femur loads in a 35 mph head-on crash test against a barrier. (See Table 2.)

CONCLUSION

The modification of knee bolster characteristics enabled us to prepare an experimental vehicle with a driver air bag system that produced good results. Unusual spikes in chest G traces appearing when the dummy's hip joints are bent to the utmost limit are very likely to occur in small automobiles that have severe crash pulses. The improvement of the restraint system discussed in this report required the use of a larger knee bolster. Therefore the front seats had to be moved rearward to give the driver sufficient leg space to freely to operate the control pedals. This unfavorably affected the interior layout of the car as the rear leg space was reduced substantially. (Fig. 10) Installing an air bag system in an existing small vehicle design will drastically impact its basic layout and utility.

Table 2. Test results with air bag system—research stage (35 mph head-on crash).

Driver			
HIC	Chest G	Femur load [lbs]	
		Left	Right
465	50.5	1526	1854
859	58.5	1790	1416
437	47.2	1557	1438
364	55.8	1616	1447

REFERENCES

1. D. Theodore Zinke, "Small Car Front Seat Occupant Inflatable Restraint System, Volume II—Citation Air Bag Systems".
2. H. T. E. Hertzberg, "The Anthropology of Anthropomorphic Dummies", 13th STAPP Car Crash Conference.
3. Gerald W. Nyquist and Clarence J. Murton, "Static Bending Response of the Human Lower Torso", 19th STAPP Car Crash Conference.
4. Naveen K. Mital, Richard Cheng, Robert S. Levine and Albert I. King, "Dynamic Characteristics of the Human Spine During — G_x Acceleration", 22nd STAPP Car Crash Conference

On the Optimum Parameters of a Seat Belt Pre-loading Device

KOJI KURIMOTO, HAYAO HIRAI and
TSUTOMU SUGAWARA
Toyo Kogyo Co., Ltd.

ABSTRACT

The effectiveness of occupant restraint system is generally reduced as the impact velocity of vehicle increases. The addition of a pre-loading device to seat belt system has been proposed as one of useful measures to this kind of degradations.

This paper proposes the optimum selection of activation time and level of load produced by the assumed pre-loading device in case of 2-point diagonal seat belt system with knee bolster on the frontal impact at 40mph.

The two dimensional, five mass occupant mathematical model is developed and the validation of the model is carried out by adjusting various parameters of the model in comparison of the simulated results with those of the actual sled test, where a typical pre-loading device is employed.

The set of optimum parameters of pre-loading device is derived in relation to the level of HIC (head injury criteria) and the displacement of occupant through the computer simulation of this kinematic model.

PREFACE

On frontal collision at higher impact speed, so called "spool out" and additional elongation of the webbing reduce the restraint capability of seat belt system with retracting device. As one of the measures to avoid this, a pre-loading device is proposed which retracts a certain length of webbing during the first few milliseconds of a crash (1).

The effectiveness of pre-loading device, in correspondence to a target velocity where its maximum effectiveness is obtainable, varies substantially depending on such parameters as its activation time and the level of load produced. In this respect, this paper discusses the selection of these optimum parameters at the impact velocity of 40 mph, as the improvements of the restraint capability could be attainable with rather conventional manner below this speed.

As a typical case, a 2-point diagonal seat belt system with knee bolster is considered, where the anchorage locations are selected based on a certain 4-door sedan. In addition, the vehicle deceleration profile selected is a half-sine curve simulating a result of actual crash test of the vehicle that does not tend to undergo a large peak deceleration in the passenger compartment around the end of vehicle deformation.

The conventional anthropomorphic dummy is treated as a two dimensional, five mass mathematical model, whose validation is made as follows. First, various parameters of the mathematical model are adjusted to obtain agreement with the actual sled test results, for the case where the dummy is restrained by the 2-point diagonal seat belt without pre-loading device. Second, the results by the computer simulation with the parameters thus determined and those by the actual sled test are compared for the case where the pre-loading device is activated, resulting that the computed results are in good agreement with test results. Then, computer simulations are made to find the optimum parameters for the pre-loading device, employing the mathematical model of the aforementioned characteristics.

MATHEMATICAL MODELING

General Description

A two dimensional, five mass model is employed, the schematic of which is shown in Figure 1, since a dummy makes a virtually two dimensional movements on frontal collision, and a modeling of unnecessarily complicated design would make characterization and input to the model excessively complex. Here, the front seat passenger is dealt, since it is generally difficult for the driver to avoid impact against the steering wheel, making it necessary to consider the energy absorption of steering system by the occupant.

This mathematical model is provided with toe board, seat, and knee bolster. These surfaces are to make interaction with parts of the dummy expressed as circular segments, generating friction force on contact. The characteristics of seat belt are mathematically adjusted on two dimensional plane by designating the relative anchorage locations and the actual elongation of the webbing. The seat belt on the mathematical model is to contact with the dummy model at two points, generating friction force at respective point.

Dummy Characteristics

By referring to the geometric, inertial, and joint characteristics of Part 572 Hybrid II dummy described in publications (2–3), and by conducting some measurements, dummy characteristics are determined. The neck joint characteristic, as a representative example, is shown in Figure 2, where the torque versus rotational movement is nonlinearly represented with angular velocity depend-

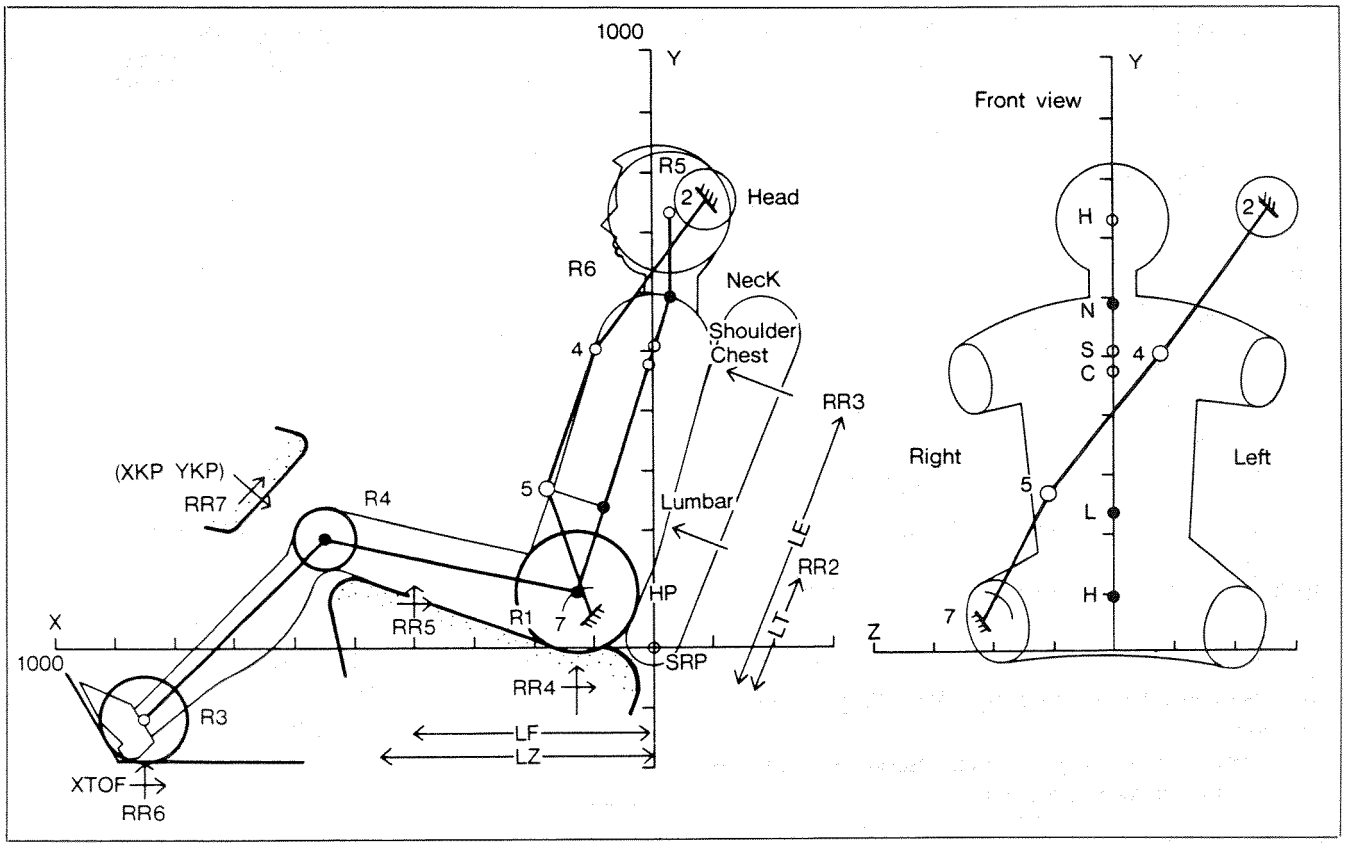


Figure 1. Schematic of mathematical model.

ent hysteresis. Similar approaches are made in determining the characteristics of other joints.

Characteristics of Restraint Components

The seat cushion is represented by a plate on two vertical nonlinear resistances, one of which is fixed at the front end of the plate. The other is connected at the bottom of the dummy's hip, making it possible to move forward with the hip displacement. These characteristics, whose typical examples are shown in Figure 3, are determined by pressing the seat cushion with hip-shaped ram.

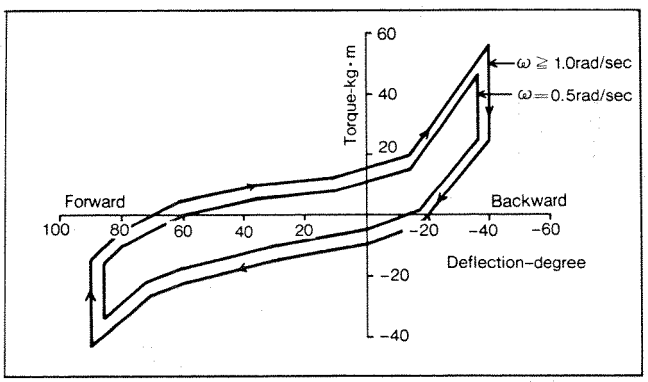


Figure 2. Representative neck joint characteristic.

The knee bolster is represented by a plate, where the force versus deflection is nonlinearly represented with hysteresis. A typical characteristic is shown in Figure 4,

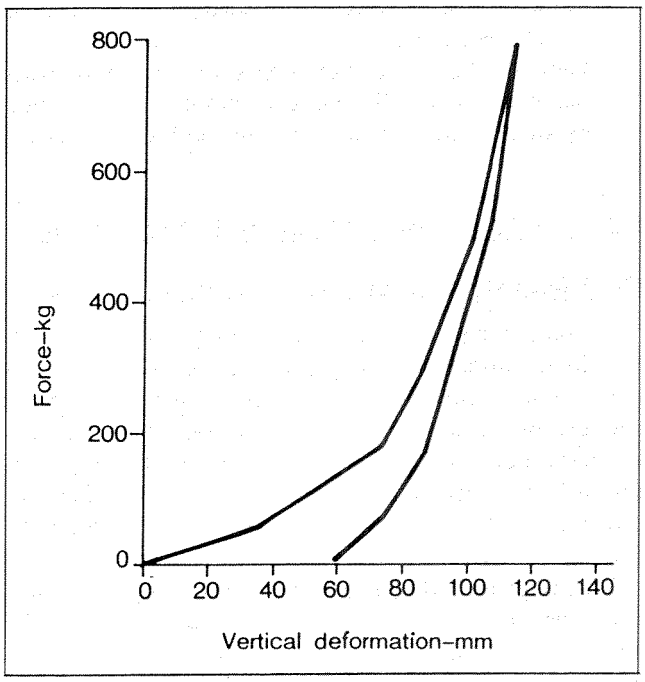


Figure 3. Representative seat cushion (rear part) characteristic.

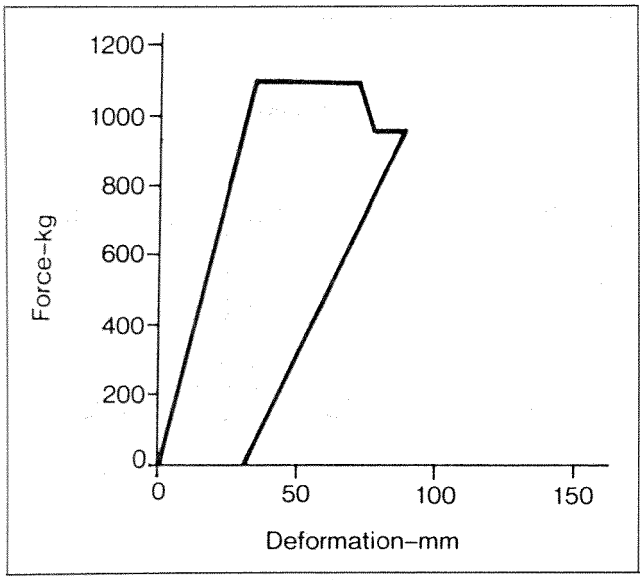


Figure 4. Representative knee bolster characteristic.

which is determined by pressing a knee-shaped ram on a knee bolster.

The load versus elongation characteristics of the seat belt webbing between upper and lower anchorages is also nonlinearly represented with hysteresis. This characteristic is determined as the combination of the following three characteristics, whose typical example is shown in Figure 5:

—Elongation characteristic of seat belt webbing is determined by the method stipulated in FMVSS 209.
—The "spool out" of seat belt webbing taken up in the retractor is determined by measuring the actual spool out characteristics.
—Deflection characteristic of chest on interaction with seat belt at Part 572 Hybrid II dummy is determined by such method as described in the literature (4).

VALIDATION OF MATHEMATICAL MODEL

Seat Belt System Without Pre-loading Device

A computer simulation is executed at 33.5 mph with the aforementioned characteristics, resulting smaller head displacement and larger HIC value compared to actual sled test results at the same velocity. The reason for this is substantially because, in actual test, the dummy's rotational movement toward sideways causes the head to move forward, whose effects is not taken into account on this mathematical model.

To compensate this inconsistency the elongation characteristic of the seat belt is partially adjusted. As the consequence, the computation yields results in good agreement with those by the actual test, as shown in Figure 6.

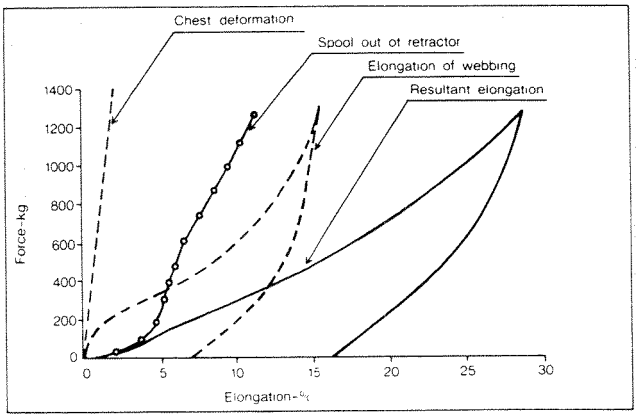


Figure 5. Representative seat belt system characteristics.

Seat Belt System with Pre-loading Device

As a result of the aforementioned mathematical computation for the case without pre-loading device, the time sequence can be plotted on the load versus elongation characteristics of a seat belt system as shown in Figure 7. Respective time on the plot is utilized to specify the activation time of a pre-loading device. Once this acti-

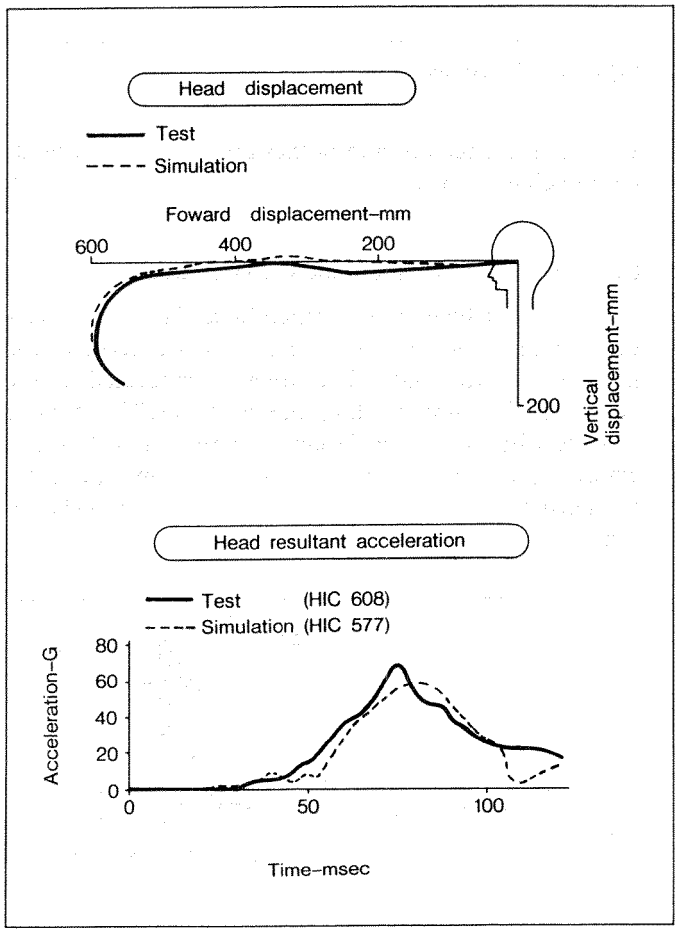


Figure 6. Comparison of the results between simulation and test (without pre-loading device).

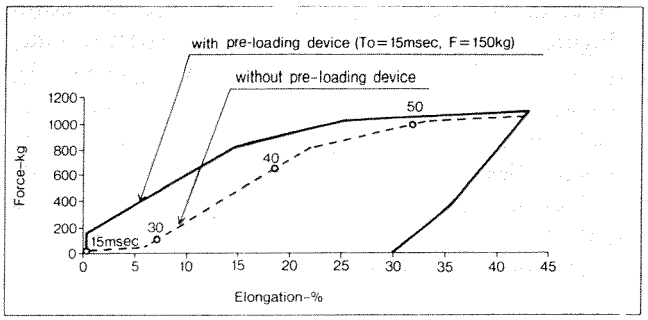


Figure 7. Representative seat belt system characteristics (with and without pre-loading device).

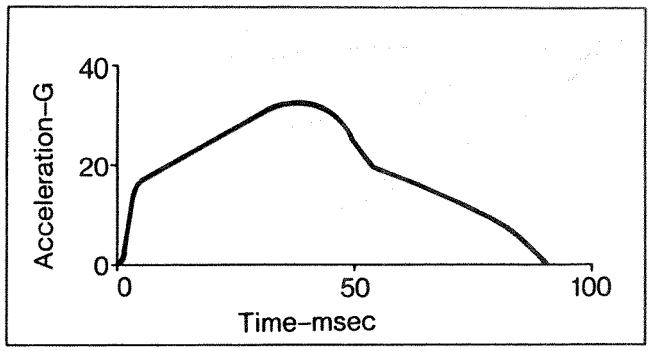


Figure 9. Crash pulse.

vation time and a particular extraction force produced by a pre-loading device are specified, the characteristic curve is shifted along the horizontal axis as the elongation increases in correspondence with the load.

This procedure is used to provide the load versus elongation characteristics of the seat belt system with a given pre-loading device of specific parameters. Figure 7 also presents an example of the characteristics of the case where the activation time is 15 msec and the extraction force is 150 kg.

To compare the results by computation with those by experiment, an actual sled test is run at 36.3 mph, where a typical pre-loading device which produces the maximum load of 150 kg is installed as shown in Figure 8 and activated at 15 msec. Then, Computer Simulation with the aforementioned parameters is executed at 36.3 mph, where a half-sine acceleration profile similar to the actual crash pulse for the test above is set as shown in Figure 9. The results thus obtained show in good agreement with those by the actual sled test, some typical examples of which are shown in Figure 10.

OPTIMUM PARAMETERS AT 40 MPH

Computer Simulations at 40 mph are carried out with various combinations of activation time and load of the pre-loading device, thus to clarify the influence of parameters on HIC level and head displacement, the results of which are shown in Figure 11. Figure 11 also indicates the shaded horizontal lines which implies the target HIC level and the permissible head displacement short of contacting a forward interior object. Here, the target HIC level is specified at 800 and the permissible head displacement is set at 600 mm, assuming probable contact with the instrument panel beyond this value.

Since this simulation model is made without instrument panel, the calculated HIC level registered is low, even when head displacement exceeded the permissible level. In actual situations, however, a higher level as shown by broken line in Figure 11 would be assumed to result, once when the head is brought into strong contact with the instrument panel. Consequently, it is important to hold the head displacement to below the permissible level.

It is observed, in Figure 11, that both HIC and head displacement are decreased as the activation time is reduced and the load of the pre-loading device is increased.

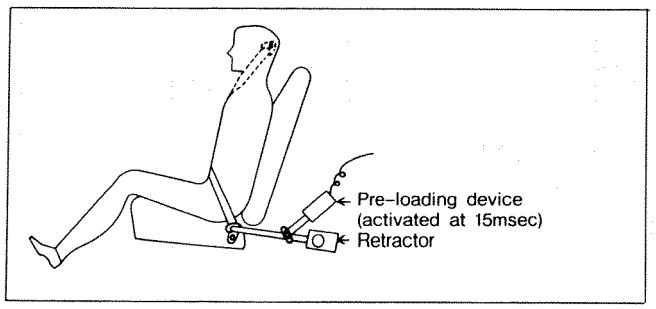


Figure 8. Schematic of pre-loading device installation.

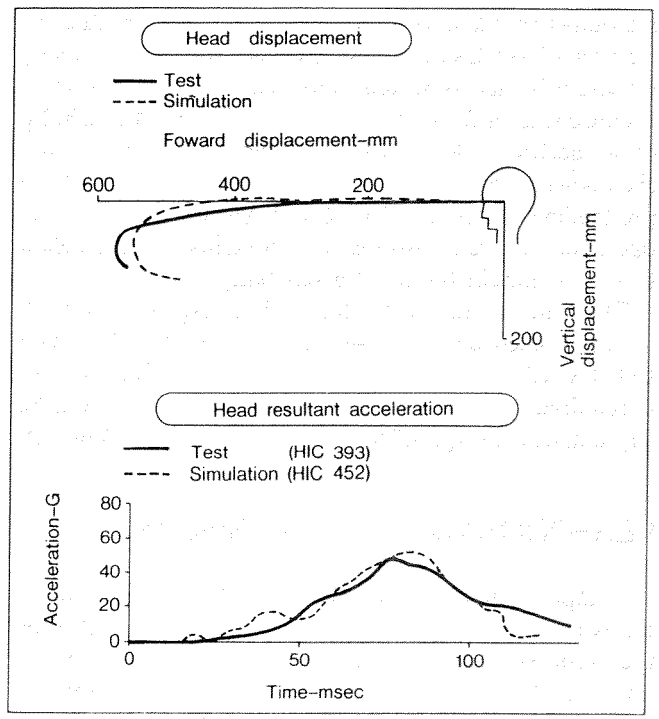


Figure 10. Comparison of the results between simulation and test (with pre-loading device).

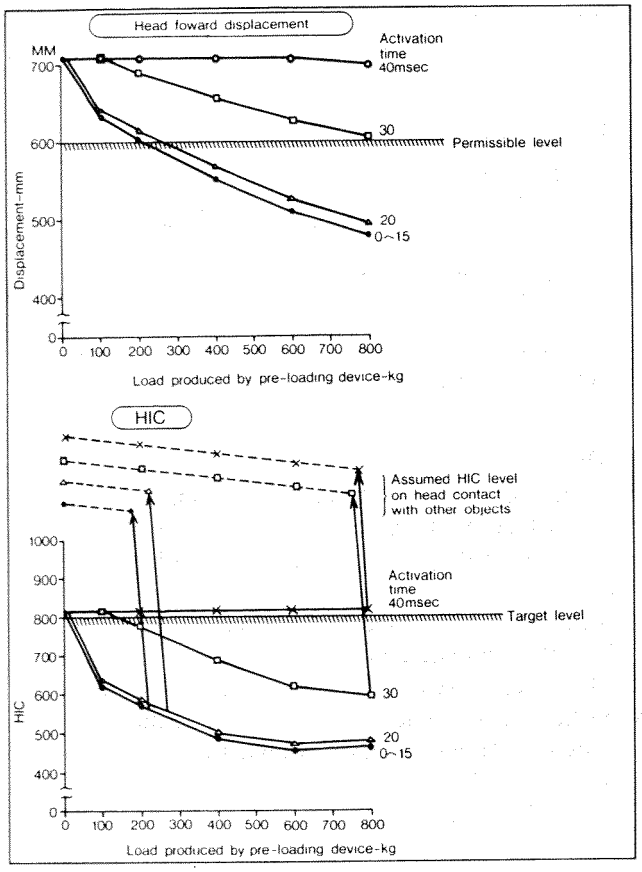


Figure 11. Influences of pre-loading device at 40 mph simulation.

However, there is restriction against the load parameter to keep the HIC and the head displacement under the respective permissible levels. Namely, it is said that the number of rib fractures increases as the load produced by seat belt increases, and there is an instance where rib fracture was suffered at as low a shoulder load as 200 kg or so, according to tests using human cadavers (5), and the higher load produced by inadvertent activation of the pre-loading device could lead to driver's error in vehicle operation. There is also restriction against the activation time to maintain the sensing reliability.

Thus, in the example cited, it is considered that the load produced by the pre-loading device should be held to below 220 kg. With this condition, the activation time is required to be less than 15 msec, as shown in Figure 11, to meet the target of both HIC and head displacement.

PERFORMANCE AT LOW SPEED

Computer simulation is executed on an impact velocity of, as an example, 25 mph, to observe the feasibility of the pre-loading device with the optimum parameters obtained at 40 mph. The sled acceleration profile for the above-mentioned 40 mph was rearranged to that for 25 mph as follows.

First, the acceleration profile at 36.3 mph, as shown in Figure 9, was doubly integrated with respect to time, resulting the force versus deformation characteristic. Then assuming one dimensional, one mass and one spring model whose spring rate is given by the abovementioned characteristics, the acceleration profile at 25 mph is obtained as response of the mass on impacting the model into the fixed barrier at 25 mph. Generally, the activation time of pre-loading device comes to be rather late as the impact velocity of the vehicle decreases. In this case, it is assumed to be 25 msec rather arbitrarily, since the precise value depends on the specific sensing device for the pre-loading device.

With this assumption and load produced by the pre-loading device to be 220 kg as before, a computer simulation is executed at 25 mph. It is demonstrated as the result that the pre-loading device is still effective in reducing HIC and head displacement at 25 mph, too, as shown in Figure 12, thus indicating that the parameters specified for 40 mph would have no adverse effects in low speed collisions.

SUMMARY

(1) A two dimensional, five mass mathematical model can be used effectively to estimate such response as HIC and head displacement occurring at actual impact test.

(2) The computer simulation is an effective tool to determine the optimum parameters of a pre-loading device with respect to activation time and load. This approach could be applicable to various types of seat belt system, anchorage locations which vary with vehicle geometric features, and vehicle body deformation characteristics.

(3) On the simulated 4-door front drive car presumed to suffer deformation at an impact velocity of 40 mph, the optimum parameters of the pre-loading device are proposed to be activation time of 15 msec and load of 220 kg.

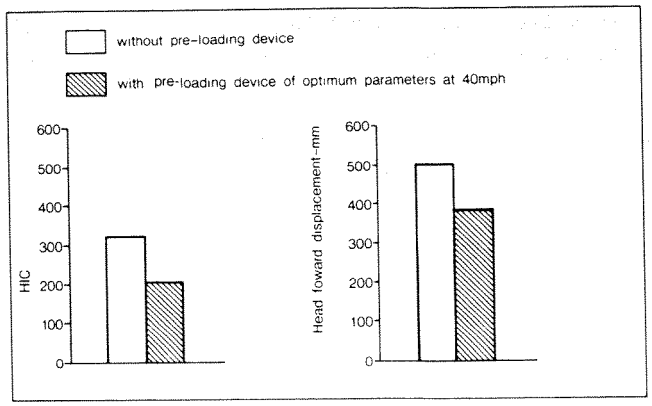


Figure 12. SWimulated effect of pre-loading device at 25 mph.

(4) The aforementioned optimum parameters obtained from the computer simulations seem to have no adverse effects at lower speed collisions and to be still effective in reducing HIC level and head displacement.

Thus it is observed that the pre-loading device is effective to the extent of a typical frontal collision studied. To put it into practical application, however, further extensive technical development has yet to be made, in addition of consumer acceptability, on such areas as elimination of occupant's uneasiness at activation of explosives, sensing reliability for the activation only when it is necessary, and ensuring reliability of the complex system.

ACKNOWLEDGEMENT

The authors wish to express heartful appreciation to related persons at Toyo Kogyo Co., Ltd. who extended valuable suggestion for this study.

REFERENCES

1. W. Reidelbach and H. Scholz, "Advanced Restraint System Concepts", SAE paper No. 790321, 1979.
2. R. P. Hubbard and D. G. McLeod, "Geometric, Inertial, and Joint Characteristics of Two Part 572 Dummies for Occupant Modeling", 21st Stapp Car Crash Conf., SAE Paper No. 770937, 1977.
3. B. M. Bowman, R. O. Bennett, D. H. Robbins and J. W. Becker, "MVMA Two-Dimensional Crash Victim Simulation, Version 4, Volume 1-3", HSRI, 1979.
4. D. C. Viano and C. C. Culver, "Test Dummy Interaction with a Shoulder or Lap Belt", 25th Stapp Car Crash Conf., SAE Paper No. 811017, 1981.
5. A. Fayon, C. Tarriere, G. Walfisch, C. Got and A. Patel, "Thorax of 3-Point Belt Wearers During a Crash (Experiments with Cadavers), 19th Stapp Car Crash Conf., SAE Paper No. 751148, 1975.

Mathematical Models for the Assessment of Pedestrian Protection Provided by a Car Contour

J. WISMANS and J. van WIJK
Research Institute for Road Vehicles TNO
Delft, The Netherlands

SUMMARY

Injuries sustained by pedestrians struck by the front of cars are dependent on the profile and the local stiffness characteristics of the vehicle. Mathematical Crash Victim models, if well-validated, could provide a suitable method for the assessment of pedestrian protection provided by different car contours.

In this presentation, first a review will be given of a number of existing pedestrian models along with the associated validation studies. On the basis of this review and results of recent accident analysis studies a series of pedestrian models with varying complexity were developed using the Crash Victim Simulation Program MADYMO.

The predictions of these models are compared with experimental results for two impact velocities and the reliability with respect to their complexity is discussed.

INTRODUCTION

Pedestrians are among the most vulnerable traffic participants. A pedestrian runs more than twice as high a risk of being fatally injured in a road accident as a car occupant. In recent years traffic safety research has concentrated more and more on the problem of pedestrian accidents.

Since the end of 1980 three research institutes: Bundesanstalt für Strassenwesen (BASt), Organisme National de Sécurité Routière (ONSER) and the Research Institute for Road Vehicles (IW-TNO) have co-operated in the field of pedestrian safety. The aim of this study is to propose a standardized test methodology that can be applied to pedestrian safety tests carried out for research or for compliance testing of passenger cars.

A part of this project was the formulation of a mathematical model of a pedestrian during an impact. Several advantages of mathematical models are the exact reproducibility of a simulation, the absence of measuring problems and the possibility to conduct sensitivity-analyses in a simple, rapid and inexpensive way.

This study was conducted with the MADYMO program package, developed at the Research Institute for Road Vehicles TNO, Delft, The Netherlands. A description of this package, along with several examples of applications can be found in (11). The main features of this package can be summarized as follows:

—a compact FORTRAN source which can be implemented on small computer systems;
—a 2D and a 3D option;
—a variable number of linkage systems;

—a set of standard force interaction routines;
—easy incorporation of user defined subroutines for specific force interactions and user defined output.

In this paper, first a brief review will be given of a number of existing pedestrian models along with the associated validation studies. On the basis of this review and results of recent accident analysis studies a series of three pedestrian models with varying complexity were formulated. The predictions of these models will be compared with experimental results with an Audi 100 for two impact velocities, namely 30 and 40 km/h.

REVIEW OF MATHEMATICAL PEDESTRIAN MODELS

In this section a literature review will be presented concerning existing mathematical models for the simulation of car-pedestrian collisions.

Table 1 summarizes the source and background of ten models that were analyzed. The models are numbered according to the numbers in the reference list. Four models are based on the CALSPAN CVS program. These models are not identical since different versions of this computer program were used and modifications were introduced by the users. The PRAKIMOD model is based on the MVMA-program.

In Table 1 the main characteristics of the models are summarized. A first distinction which can be made is between 2D and 3D models. This last type of models, in general, will be more realistic since the kinematics of a pedestrian impacted by a car are found to be of a three-dimensional nature. However, such a 3D model is much more complicated and in addition a lot of extra input data has to be defined.

A CVS-model consists of a series of rigid bodies, connected by hinge or ball-and-socket (3D) joints. The number of elements in the various models is included in Table 1.

In most of the models, the vehicle is represented by a number of straight line segments (2D) or planes (3D). In the PROMETHEUS 2 model, however, interconnected segments are used for the simulation of the vehicle contour. The position of these segments can be defined by means of an auxiliary program, which transforms the input parameters into a finite element model of the vehicle. The user can define the hood-contour by a skewed hyperellipse.

Most of the mathematical models for pedestrian collisions are limited to the impact of the pedestrian with the vehicle. Ground impact is not considered in these simulations. Reasons for this are (6):

—a meaningful simulation of the secondary impact is extremely difficult since inaccuracies in the simulation of the primary impact will strongly affect the pedestrian kinematics in the secondary impact;
—in the airborne phase the pedestrian has time for voluntary muscle action;

Table 1. Summary of ten pedestrian models.

Ref.	author/model	Year	2D/3D	Number of segments	Institute
1	Transportation Research Department	1971	2D	3	Cornell Aeronautical Laboratory (USA)
2	Glöcker	1973	2D	1	Institut für Kraftfahrzeuge, Technische Universität Berlin (Germany)
3	Kramer	1974	2D	3	Institut für Kraftfahrzeuge, Technische Universität Berlin (Germany)
4	Mac Laughlin	1974	2D	4	National Highway Traffic Safety Administration. U.S. Dept. of Transportation (USA)
5	Young, TTICVS	1975	3D	12	Texas Transportation Institute, Texas A&M University (USA)
6	Twigg, Prometheus 2	1977	2D	11	Boeing Computer Services Inc. (USA)
7	Fowler, Calspan 3-D CVS, version III	1976	3D	15	British Leyland Limited (Britain)
8	Padgaonkar, Calspan version III	1977	3D	15	Biomechanics Research Center, Wayne State University, Detroit (USA)
9	Lestrelin, Prakimod (MVMA)	1980	2D	8	Laboratoire de Physiologie et de Biomécanique de Peugeot S.A./ Renault (France)
10	Cotte, Calspan version III	1980	3D	15	Laboratoire de chocs et de Biomécanique ONSER (France)

—the simulation time must be increased from 200 ms to about 1000 ms resulting in a considerable increase of computer costs.

In addition it follows from accident analyses that the secondary impact in general causes less severe injuries than the primary impact (Ashton (12), Mackay (13)).

For the interaction between pedestrian and vehicle three types of contact models are used:

—in models 2 and 3 contact interaction is based on the classical theory of collisions between two rigid bodies. According to this theory the impact time is taken as zero. Consequently force and acceleration time histories during the impact phase cannot be evaluated by this type of model;

—in model 6 (PROMETHEUS 2) the vehicle contour is represented by an arbitrary number of interconnected segments;

—in the other models description of the contact is based on interactions between contact surfaces (lines, planes, ellipses, etc.) connected to the vehicle and the predestrian. Whenever a positive penetration between contact surfaces is detected, normal and friction forces are calculated. Force-penetration characteristics have to be defined and are based on measurements or assumptions. Realistic simulation of contacts between pedestrian and sharp edges (e.g., between lower leg and bumper) may cause problems in this type of contact models (7).

In most studies model predictions have been compared with experimental results in order to get an impression of the reliability of the models. Table 2 summarizes some of the test conditions used for validation of the various models. The last item of Table 2 is the type of data used for validation.

The degree of validation, however, differs strongly in the various studies. Some models are not validated at all (models 2 and 4); others are compared with several experiments for a number of conditions. The first column shows the pedestrian surrogate used in the test. Most researchers have concentrated on dummies, because these are a relative easily accessible source for model input data. Measurements of masses, moments of inertia, joint-torques, etc. easily and accurately can be carried out at dummies. Padgaonkar (8) has simulated cadaver experiments. One of the differences between his dummy- and cadaver-model was in the knee-joint: a hinge-type for the dummy and a ball and socket joint for the cadaver in order to admit lateral deflection.

The orientation of the pedestrian, in these tests, varies from frontal via oblique to lateral (see Table 2). Simulation of a lateral or oblique impact in general will be more difficult than a frontal impact, due to the more complex three-dimensional motions. Twigg, for instance, (model 6, 2D) observes that the elbow of the pedestrian can act as a lever to vault the torso up over the hood, thus reducing the injury incurred by the head and torso.

Table 2 also summarizes the cars which were used in

Table 2. Validation of the models.

Ref.	Pedestrian	Pedestrian orientation	Vehicle	Velocity (km/h)	Validation criteria
1	50th % male child dummy	Frontal	Ford Galaxie 1966	16	gross motion
2	—	—	—	—	—
3	50th % male	Frontal	—	36	gross motion throwing distance
4	—	—	—	—	—
5	6-yr Sierra dummy 5th % Sierra dummy female 95th % Sierra dummy male	Frontal Oblique	Mock-up	*	gross motion accelerations
6	Part 572 modified 6-yr child dummy	Lateral	Impala 1974, Test bucks	32	accelerations
7	Ogle OPAT	Lateral	Leyland cars SRV2 Marina	16,32	gross motion, accelerations
8	95th % Sierra dummy	Lateral Frontal	Chevrolet 1973	22,24) 30,39)**	gross motion, accelerations
9	50th % dummy	Frontal	Ford Fairlane Renault 5 Honda N360 Peugeot 204 Opel Kadett Peugeot 304 Citroën GS	16,28,33,40 36 43 40 45 22 43,48	trajectory head
10	ONSER 50	Frontal	Citroën Visa	20,25	gross motion, head impact

*Drop tests on mock-up. Drop height 0,4-0,8 m.
**In addition four cadaver tests and drop tests of Young (5).

the experiments as well as the impact velocity. The fact that different validation criteria are used prevents an adequate comparison of the reliability of the several models.

Most researchers stress in their conclusions the importance of the contact model. The contact model must be able to cope with the problem of edge-contacts, as well as inertial effects. Another crucial point is the description of the joints. Inelastic failure and dynamical effects (damping) must be taken in account. Both the contact and the joint-model must be based on realistic, preferably measured, input data.

MADYMO 2-DIMENSIONAL PEDESTRIAN SIMULATIONS

Based on the preceding literature review of existing pedestrian models and results of several recent accident analyses, a number of requirements were formulated for simulations of pedestrian-vehicle impacts with the general CVS program package MADYMO. The literature study did not show a clear relationship between the complexity of the different models (i.e., number of elements, 2D versus 3D) at the one side and their reliability at the other side. One of the aims of our study therefore was to get first a better insight in this problem. It was decided to develop several models with a differing complexity. Three models are presented which were formulated with the 2D option of MADYMO. In a future study (14) results of 3D-simulations will be presented.

The simulations are limited to the primary impact (pedestrian-car contact) and are concerned with lateral impacts, since this is the most frequent type of impact observed in pedestrian accidents (12). The three models have 2, 5 and 7 segments, respectively, as is shown in Figure 1. The same contact ellipses are attached to the 2- and 5-segment model. In the present models the arms are not incorporated as separate segments: a part of the mass of the arms is added to the mass of the thorax segments.

The input data set describing the pedestrian (e.g., the geometry, mass distribution and joint characteristics) are derived from a standard data set of a Part 572 50th percentile male dummy, which itself is based on a number of measurements conducted in our laboratory.

One of the most important aspects concerning the simulation of pedestrian accidents is the representation of the contacts between vehicle and pedestrian, especially for the edge-contacts. A special contact model was developed in which the external geometries of pedestrian and vehicle are simulated by hyperellipses. A hyperellipse is a general form of a standard ellipse and can be described by the following equation:

$$\left(\frac{|x|}{ea}\right)^n + \left(\frac{|x|}{eb}\right)^n = 1$$

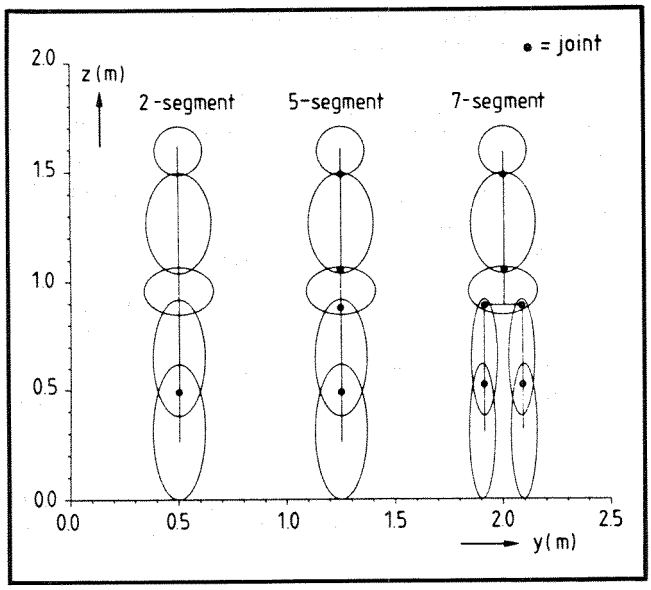


Figure 1. Geometry and contact-ellipses of resp. 2-, 5- and 7-segment model.

where ea and eb are the semi-axes of the hyperellipse and n the degree (see Fig. 2). If n = 2, this equation describes a standard ellipse; however, if n increases, the hyperellipse approximates more and more a rectangle as is shown in Fig. 2 for n = 8. This geometrical description is particularly of interest for the representation of the car and bumper geometry, since vehicle edges quite well can be approximated in this way. A more detailed description of hyperellipse contact models will be presented in reference (14).

The three models presented were applied to simulate a pedestrian impact with a vehicle of the type Audi 100. The geometry of this vehicle is represented by two hyperellipses: one for the bumper and one for the hood (see Fig. 3). The vehicle dimensions were determined from scale drawings and measurements.

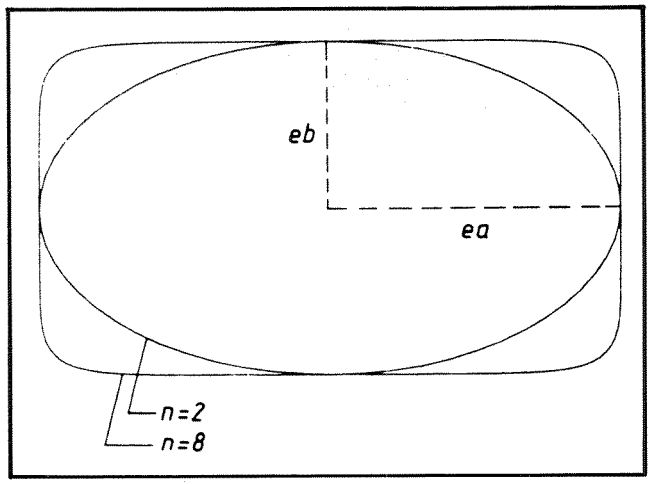


Figure 2. Hyperellipses with identical semi-axes, n = 2 and n = 8.

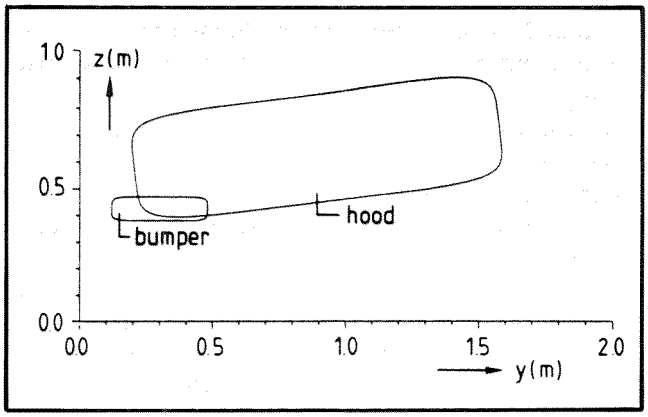


Figure 3. Geometry of Audi 100.

Dynamic force-deflection characteristics of the bumper, hood and hood edge of the Audi 100 vehicle were determined experimentally by the BASt (Bundesanstalt für Strassenwesen). Pendulum tests with a rigid wooden pendulum were used for the bumper and the hood edge. This pendulum was equipped with an accelerometer, while the vehicle deflection was measured with a linear transducer, mounted in the car. The pendulum mass was 10 kg for the bumper impact and 15 kg for the hood edge while the impact velocity was 25 km/h in these tests. For the hood instead of a pendulum test a drop-test was used. The impacting body was a rigid wooden sphere with a mass of 5.25 kg and an impact velocity of 30 km/h.

VALIDATION TESTS

The mathematical model results are compared with a number of dummy tests, which were conducted by the BASt. The dummy in these tests, a 50th percentile male, Part 572 was equipped with triaxial accelerometers in the head, chest and pelvis and uniaxial accelerometers in the knees and feet. Test velocities were taken 30 and 40 km/h and the car deceleration 6 m/s^2. At each impact velocity three tests were conducted.

The dummy position before impact is shown in Figure 4. This position was selected after several pretests. In these pretests it could be observed that in case of a pure lateral impact no direct head-hood contact occurs due to the stiff neck and shoulder assembly of the part 572 dummy. Since head-impact was desired in these tests the dummy torso was slightly rotated (25°) causing the dummy to rotate around its vertical axis during impact and resulting in a direct head impact. The geometry of the ellipses of the pedestrian model was selected in such a way that they approximate the projection of the geometry of the rotated dummy on the plane of simulation.

Experimental results of these tests will be presented in the next section together with mathematical model results.

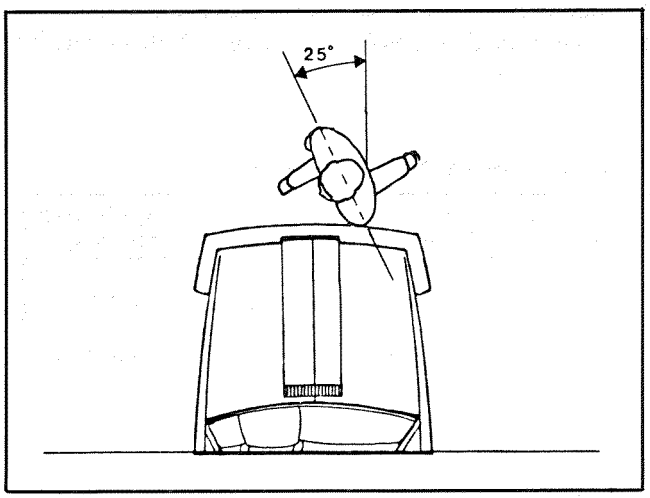


Figure 4. Dummy position at impact.

RESULTS

Figure 5 shows model predictions for the kinematics resulting from the 7-segment pedestrian model in a 40 km/h impact. A good agreement in general between model and experimental result could be observed. A comparison of predicted trajectories of the head, chest, pelvis and foot relative to the vehicle, resulting from the 2-, 5- and 7-segment model, is presented in Figure 6 (30 km/h impact) and Figure 7 (40 km/h impact). Locations of the head impact point on the hood predicted by the various models are summarized in Table 3. All models appear to predict this location within or close to the range of experimental results.

Table 3 includes model predictions and experimental results for the head impact velocity just before impact with the hood. Both the 5- and 7-segment model appear to predict too high values for this quantity compared to experimental observations.

Figure 8 presents model results together with experimental data for the knee, pelvis, chest and head accelerations in a 40 km/h impact. Results are given for the 2-, 5- and 7-segment model respectively. For the pelvis, chest and head, resultant linear accelerations are pre-

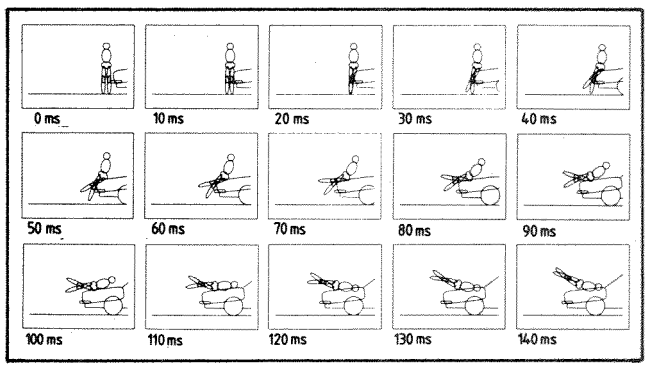


Figure 5. Kinematics of 7-segment model, v = 40 km/h.

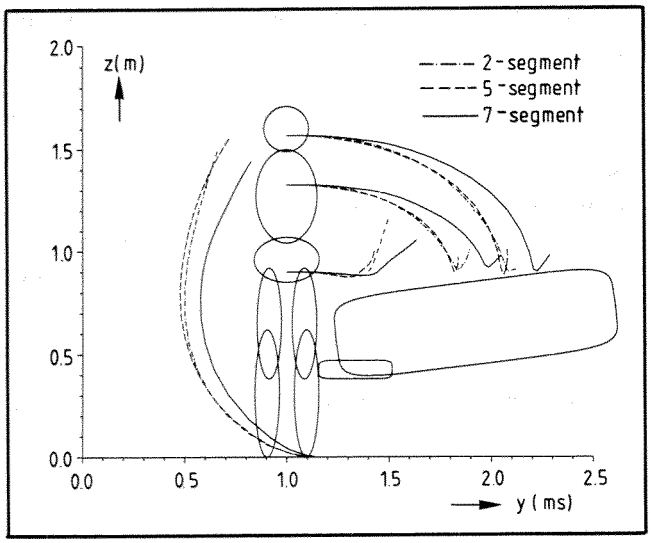


Figure 6. Trajectories of 2, 5 and 7 segment models, v = 30 km/h.

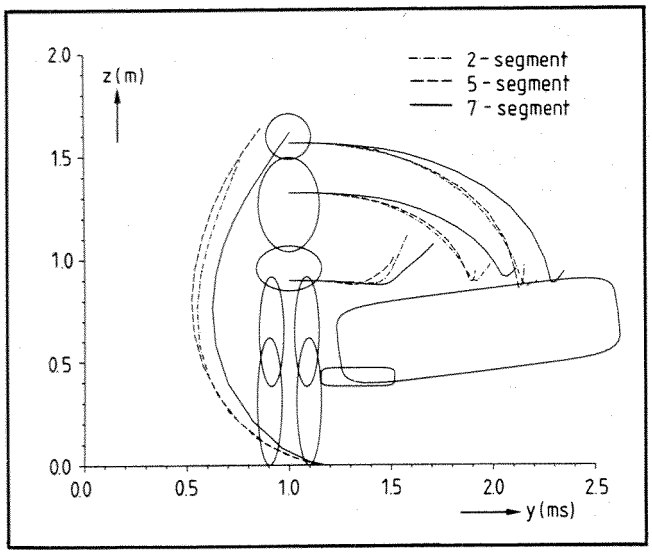


Figure 7. Trajectories of 2, 5 and 7 segment models, v = 40 km/h.

sented and for the knee joint the linear acceleration in lateral direction. It follows that the simple 2-segment model gives quite reasonable results for the acceleration-time histories (i.e., these accelerations appear to be in or close to the experimental corridors). Application of the 5-segment model does not result in better predictions for the knee and pelvis acceleration. A small improvement of the head and chest acceleration-time histories, however, can be observed particularly for $t < 20$ ms, where head and chest acceleration become smaller and more corresponding to the experimental observations. The peak head acceleration, however, becomes too high in this simulation.

Extension of the 5-segment model with 2 segments in order to represent the left and right leg separately in the model, results in a more realistic prediction of the knee accelerations. Also, the alignment between model and experimental head and chest accelerations appears to become more realistic now.

A comparison of bumper load-time histories for the 40 km/h impact, predicted by the 5- and 7-segment model, respectively, is shown in Figure 9. Due to the introduction of a second leg in the model, peak bumper loads are found to decrease by about 25%. Furthermore, the curve has two peaks. The bumper loads resulting from this model are more close to the results of experiments than results from the more simple models.

Accelerations predicted by the 2-, 5- and 7-segment models in a 30 km/h impact showed in general the same characteristics as in the 40 km/h impact. The agreement between model and experiment in this impact was found to be less, however, than in the more severe 40 km/h impact.

A limited sensitivity study was conducted to analyze the response of the 2-, 5- and 7-segment models to variations in some of the model input parameters. Two different series of variations will be presented here.

The first series concerns a change on the stiffness of the bumpers by +25% and −25% respectively. Results of these calculations are summarized in Table 4. It follows that the 3 models predict an almost identical relative

Table 3. Head impact velocity and head impact point for three models, along with experimental results.

	Model			Experimental
	2 segment	5 segment	7 segment	test-range
v = 30 km/h				
resultant head-impact velocity (m/s)	9.1	12.3	12.0	6.7-9.2
distance head-impact point/hood-edge (m)	.91	.90	1.02	0.82-1.00
v = 40 km/h				
resultant head-impact velocity (m/s)	12.7	16.6	15.8	11.2-12.5
distance head-impact point/hood-edge (m)	.96	.95	1.08	1.00-1.07

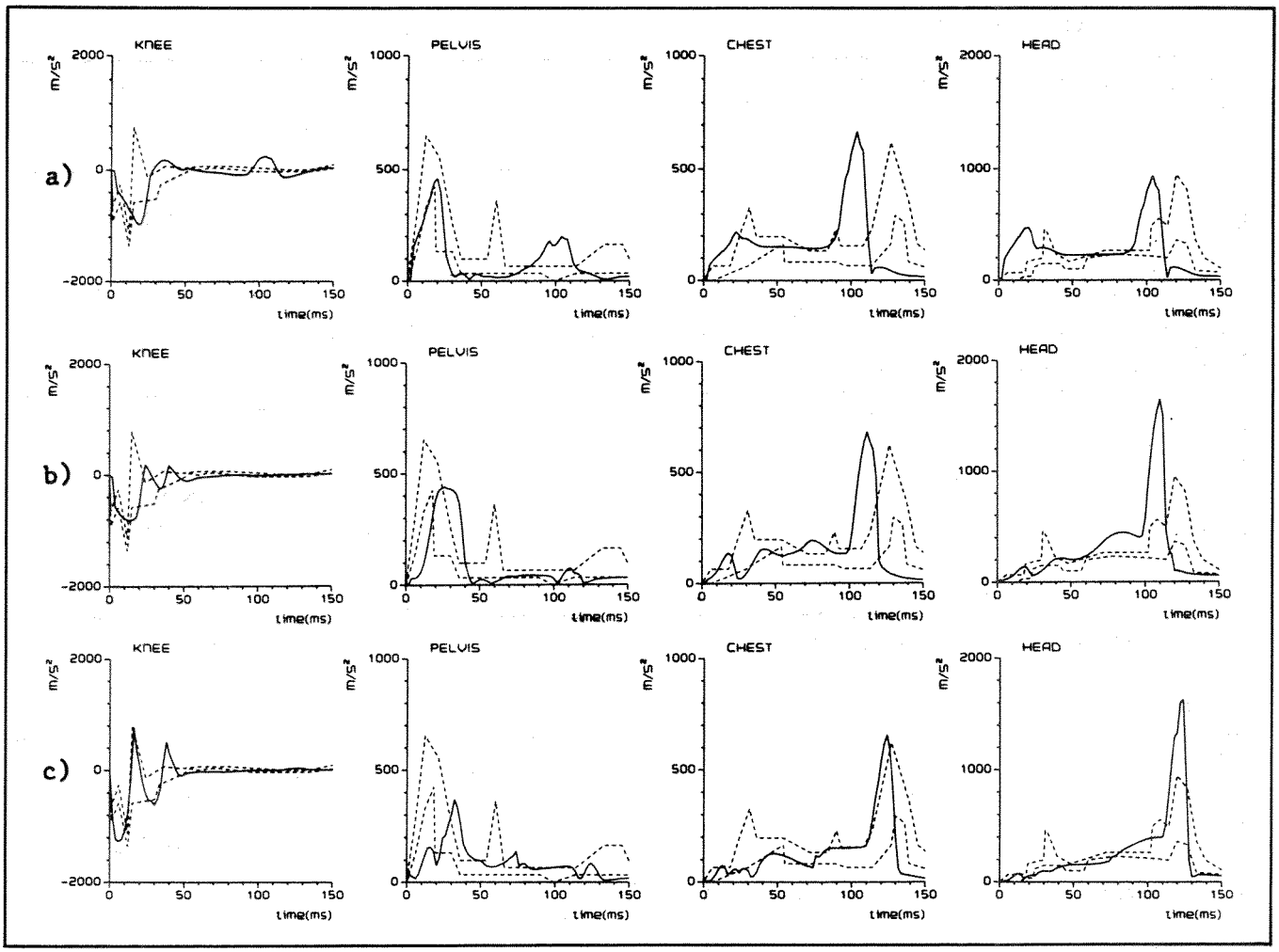


Figure 8. Accelerations of knee, pelvis, chest and head for a) 2-segment, b) 5-segment and c) 7-segment model (— = model, -- = experimental corridor) in a 40 km/h impact.

change in peak bumper loads. However, predictions for the relative change in accelerations of the impacted leg (i.e., foot and knee accelerations) are found to be strongly dependent on the number of elements in the model. In the models with a greater number of elements, the peak foot and knee accelerations are found to be much more sensitive to changes in the bumper stiffness.

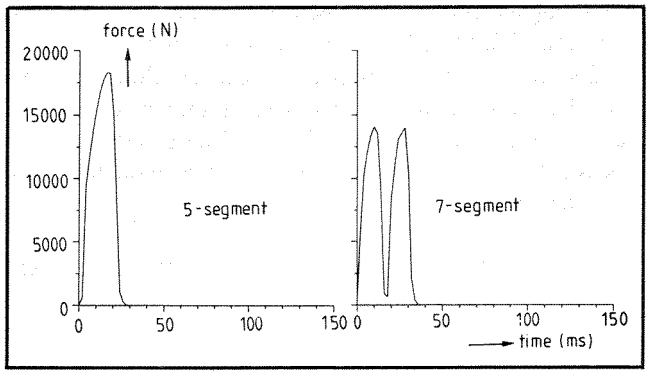


Figure 9. Bumper force for (a) 5-segment and (b) 7-segment model in a 40 km/h impact.

A second series of variations is concerned with the friction between foot and ground. In the reference simulation (Audi 100, 40 km/h impact), the friction coefficient was taken 0.7. Table 5 shows the results of a series of simulations in which the friction between ground and foot is omitted. Predictions of the three models for most of the output quantities are found to be close to each other. The influence of this variation in general is minor: bumper force and foot acceleration are somewhat lower and the knee acceleration becomes higher.

DISCUSSION AND CONCLUSIONS

Mathematical simulation of the highly complicated gross motion of the human body impacted by a vehicle has gained increasing importance in the past years. A brief literature review was given of various pedestrian models along with the associated validation studies. These models varied strongly in complexity: 2-dimensional models with the number of segments for the pedestrian varying between 1 and 11 as well as 3-

Table 4. Effect of bumper stiffness[1].

Bumper Stiffness Increased by 25%							
	Max. accelerations (Δ %)					Max. contact forces (Δ %)	
Model	foot	knee	pelvis	chest	head	bumper-(left) lower leg	hood edge-(left) upper leg
2 segment	3	2	−2	6	5	16	−30
5 segment	8	16	−10	−4	1	14	−2
7 segment	12	24	−1	−5	−3	17	−1
Bumper Stiffness Decreased by 25%							
	Max. accelerations (Δ %)					Max. contact forces (Δ %)	
Model	foot	knee	pelvis	chest	head	bumper (left) lower leg	hood edge-(left) upper leg
2 segment	−3	0	3	−2	−3	−17	40
5 segment	−5	1	13	−3	−4	−15	7
7 segment	−14	−26	−5	1	3	−15	0

[1] Changes with respect to reference simulation: a 40 km/h Audi 100 impact.

Table 5. Effect of ground friction[1].

	Max. accelerations (Δ %)					Max. contact forces (Δ %)	
Model	foot	knee	pelvis	chest	head	bumper-(left) lower leg	hood edge-(left) upper leg
2 segment	−13	2	−1	0	−1	−2	−1
5 segment	−5	4	−1	−5	−2	−1	1
7 segment	−6	2	0	−3	0	−1	0

[1] Changes with respect to reference simulation: a 40 km/h Audi 100 impact.

dimensional models having up to 15 segments were reported. In addition, methods for representation of the interaction between pedestrian and vehicle were found to vary considerably in these models. This literature study did not show a clear relationship between the complexity of the models and their reliability. One of the aims of our study therefore, was to get first a better insight into this problem.

A series of three 2-dimensional pedestrian models with 2-, 5- and 7-segments, respectively, was formulated using the general CVS program package MADYMO. The literature review showed that adequate description of the contact between pedestrian and vehicle is of crucial importance for a successful simulation. Particularly the pedestrian interactions with sharp vehicle edges (like the bumper and the hood) appeared to cause sometimes problems in the existing contact models. Therefore, within our project a more advanced contact model was developed in which the vehicle is represented by a number of hyper-ellipses as illustrated in Figure 3. This new contact model in MADYMO was found to perform very well for this type of applications. Extension of this contact model for incorporation in the 3-dimensional version of MADYMO is planned for the near future.

The three proposed pedestrian models were used to simulate a Part 572 dummy impacted at two different impact velocities (30 km/h and 40 km/h) by an Audi 100 vehicle. All three models were found to predict the head impact point location on the hood within or close to the experimental range of results. Predictions for the head impact velocity just before impact with the hood were too high (± 35%) in the 5 as well as the 7-segment model. Knee, pelvis, chest and head accelerations predicted by the various models were found in or close to the experimental corridor (Fig. 8). The observed differences between models and experiments may be due to the following reasons:

—The dummy in the experiments was slightly rotated before impact, causing the dummy to rotate around its vertical axis during the impact. In addition, the arms were found to interact with the hood. The effect of these aspects will be analyzed in future with a 3-dimensional pedestrian model.

—High speed films were used to determine the head impact velocity before impact with the hood. Due to 3-dimensional head motions and absence of adequate calibration procedures, this measurement might be rather inaccurate.

—Dynamic force-deflection characteristics were determined for the bumper, hood and hood edge. However, due to possible differences in impact velocities, shape of contact bodies, and location of the impact, the force-deflection characteristics in the actual dummy-vehicle impact may vary. Development of a contact model that accounts for geometric and velocity effects could considerably contribute to the improvement of the model's reliability. The sensitivity of the model to changes in the bumper stiffness (see Table 4) indicates the importance of an adequate description of the pedestrian-vehicle contact.

The influence of the complexity of the model (i.e., the number of model segments) can be summarized as follows: The reliability of the model if used for a lateral impact seems to be slightly improved if a greater number of segments is used to represent the pedestrian. The most significant changes are absence of an initial peak in head (and chest) accelerations if the number of segments increases from 2 to 5 and more realistic lower leg accelerations (and probably also bumper loads) if the number of segments is increased to 7.

In the next phase of this project, mathematical simulations for different car types are planned. In addition to adult dummy tests, also child dummy and cadaver experiments will be simulated. Further, it will be analyzed to what extent more complex models like a 15-segment 3D model can contribute to the reliability of the simulations. If the mathematical models then show reliable results for such different conditions, successful model application for the evaluation and improvement of pedestrian protection provided by different car contours might be expected.

REFERENCES

1. Transportation Research Department: "Research in Impact Protection for Pedestrians and Cyclists". Final NHTSA Contract Report, Cornell Aeronautical Laboratory, Buffalo, 1971.
2. Glöckner, H.: "Beitrag zur Simulation des Zusammenstosses Fahrzeug-Fussgänger". Automobil-Industrie, pp. 71–76, 1973.
3. Kramer, M.: "Ein einfaches Modell zur Simulation der Fahrzeug-Fussgänger Unfall". Automobiltechnische Zeitschrift 76, 3, 1974.
4. Mac Laughlin, T. F., Daniel, S.: "A Parametric Study of Pedestrian Injury". Proceedings of the 3rd International Congress on Automotive Safety, San Francisco, 1974.
5. Young, R. D., Lammert, W. F., Rose, H. E.: "Vehicle Exteriors and Pedestrian Injury Prevention, Vol. V, A 3-D Mathematical Simulation of a Crash Victim". Final NHTSA Contract Report, Texas Transportation Institute, Texas, 1975.
6. a. Twigg, D. W.: "PROMETHEUS 2—A User Oriented Program for Human Crash Dynamics". Final NHTSA Contract Report, Boeing Computer Services, Seattle, 1977.
   b. Twigg, D. W., Tocher, J. L.: "Pedestrian Model Parametric Studies, Vol. II". Final NHTSA Contract Report, Boeing Computer Services, Seattle, 1977.
7. Fowler, J. E., Axford, R. K., Batterfield, K. R.: "Computer Simulation of the Simulation of the Pedestrian—Development of the Contact Model". Proceedings of the 6th International Conference on Experimental Safety Vehicles, Washington, 1976.
8. Padgaonkar, A. J., Krieger, K. W., King, A. I.: "A Three-Dimensional Mathematical Simulation of Pedestrian-Vehicle Impact with Experimental Verification". Journal of Biomechanical Engineering, May 1977, pp. 116–123.
9. Lestrelin, D., Brun-Cassan, F., Fayon, A., Tarriere, C., Castan, F.: "PRAKIMOD: Mathematical Simulation of Accident Victims. Validation and Application to Car Pedestrian Collisions". Proceedings of the 8th International Conference on Experimental Safety Vehicles, Wolfsburg, 1980.
10. Cotte, J. P., Laurent, M.: "Improvement of a Mathematical Model to Study Pedestrian Safety". Proceedings of the 5th IRCOBI Conference on the Biomechanics of Impacts, Birmingham, 1980.
11. Wismans, J., Maltha, J., Wijk, J. J. van, Janssen, E. G.: MADYMO—A Crash Victim Simulation Computer Program for Biomechanical Research and Optimization of Designs for Impact Injury Prevention". AGARD Conference Proceedings, Cologne, 1982.
12. Ashton, S. J., Mackay, G. M.: "Car Design for Pedestrian Injury Minimisation". Accident Research Unit, University of Birmingham. Proceedings of the 7th International Conference on Experimental Safety Vehicles, Paris, 1979.
13. Mackay, G. M., Fonseka, C. P. de: "Some Aspects of Traffic Injury in Urban Road Accidents". Proceedings of the 11th Stapp Car Crash Conference, Los Angeles, 1967.
14. Wijk, J. J. van, Wismans, J., Maltha, J.: "MADYMO Pedestrian Simulations". To be presented at the SAE 1983 Winter Congress.

ACKNOWLEDGEMENTS

The authors wholeheartedly thank the BASt for conducting the experiments and Mr. L. Wittebrood for his efforts in running the MADYMO package.

Practical Vehicle Design for Pedestrian Protection

J. E. FOWLER and J. HARRIS
Austin Rover Group Ltd, BL Cars PLC, Cowley, Oxford
Transport and Road Research Laboratory, Crowthorne

ABSTRACT

The objective of the study described in the paper is to determine the extent to which pedestrian protection can be provided by practical car design measures. The project examines the effects of vehicle impacts upon the six-year-old child and 50th percentile male adult.

Evaluation of vehicle designs primarily involves the use of the Calspan CVS computer program for pedestrian impact simulation. Computer models of dummies have been developed with the simulation method being validated against practical testing. Modifications have been carried out on the OGLE adult dummy to improve the performance of the leg in lateral impacts. Adduction of the hip joint has been increased and the knees have been given lateral compliance together with suitable torque characteristics. The results from tests and simulation show good correlation and give confidence in the modelling technique.

The influence of various front-end changes have been studied with computer simulation using a simplified vehicle representation.

INTRODUCTION

Pedestrians form a significant proportion of road accident casualties and therefore warrant an investigation to establish if vehicle design measures can mitigate injuries and reduce the costs incurred by society.

This paper describes the first stages of a 2½ year collaborative project between the UK Government and BL Cars PLC that studies simulated pedestrian impacts up to a speed of 40 km/h. Such an investigation should give car designers a better understanding of the interaction between changes in car design and the resulting change in severity of an impact with a pedestrian.

The project is based on computer simulation of pedestrian impact and examines the influence of car shape and structural stiffness on the kinematics, impact forces and accelerations imparted to adult and child pedestrian models. It is confined to the most important and predictable injury-producing phase of the pedestrian collision, namely, the impact between the pedestrian and the vehicle (1).

A computer simulation modelling technique was chosen since it facilitates the study of many different shapes and stiffnesses and gives complete repeatability, thereby enabling the effect of changes to a single component to be clearly resolved.

COMPUTER SIMULATION MODEL

For many years BL Cars have been using computer simulation techniques to study and optimise vehicle performance in terms of occupant and pedestrian protection (2), (3), (4). During this time, the Calspan Corporation's 3D Crash Victim Simulation Program has been a major tool (5), (6), (Figure 1). For the work reported here BL have made changes to the current version of the program (CVS III Version 20) to:

- improve the vehicle to victim contact model (7)
- output additional joint force data
- retain kinematic dummy plotting facility from version 15

The program has been extensively validated and an example of this is given in Section 6.

Dummy Models

The simulation models of the OGLE adult and child dummies have been developed from data derived from a comprehensive study of the two dummies. This included the establishment of:

- the location, axis of rotation and ranges of motion of each joint;
- the joint's stiffness and viscous properties, including the nature of the joint stops;
- the inertial characteristics of each body segment;
- the contact stiffness and energy recovery properties of each body segment;
- the external profile of each body segment.

For the project, the simulation of the adult dummy was modified to give increased limits of adduction at the hip and also lateral compliance of the knees (described in Section 3). The latter entailed the addition of an extra segment in each leg at the knee to enable the inclusion of a joint to provide the extra direction of knee movement.

The victim contact surface model is defined by ellip-

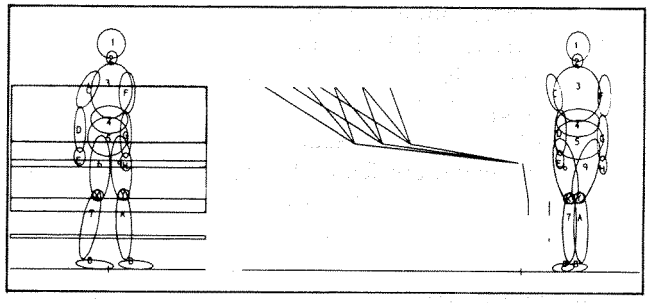


Figure 1. Computer simulation model.

soidal contact surfaces corresponding to each body segment and these were determined from the data. The stiffness characteristic of each segment was obtained by compressive tests between flat and curved rigid surfaces.

In the simulation program, contact forces can be generated between ellipsoids and vehicle panels, and are calculated as a function of penetration of the surfaces, with sliding friction forces generated to oppose any relative motion. Any such contact must therefore be defined in terms of the combined characteristics of the two surfaces involved as a tabular or analytical function (7).

Vehicle Model

The vehicle contact surface model consists of up to 30 rectangular plane panels. For a particular vehicle model, panels are chosen to represent the surfaces as required. The stiffness data are determined from component impact tests. Each significant area is impacted normal to its surface using an appropriate rigid form weighted according to the part of the body it represents, for example, the bumper would be impacted with a leg form and the windscreen by a head form.

Several impact speeds are used up to and including the speed to be used in the simulation. From these results each force versus deflection characteristic and the nature of the energy recovery and permanent distortion can be determined.

Program Operation

When setting up a full impact simulation model the contacts between each vehicle panel and the appropriate body segment ellipsoids are specified, and, using the available stiffness data, the mutual force deflection characteristics are derived. The output from the program is both by printout of simulation parameters and by post processor plotting of the dummy kinematics at selected time frames. In addition, it is possible to plot variables in a graphical format either against each other or against time, and to calculate relevant injury criteria. A BL modification makes it possible to printout the forces and torques at any joint in the geometric reference system of a segment as seen at any point within that segment. Additionally, the data are output in the same reference system as the vehicle. From these data and a knowledge of contacts with vehicle panels, it is possible to investigate segment bending moments. This is particularly useful when considering the lower limbs of an impacted pedestrian.

PEDESTRIAN DUMMIES

Although the project is based on computer simulation, it was necessary to conduct some experimental tests with dummies. Firstly, to validate the program and its input data, and secondly to provide occasional experimental 'reference points' to check for drift in the computer prediction that might occur after a wide range of parameter changes.

The dummies used as the standard for the pedestrian models were of OGLE design and manufacture, and represented a 50th percentile male adult, 1.76 m tall weighing 75 kg and a six-year-old child, 1.19 m tall weighing 21.5 kg. They were basically conventional vehicle occupant test devices, strengthened where appropriate and modified to allow the dummy to stand upright. All joints were torque loaded at 1 g.

The adult dummy also had additional modifications to the hip and knee joints as described below.

Hip Joint

In the human body, values of hip joint adduction of up to 40° have been reported (8). With the dummy in the required stance, the hip joint of the impacted leg was found to have no residual adduction. To represent the human characteristic more realistically, the hip joint of the impacted leg was modified to the maximum practical extent so that adduction was increased to 28° but at the expense of some abduction.

The leg on the non-impacted side was not modified; so both legs were able to swing relative to the torso for at least 25° in the direction of impact.

Both hip joints were fitted with compressible washers to reduce the severity of the shock loads when the joints reached the limits of their travel.

Knee Joint

Impact tests on cadavers (9), (10) have shown that the human knee will bend to a limited extent in the lateral direction. To reproduce this effect both knee joints were modified to permit rotation in both lateral directions, with friction plates added to give an adjustable but constant level of friction torque (Figure 2).

INJURY TOLERANCE LEVELS

Tolerance levels for the different body regions have been selected so that an assessment can be made of the relative safety potential of the car configurations studied.

They are based on quantities that can be measured from practical tests as well as computer simulation, and are acceleration of the head, thorax and pelvis, and bending moments in the leg.

Head, Thorax and Pelvis

The acceleration levels chosen, are at the lower end of the range known to be in common use, and are shown in Table 1.

However, to enable several vehicle profiles to be assessed simultaneously during the first stages of this study, a head impact velocity criterion was preferred to accel-

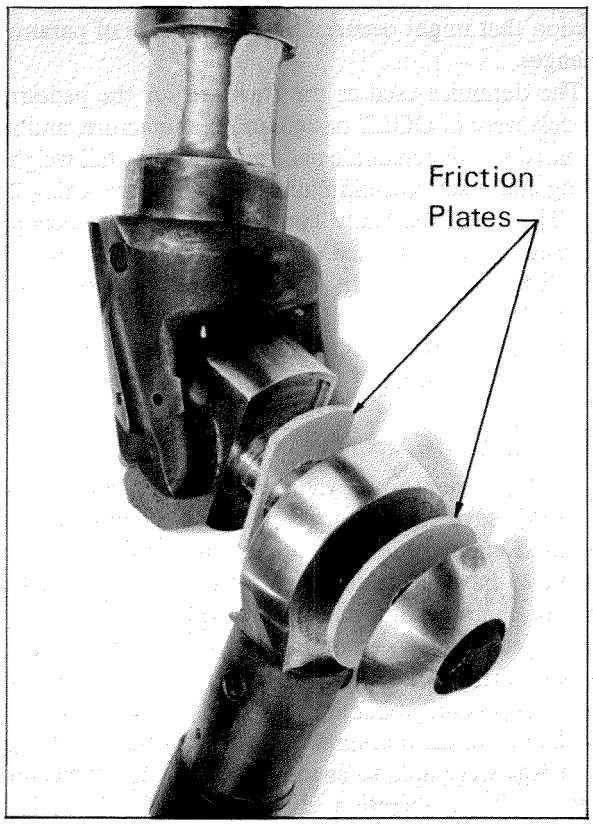


Figure 2. Modified adult knee.

eration. This was set at the maximum vehicle impact velocity of 11 m/s and represented the level of kinetic energy which might realistically be absorbed whilst maintaining an acceptable acceleration condition.

This relationship between energy absorption and maximum acceleration does not apply to the stiffest parts of the vehicle structure and so the head impact location was also considered in conjunction with its velocity.

The Leg

The aim of the research concerning the legs is primarily to save the knee from serious injury, and secondly, to reduce the risk of long bone fracture.

For the lower limbs it has been assumed that long bone fracture or knee injury results from either horizontal shear, crush or bending loads. The torsional failure mode has not been considered. However, it was found in early tests that to obtain an acceptable level of bending moment in the leg, the necessary low stiffness of the contacting car structure would reduce the risk of crush or shear failure. So, to simplify the assessment of injury, only bending moments are considered. Values of bending strength for the knee and long bones were not available and estimates have therefore been developed from existing data.

Table 1. Tolerance levels based on acceleration.

	Acceleration g for 3ms	HIC	SI
Head	80	1000	—
Thorax	60	—	1000
Pelvis	60	—	1000

The Long Bones

Estimates of long bone tolerance values have been obtained from published data on static bending tests in the anteposterior direction (11). There was claimed to be no significant difference in the ultimate strength of the bending breaking load in the lateral and the anteposterior direction. Consequently, the derived values have been used as a first estimate for bending in any direction.

Quoted values of ultimate deflection, ultimate specific deflection and bending breaking load have been used to calculate the following bending moments at fracture:

Femur		212Nm
Tibia	186Nm	214Nm
Fibula	28Nm	

A value of 200Nm has therefore been adopted for both the upper and lower leg. 200Nm has also been used for the child because no data were available.

Knee—Adult

To establish the tolerance limit of lateral compliance for the adult knee there were two parameters to be determined. The first was joint stiffness (represented by friction torque in the model) and the second, the magnitude of lateral rotation representing the tolerance limit.

For the lateral stiffness, comparative tests on cadavers and adult dummies (9) claimed that representative deformations of the dummy lower leg were seen when a short length of 12.5-mm-diameter threaded rod was inserted axially into the leg directly below the knee joint. In the model, a lateral friction torque of 200Nm at the knee joint would provide a similar resistance to that of the threaded rod.

Consequently, a lateral friction torque of 200Nm was adopted.

Because the friction torque setting in the knee joint was the same value as the bending moment tolerances adopted for the long bones, the leg model had a constant tolerance to applied bending moment over its entire length. The effect of this was that the leg tolerance level was most frequently exceeded at the point of impact. This is in agreement with accident studies (15) which found that leg injury most frequently occurred adjacent to the point of major impact.

For lateral rotation an angle of 6° was chosen to represent collateral ligament failure. This value was determined by utilising the work by Aldman et al. (14). By

taking the maximum reported elongation for the medical collateral ligament (7.2 mm) and the active distance of the ligament from the condyle (70 mm), an angle of 6° was produced.

Knee—Child

No attempt was made to determine a tolerance value for the child knee because of the infrequency of serious injury to the knees of children as noted in an appraisal of accidents investigated by Dr. S. J. Ashton (Birmingham University, Accident Research Unit). In this investigation, from a total of 83 accident cases of children ten years of age or younger, there were 24 cases of fractured long bone, 15 cases of minor surface injury at the knee and only 1 case of non-minor injury—a fracture of the tibial plateau rated at AIS 2. It was therefore assumed for this study that for the range of shapes and stiffnesses to be investigated, bending moment at the knee would be unlikely to cause serious injury.

IMPACT CONDITIONS

The following conditions applied throughout the project.

Dummy

The dummy was struck on the right hand side, with the right leg backward and the left leg forward to represent a walking stance. Both legs were straight and the full weight of the dummy was judged to be evenly distributed between the two legs at the moment of impact. The dummy was rotated 60° from a position directly facing the vehicle, as shown in Figure 3.

The left arm of the dummy was allowed to hang vertically down whereas the upper segment of the right arm was inclined rearwards at 30° to the vertical plane and the lower segment allowed to hang vertically down.

The torque settings for the joints were 1 g.

This stance was chosen for several important reasons:

- to avoid knee to knee impact
- to give a lateral impact to the lower limbs that is representative of typical accident conditions
- to improve the probability of head to vehicle contact without the shoulder striking in such a manner that it gives unrealistically high protection to the head
- to give a predictable trajectory, the dummy being inclined to rotate face down onto the vehicle.

Vehicle

The dummy was impacted on the centre line of the car at 40 km/h. This speed was considered to be the maximum at which pedestrian protection could be practicable.

The vehicle was braked at the instant of dummy contact with a nominal deceleration of 0,7g. The vehicle suspension was locked at normal running height to give repeatable impact conditions.

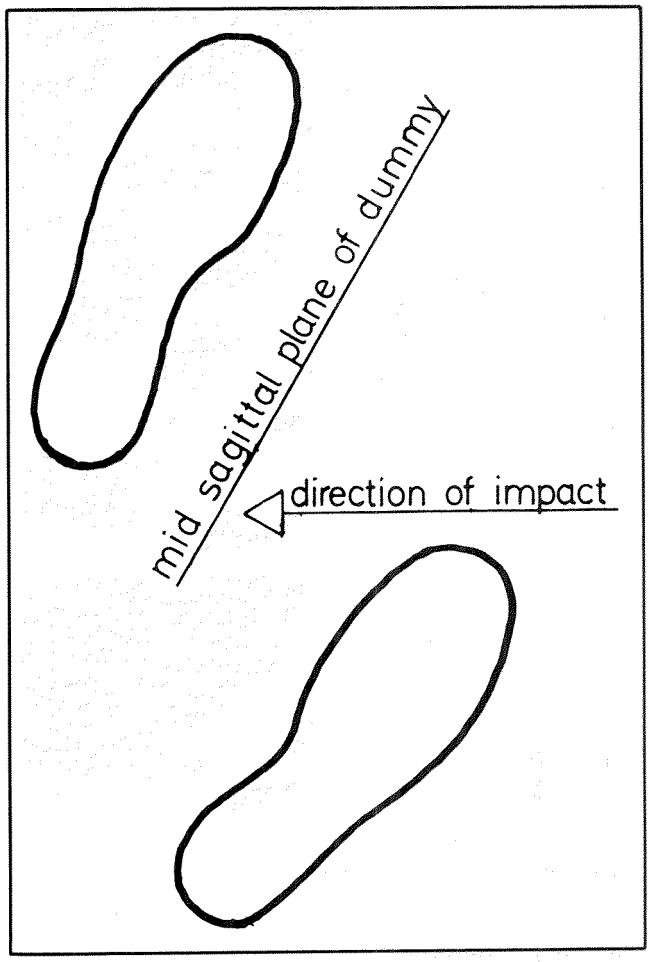


Figure 3. Pedestrian standing position.

COMPARISON BETWEEN EXPERIMENTAL TEST AND COMPUTER SIMULATION

Prior to the start of this project, it was essential to establish that computer simulation could accurately reproduce the results from practical tests. The simulation method was validated by comparing the results from high speed cine records of dummy impacts with post processor plots from the mathematical model. From these, one such adult comparison is presented to demonstrate the accuracy of the computer simulation, using the dummy and impact conditions described in Section 5. The results from the simulation and practical test are compared with respect to the kinematics (Figure 4), and head impact location and velocity (Table 2 and Figure 5).

Detailed analysis of the head plus a visual trajectory comparison of all the body segments was considered to

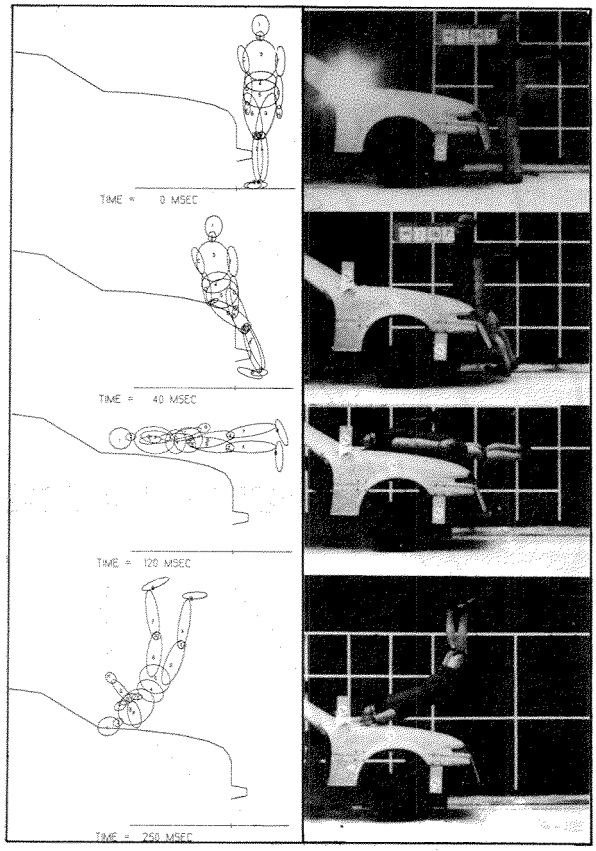


Figure 4. Kinematic validation.

be sufficient for final confirmation of the performance of the model. From these results, it was concluded that, in general, the correlation was good, especially during the critical periods of impact, e.g., head contact. It was considered sufficient for the computer predictions to be within the order of variation normally associated with nominally identical dummy tests (12). Consequently, the overall agreement in results, including those from numerous other validations, was such as to allow the project to proceed with confidence.

PARAMETRIC STUDY BY COMPUTER SIMULATION

This section describes the use of the computer program to evaluate the effect of various vehicle front-end profiles on impacted pedestrians. Since the project is ongoing, only the initial findings are discussed.

Vehicle Representation

A typical vehicle front was modelled by using a minimum number of flat planes to represent a simplified shape which nonetheless contained the most important features for pedestrian impact. The planes themselves were given idealised stiffness functions based upon those for current production vehicles.

Table 2. Summary of validation results—head.

	Simulation	Practical Test
Contact Time to Vehicle	122 ms	119 ms
Location Head to Vehicle		
—Horizontal	−1350 mm	−1425 mm
—Vertical	−560 mm	−585 mm
Resultant Head Impact Velocity	10,9 m/s	11,3 m/s
Head Impact Contact Angle (to horizontal)	72°	68°

Figure 6 shows the six panels or groups of panels used in the model. These represent the under-bumper region, bumper, grille, leading edge, bonnet and windscreen. To enable an extended amount of information to be gained from each run of the program, three bonnet lengths were modelled simultaneously, each having the same leading and trailing edge heights. Associated with each bonnet length was a group of three windscreens to which were given negligible stiffnesses. By this means the impact velocity of the head with each windscreen could be obtained. Where a radiused leading edge was investigated, a slightly

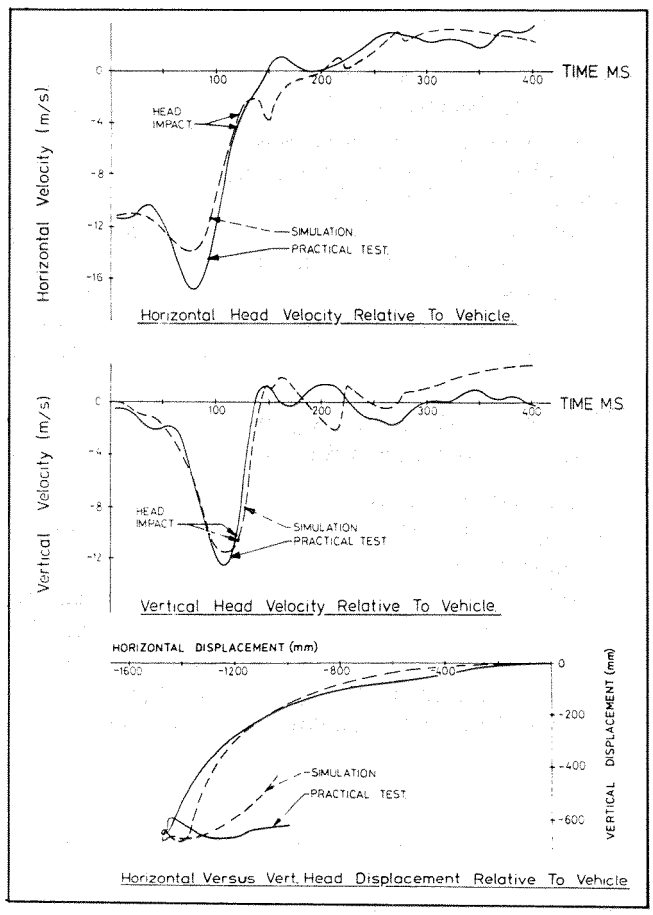


Figure 5. Head validation results.

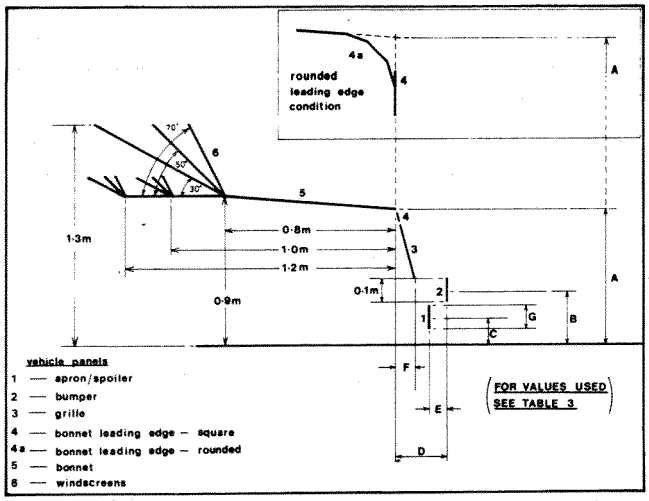


Figure 6. Vehicle simulation panels.

more complex model was used (Figure 6 inset). The three panels used to model the curvature operated in a dependent manner, the panel with the greatest contact with each segment being used at any one time.

Stiffness Characteristics

The idealised stiffness characteristics shown in Figure 7 describe forces normal to the vehicle panels. All reached a force plateau at which there was no limit on deflection (the stiffness of the understructure not being considered). By this means, necessary material crush depths could be assessed for each condition. Within the program, the stiffness for the interaction of each panel upon the relevant body segment was derived by combining their characteristics. For each combined stiffness, the permanent deflection and energy recovery were set to be constant proportions of the maximum values reached after impact.

Parametric Variables

Throughout the initial parametric study the bonnet trailing edge height and windscreens were maintained constant while the parameters under investigation were concentrated at the front face of the vehicle. Table 3 and Figure 6 summarise the type and extent of the variations. Since the total number of permutations for the parametric adjustments selected was extremely large, the choice of combinations had to be selectively based upon logical progression and a deepening understanding of the mechanics of the impacts. It became apparent that the three initial leading edge heights chosen displayed distinctive characteristics during pedestrian impact. Consequently, the approach adopted was to assess the effects of parametric change against each of these leading edge heights, using the primary run as the baseline. The comments in the following sections refer specifically to these simulations.

Adult Impact Response

To assist comparison of the different conditions, the period of impact has been divided into four phases as described in Figure 8. The length and timing of each phase varied depending upon the vehicle shape. Figure 9 summarises the results to date.

Low Leading Edge

Phase 1 tends to be at its longest with this profile because of the delay before leading edge contact. Consequently, a large proportion of the total energy imparted to the victim is transferred from the bumper. The knees undergo a high level of abduction and the lower legs are subjected to high bending moments with the localised impact close to the knee.

Phase 2 is short because the leading edge contact is only slight, its contribution being again close to the knee.

Phase 3 involves high rotational velocity with little thorax or arm contact with the bonnet. This trajectory is a consequence of the bumper and leading edge energies being centred on an area that is well below the overall centre of gravity of the victim.

Head contact (Phase 4) velocities are high due to the angular velocity of the whole body. All windscreens are contacted.

Medium Leading Edge

Phase 1 is shorter than for the low leading edge profile because of the earlier leading edge contact. The bumper therefore impacts less energy during this phase and while the bending moments in the lower legs are similar, knee abduction cannot reach as great an angle in the shorter time.

Phase 2 is initiated by the leading edge contacting the central region of the upper leg. The still considerable difference in speed between vehicle and victim means that the contact is severe and causes a high local bending

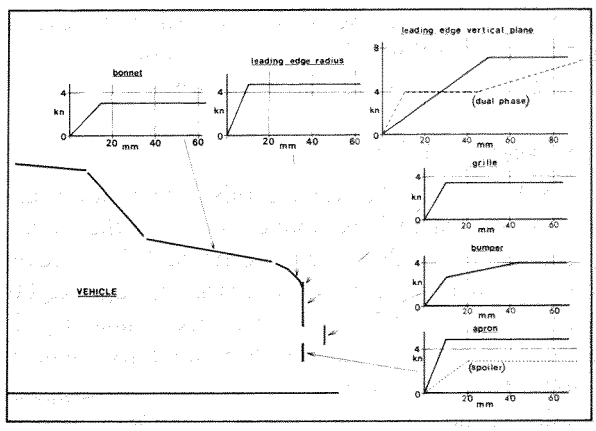


Figure 7. Simulation vehicle panel stiffness.

Table 3. Vehicle parametric variables.

RUN NUMBER		L1	L2	L3*	M1	M3*	M4	M5	M6	M7	M8	H1	H2	H3*	H4	H5	H6	H7
VEHICLE DIMENSIONS (mm) (SEE FIG. 6)	A	600	600	600	720	720	720	720	720	720	720	850	850	850	850	850	850	850
	B	450	350	450	450	450	450	450	450	350	450	450	350	450	450	450	450	350
	C	320	270	320	320	320	320	320	320	270	262	320	270	320	320	320	320	270
	D	150	150	150	150	150	250	350	150	150	150	150	150	150	250	350	150	150
	E	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
	F	0	0	0	0	0	100	200	0	0	0	0	0	0	100	200	0	0
	G	160	160	160	160	160	160	160	160	160	25	160	160	160	160	160	160	160
LEADING EDGE SHAPE (SEE FIG. 6)		⌐	⌐	⌐	⌐	⌐	⌐	⌐	⌐	⌐	⌐	⌐	⌐	⌐	⌐	⌐	⌐	⌐

(*) Dual Phase Leading Edge Stiffness — See Fig 7

moment. In addition, rapid angular motion of the upper leg puts the knee joint into severe abduction as the lower leg is being accelerated. This is in addition to that already imposed by the bumper during Phase 1. It is acknowledged that in a human victim, the knee injury would be greatly different if the upper leg was in fact broken.

Compared with the low leading edge, Phase 3 involves lower angular velocity of the torso because the leading edge is closer to the overall body centre of mass.

Head impact (Phase 4) velocities are close to the initial vehicle impact velocity but are less than those for the low leading edge case because of the reduced rotational velocity of the torso. Since the torso pivots about the leading edge, the impact sites are also less rearward.

High Leading Edge

Phase 1 is at its shortest for this configuration and there is only limited knee abduction before the leading edge contact, although the bending moments in the lower legs reach similar values to the other leading edge heights.

Phase 2 starts with the leading edge contacting the upper leg near to the hip at almost initial impact velocity (11 m/s). There is very little hip rotation because of the proximity of the impact and the force is transmitted almost directly into the pelvis; this also gives reduced upper leg bending moments. The consequence of this is that the hip joint is subjected to high forces and the pelvic region therefore sustains high accelerations. With a high bonnet there is a low rate of leg rotation about the leading edge, and therefore low inertial forces across the knee results in little abduction of this joint.

Phase 3 is controlled by the leading edge contact being close to the centre of body mass with the result that the rate of body rotation is low.

Phase 4 head impacts are well below the vehicle impact velocity as a consequence of the slow rotation rate. The contacts are only with the foremost group of windscreens.

Child Impact Response

The impact has again been divided into four phases as shown in Figure 10. Figure 11 summarises the child results to date.

Low Leading Edge

Phase 1 is again at its longest with this profile because of the delayed leading edge contact. As the bumper accelerates the upper leg, the inertia of the lower leg puts a bending moment across the knee. There is also a bending

moment at the site of impact due to the inertia of the whole leg.

Phase 2 is brief and involves a moderate contact with the leading edge.

Phase 3 involves the body flexing around the leading edge. The torso gains a high angular velocity constrained only by the stiffness of the hips. The impact velocity of the thorax with the bonnet is therefore high and results in a high chest deceleration.

Phase 4 continues from the previous phase with a head impact velocity just less than that of the vehicle.

Medium Leading Edge

Phase 1 is similar to that for the low leading edge but shortened by the earlier leading edge contact.

Phase 2 involves direct leading edge contact with the pelvis and this results in both high forces and accelerations.

Phase 3 is similar to that for the low leading edge except that it is the thorax and head which are rotating above the contact. The thorax contact velocity is low and both acceleration and rotation are small. The head rotation velocity is however affected by its inertia causing initial neck fluxion away from the vehicle only for the head to be rapidly accelerated forward when the neck recovers and the thorax decelerates.

Phase 4 therefore involves a head impact velocity which is only slightly below that of the vehicle.

High Leading Edge

Phase 1 is little affected by raising the leading edge although it is shortened slightly.

Phase 2 involves direct leading edge to thorax contact with resulting high chest accelerations.

Phase 3 is significantly different from those of previous profiles in that the torso does not rotate onto the bonnet, thus exacerbating the inertial effects upon the head and neck.

The head impact velocity (Phase 4) is low as most of the deceleration of the head is provided by the neck. For this reason, neck injury might well arise in real accidents of this type.

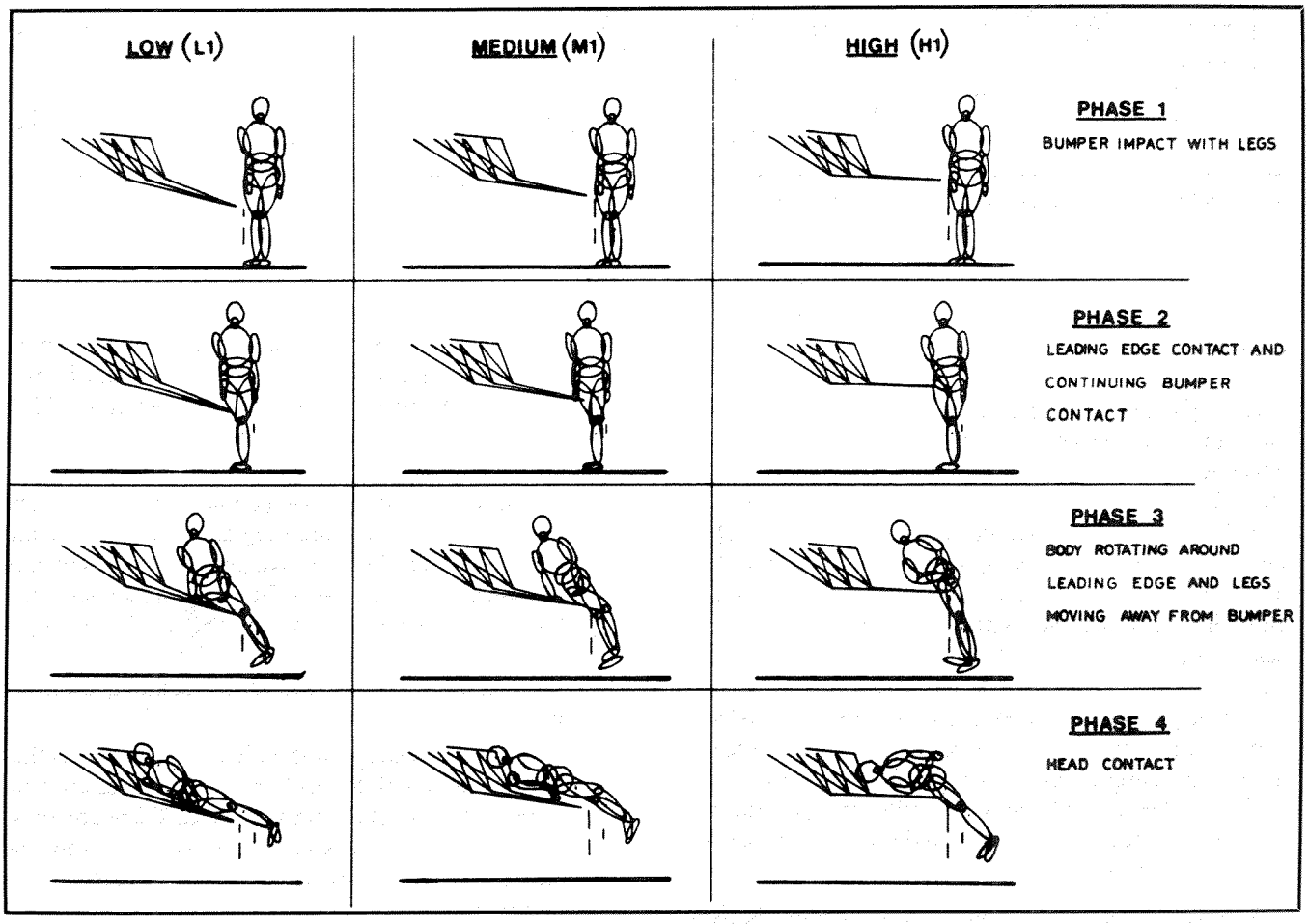


Figure 8. Adult impact phases for baseline profiles.

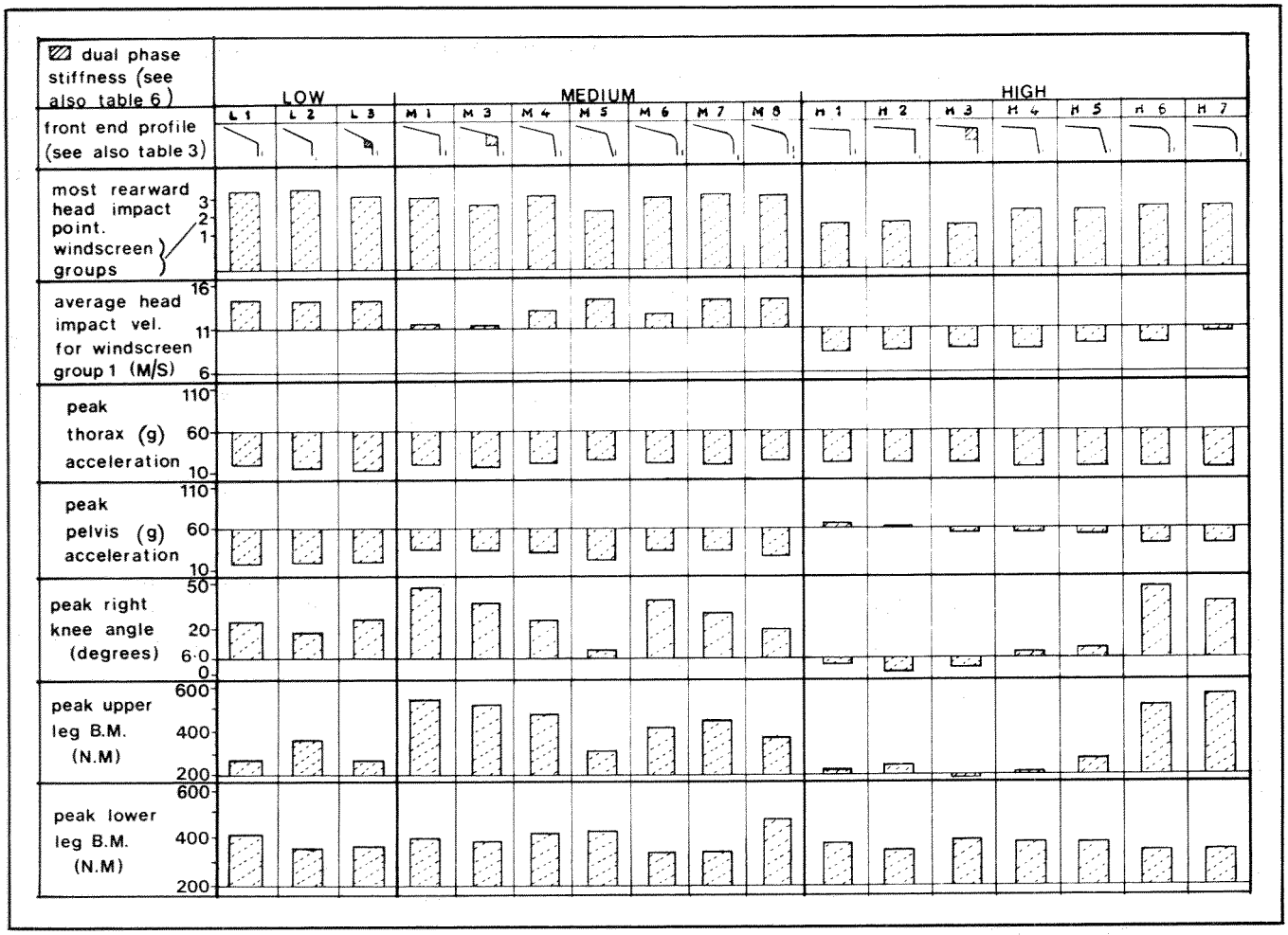


Figure 9. Parametric study results—adult. (Values related to applicable tolerance levels).

CONCLUSIONS

A mathematical model for the simulation of a pedestrian dummy has been described and its capability to effectively reproduce a car to dummy impact, demonstrated.

Tolerance levels for leg bending moments and lateral knee compliance have been determined and these have been used to assess the performance of various car shapes and stiffnesses, together with the generally accepted acceleration-based tolerance limits for head, thorax and pelvis.

A knee joint with limited lateral rotation, coupled with a constant frictional torque proved to be an effective method of representing the lateral flexibility of the knee.

The studies to date show the following general relationship between vehicle design and the resulting severity of impact to pedestrians at speeds of 40 km/h.

- A low leading edge profile has two major disadvantages. By concentrating most of its load input below the centre of gravity of the pedestrian high angular rotation is induced and this results in head impact velocities of greater magnitude than the initial vehicle impact speed. Secondly this concentration of load about the knee causes severe local injury.
- The medium leading edge profile has serious problems associated with adult leg and knee injuries and child pelvis acceleration. All the geometric changes to reduce these, increases the head impact velocities for the adult, but not for the child. Of the shapes considered, only the rounding of the leading edge reduced both upper and lower leg bending moments in the adult.
- A significant feature of the high leading edge is that both adult and child head impact velocities are consistently below vehicle impact speed. There are, however, problems associated with direct child thoracic and pelvis impact but these can be reduced by increasing the bumper lead.
- For the structural stiffnesses and leading edge heights

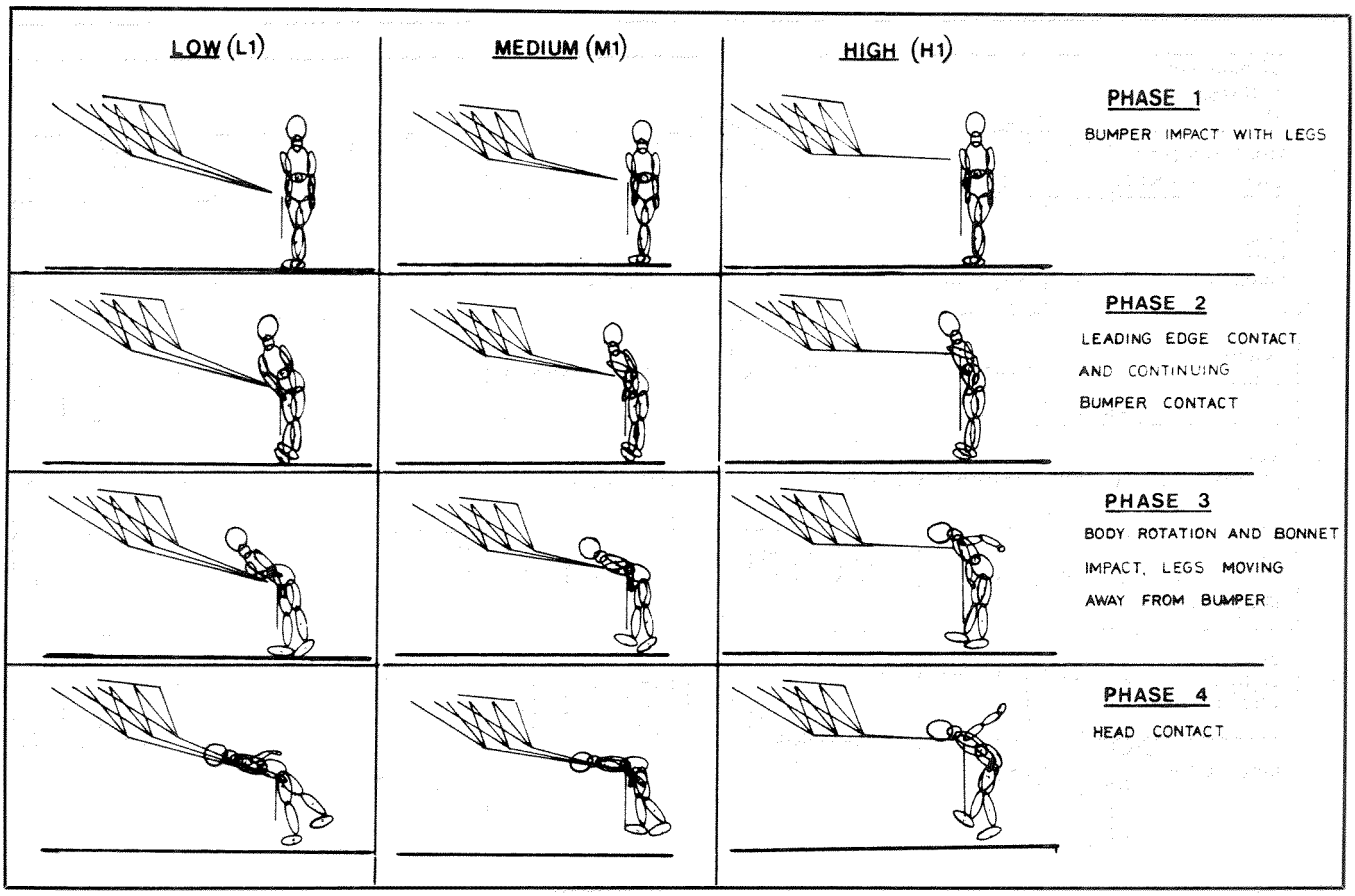


Figure 10. Child impact phases for baseline profiles.

studied, the resulting adult thoracic accelerations were always low and the pelvic accelerations only exceeded 60g for 3 milliseconds on two occasions.

The results to date suggest that further reductions in the severity of impact can probably be achieved with the medium to high leading edges. More detailed stiffness and geometric investigations will be conducted to study this possibility.

ACKNOWLEDGEMENTS

The authors would like to express their thanks to those who have contributed towards this project. Thanks are especially due to Mr. N. D. Grew, Mr. G. O. Davies and Mr. D. R. Gebbels of Austin Rover Group Limited.

REFERENCES

1. S. J. Ashton, G. M. MacKay, "Car Design for Pedestrian Injury Minimisation". Proc 7th Int Tech Conference on Experimental Safety Vehicles.
2. J. E. Fowler, K. F. Newman, "The use of Computer Simulation for the Design of Safer Vehicles". Proc I Mech E Conference—Progress Towards Safer Passenger Cars in the UK—1980.
3. W. E. Emmerson, J. E. Fowler, "Simulation of Frontal Vehicle Impacts". Proc I Mech E Conference—Vehicle Safety Legislation—Its Engineering and Social Implications—1973.
4. W. E. Emmerson, J. E. Fowler, "The Application of Computer Simulation in Vehicle Safety". Proc 5th Int Tech Conference on Experimental Safety Vehicles.
5. J. A. Bartz, "A Three-Dimensional Computer Simulation of a Motor Vehicle Crash Victim". Phase I—Development of the Computer Program, Cornell Aeronautical Laboratory 1971.
6. J. A. Bartz, F. E. Butler, "A Three-Dimensional Computer Simulation of a Motor Vehicle Crash Victim. Phase II— Validation Study of the Model, Cornell Aeronautical Laboratory 1972.
7. J. E. Fowler, R. K. Axford, K. R. Butterfield, "Computer Simulation of the Pedestrian Impact—Development of the Contact Model", Proc 6th Int Tech Conference on Experimental Safety Vehicles—1976.
8. J. A. Searle, C. M. Haslegrave, "Improvements in the Design of Anthropometric/Anthropomorphic

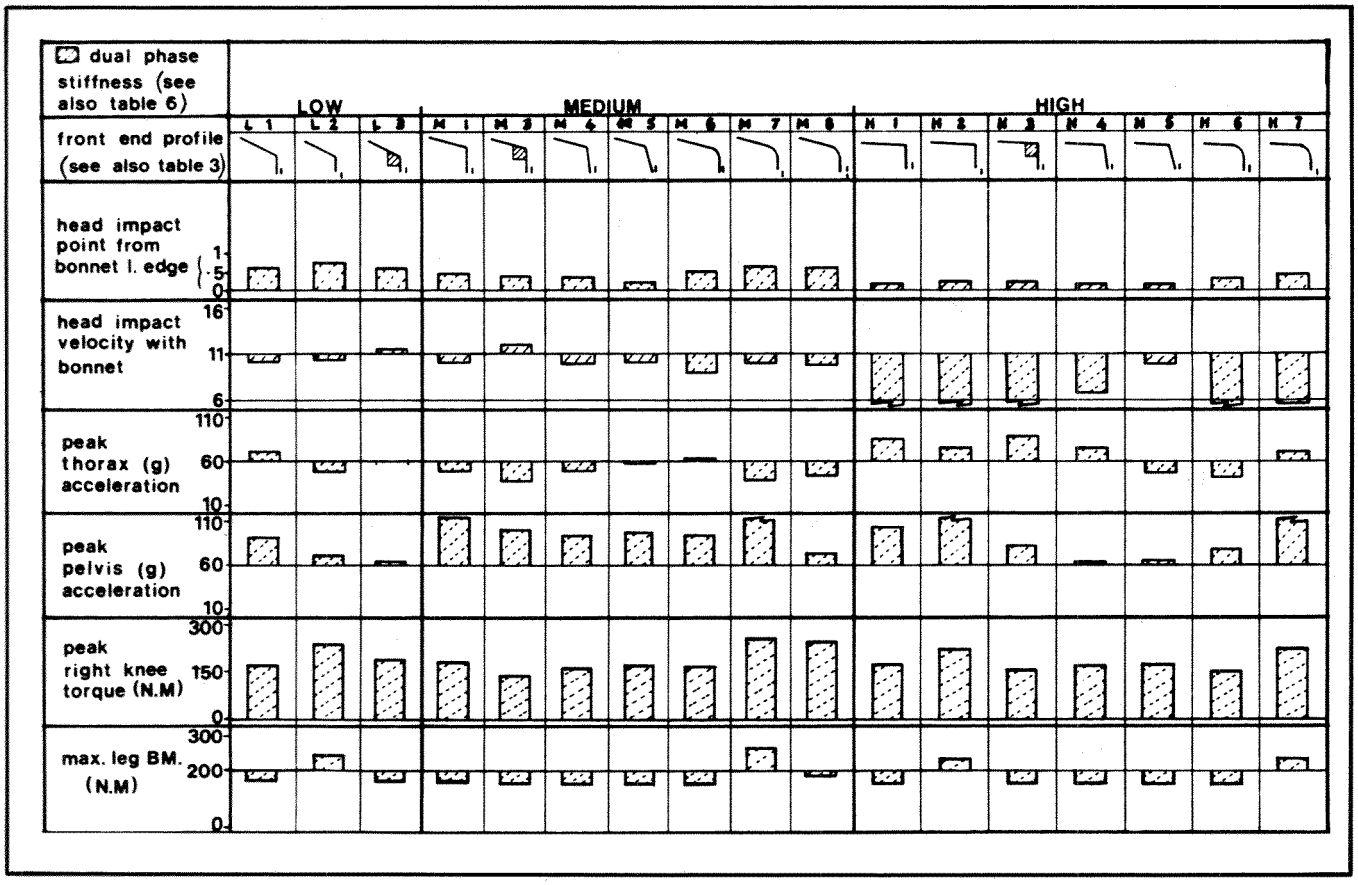


Figure 11. Parametric study results—child. (Values related to applicable tolerance levels).

Dummies", MIRA BULLETIN No. 5 1970 Sept/ Oct 10–2.

9. H. B. Pritz, "Comparison of the Dynamic Response of Anthropomorphic Test Devices and Human Anatomic Specimens in Experimental Pedestrian Impacts. Proc 22nd STAPP Car Crash Conference Ann Arbor USA October 1978.
10. B. Aldman, et al., "An Experimental model for the Study of Lower Leg and Knee Injuries in Car-Pedestrian Impacts", Proc 5th Int Conference on the Biomechanics of Impact IRCOBI Birmingham England September 1980.
11. Hiroshe Yamada, "Strength of Biological Materials", Baltimore 1970—The Williams and Wilkins Co.
12. Joint Biomechanical Research Project KOB—1982.
13. R. H. Eppinger, H. B. Pritz, "Development of a Simplified Vehicle Performance Requirement for Pedestrian Injury Mitigation", Proc of 7th Int Tech Conference on Experimental Safety Vehicles, Paris, June 1979.
14. B. Aldman, L. Thorngern, O. Bunketorp, B. Romanus, "An Experimental Model System for the Study of Lower Leg and Knee Injuries in Car Pedestrian Accidents", Proc of 8th Int Tech Conference on Experimental Safety Vehicles, Wolfsburg, Germany, October 1980.
15. S. J. Ashton, J. B. Pedder, G. M. MacKay, "Pedestrian Leg Injuries, The Bumper and other front structures", Proc 3rd International Conference Biokinetics of Impact, International Research Committee on Biokinetics of Impact, Lyon 1977.

Application of the Fiat Methodology for Characterizing Vehicle Structural Responses in Frontal Impacts

L. M. "MORRIE" SHAW
Arndt & Associates

CARL RAGLAND
National Highway Traffic Safety Administration

ABSTRACT

Over the past several years, Dynamic Science, Inc., under funding from Fiat Auto S.p.A., developed a methodology for evaluating vehicle crash compatibility. The ultimate goal was to provide compatibility characterization technology in the frontal, side, and rear impact environments. The result of this research has been extremely encouraging, providing accurate analysis and predictive capabilities, as well as justification of the methodology approach.

Because of the increasing concern for vehicle crash compatibility, the U.S. National Highway Traffic Safety Administration (NHTSA) acquired the Fiat Methodology in 1980. The NHTSA then increased the funding of an on-going program to apply the Fiat Methodology to a side impact research program. Frontal and side structural characterizations were used in the side impact analysis.

This paper summarizes the results from the above NHTSA research program emphasizing the applicability of the Fiat Methodology to the characterization of vehicle structural responses in frontal impacts. Validation of the frontal structure characterization is discussed and presented along with comparisons between predictive analysis and crash test results.

INTRODUCTION

For more than a decade automotive safety researchers have recognized the significance of vehicle crash compatibility in evaluating vehicle crashworthiness within the overall accident environment. This problem has become particularly evident in the United States due to the increasing number of small vehicles. During that period, however, the traditional measure of crashworthiness and compliance in frontal impacts has been and remains based on the rigid barrier SAE J 850a test. Researchers have voiced concern with regard to the limitations and ability of this test procedure for representing real world accidents. Some of the rigid barrier test limitations include:

- Is unable to simulate the great majority of automobile encounters
- Produces vehicle crashworthiness results which can deviate significantly from the traffic mix environment
- Overestimates the survival performance of smaller vehicles
- Underestimates the survival performance of larger vehicles.

These limitations have prompted researchers to study and recommend other testing and evaluative approaches which more closely represent the crash dynamics and structural interactions associated with traffic mix crash encounters. To effectively manage such a complex interactive evaluation, it would be necessary that efforts be concentrated on vehicle test and analysis techniques which consider all significant aspects of the crash environment.

In 1973, Fiat Auto S.p.A. and Dynamic Science, Inc. began formulation of test and analysis techniques for evaluation of vehicle crash compatibility. Since this initial formation, Dynamic Science, Inc., under funding from Fiat Auto S.p.A. developed a methodology for evaluating vehicle crash compatibility. The ultimate goal was to provide compatibility characterization technology in frontal, side and rear impact environments. The results of this research have been extremely encouraging—accurate analysis and predictive capabilities have been developed, as well as justification of the methodology approach.

Because of the increasing concern for vehicle crash compatibility, the U.S. National Highway Traffic Safety Administration (NHTSA) acquired the Fiat Methodology in 1980. The NHTSA then increased the funding of an on-going program (Reference 1) to initialize the applicability of the Fiat Methodology to side impact analysis. Both frontal and side structural characterizations were used in this study.

This paper summarizes the results from the above NHTSA research program emphasizing the applicability of the Fiat Methodology to the characterization of vehicle structural responses in frontal impacts. A companion paper, Reference 2, deals with the applicability of the Fiat Methodology to the characterization of side impacts, utilizing the frontal model characterizations presented herein.

FIAT METHODOLOGY APPROACH

Franchini (References 3 and 4) discussed and highlighted the Fiat Methodology in prior Experimental Safety Vehicles (ESV) conferences. However, it seems

appropriate to summarize the Fiat Methodology approach prior to presenting the results used for the NHTSA study.

The Fiat Methodology has resulted in new test and analysis approaches and techniques for evaluating vehicle-to-vehicle crash interactions. The research accomplished to date has resulted in the design and development of test hardware, test techniques, data analysis software and crash simulation software, along with validation of the basic methodology. Figure 1 flow charts the basic engineering approach and illustrates the coupling of experimental test data and analytical technology to define and characterize a vehicle's response to crash environments.

It was recognized from the beginning of the Fiat Methodology development effort that the results and analyses must be based on experimental data. As illustrated in Figure 1, the first step is a structural characterization test of the vehicle under the appropriate impact conditions. For our research, this was accomplished through the use of a test device developed to enhance structural data acquisition. The test device has been discussed and presented by Franchini in References 3 and 4 and consists of a 36-module load-measuring moving barrier fitted with energy-absorbing honeycomb blocks attached to each module. The purposes of the test device include:

1. Simulation of the structural interface interactions involved in vehicle-to-vehicle encounters,
2. Measurement of crash interface loads and deflections between the test device and vehicle being characterized, and
3. Simulation, as closely as possible, of inertia reactions associated with vehicle-to-vehicle impacts.

Of equal importance in the characterization test is the instrumentation of the vehicle being characterized. It must adequately define the structural dynamics and inertial reactions (including occupants, restraints, engine, suspensions, etc.) that characterize the vehicle's response to the crash environment. The vehicle instrumentation is dependent upon the impact mode (front, side, rear) and upon the vehicle's design configuration.

The second step of the Fiat Methodology was to develop analysis techniques which would permit characterization of a vehicle's structural response to a crash test environment. This was accomplished by developing a data processing software package referred to as Computer Program A. As illustrated in Figure 1, Program A accepts as input the kinematic and dynamic behavior obtained from the vehicle characterization test data, the vehicle parametric data, and analytical model configuration. The program then processes these data to define the necessary structural properties of the general lumped-parameter vehicle model which are required to reproduce the given kinematic input. The end product is an analytical model of the vehicle being characterized, using full-scale crash data.

The third step of the Fiat Methodology was to develop

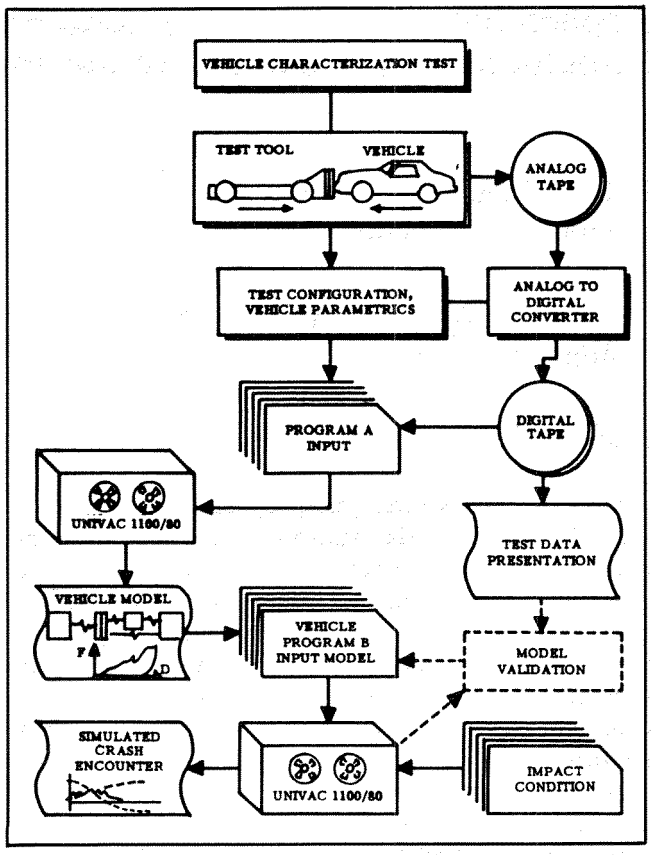


Figure 1. Fiat methodology approach.

techniques which simulate crash encounters between characterized vehicles. This was accomplished through the development of a software package referred to as Computer Program B. As illustrated in Figure 1, Program B accepts as input lumped-mass non-linear spring model representations such as defined by Program A output (or other desired impact conditions) and computes the crash response of the vehicles. Program B can also be used to check Program A output by simulating the vehicle characterization test, thus providing model validation and a means for model improvement.

Once a vehicle's model characterization has been validated, it can be used to study structural crash interaction with other characterized vehicle structures or barriers. A sufficient number of characterized vehicles representing the traffic mix environment could then provide a data base for evaluating an individual vehicle's structural crashworthiness compatibility with a traffic mix population environment.

FRONT STRUCTURAL CHARACTERIZATION

In the Fiat S.p.A.-sponsored Fiat Methodology development efforts, the Fiat 132 sedan was the primary evaluation vehicle. As a result, a considerable test data base

had been generated for that vehicle in both the frontal and side impact configurations. The Fiat 132 was consequently selected as the study vehicle for the NHTSA demonstration program (Reference 1). The Fiat 132 four-door sedan is a conventional front engine, rear wheel drive vehicle with a curb weight of approximately 2,380 pounds (1,080 kg).

The Fiat 132 front structures characterization effort is illustrated in Figure 2. It included full-scale characterization testing, computer data processing, model development, and model validation.

STRUCTURAL CHARACTERIZATION TEST

The front characterization test consisted of a head-on impact between the Fiat test tool (described in References 3 and 4) and a Fiat 132 Sedan. Table 1 summarizes the test conditions for this test. The Fiat 132 carried fully instrumented driver and right front passenger Part 572 dummies and extensive accelerometer instrumentation on all significant inertial masses. The test tool carried 36 load cells along with string potentiometers for measuring test tool honeycomb deflections and frame accelerometers.

Table 1. Fiat test tool to Fiat 132 frontal characterization test.

Fiat 132 Test Weight	2798 lb (1269 kg mass)
Test Tool Weight	4040 lb (1833 kg mass)
Closure Velocity	39.2 mph (63 km/h)
Impact Orientation	Head on with Aligned Centerlines

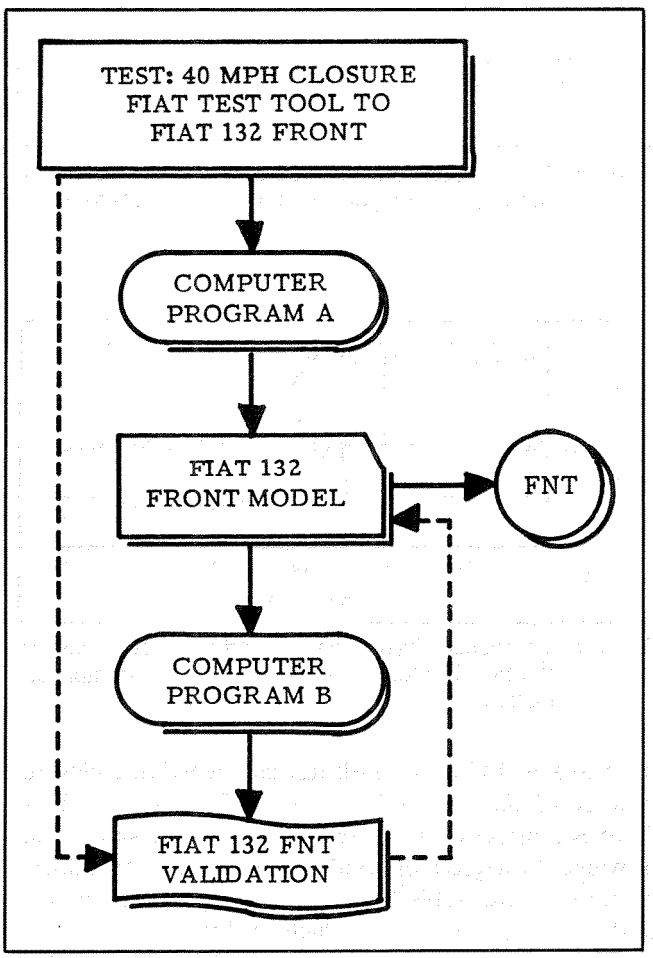


Figure 2. Flow chart of front structural characterization.

STRUCTURAL MODEL DEVELOPMENT AND VALIDATION

The data from the Fiat test tool-to-Fiat 132 frontal characterization test was processed through a Class 60 digital filter and input, along with the Fiat 132 parametric data and representative model configuration into Computer Program A. The output of Program A defined the interconnecting spring load deflection characteristics between the analytical model masses. For the Fiat 132 characterization test, the analytical model configuration, with respect to vehicle mass representations, is illustrated in Figure 3. This model incorporates both the Fiat 132 and Fiat test tool inertial representations.

The Fiat 132 model, along with the interconnecting spring characteristics and the analytical model of the Fiat test tool were input into Computer Program B and exercised under the impact conditions of the characterization test. This procedure validated the Fiat 132 analytical model by direct comparison of predicted and test results and provided an opportunity to fine tune the spring characteristics. It has been our experience that fine tuning, following the initial Program B validation run, is normally confined to improvements in the definition of the analytical spring unloading characteristics. This definition is extremely sensitive to data inaccuracies near the end of

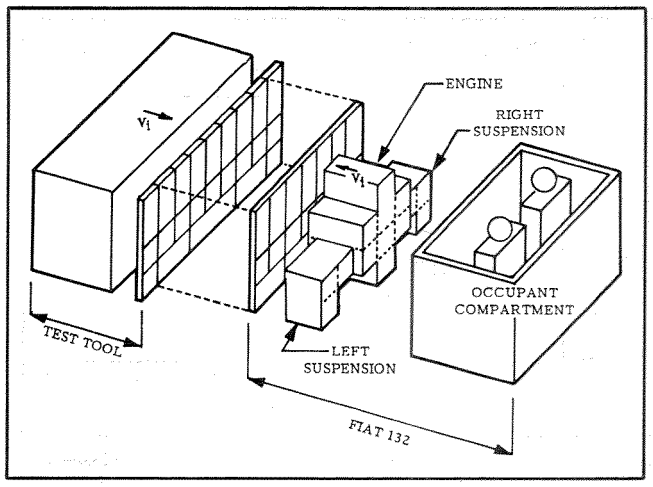


Figure 3. Model configuration for the Fiat front.

Table 2. Fiat 132 frontal model validation results summary

Parameter	Test Data	Simulation
Closure Velocity (mph)	39.2	39.2
Fiat 132 Weight (lb)	2798	2798
Test Tool Weight (lb)	4040	4040
Fiat 132 Velocity Change (mph)	24.5	26.2
Test Tool Velocity Change (mph)	17.4	17.4
Maximum Dynamic Mutual Crush (in.)	24.6	24.3
Fiat 132 Average Dynamic Crush (in.)	21.0	20.6

the crash pulse. Other fine tuning should not be necessary if test data retrieval is accurate.

The results of the Fiat 132 frontal model valiation are summarized in Table 2. Figure 4 compares the predicted response of the compartment of the Fiat 132 to the actual test data. Similarly, Figure 5 compares the predicted response of the test tool to the actual test data. Of particular interest in a frontal simulation is the ability to characterize the dynamics of vehicle components as well as structural responses. Figures 6 and 7 respectively compare Fiat 132 engine and left front suspension predicted responses to actual test results. The right front suspension response (not shown) was essentially the same as that shown in Figure 7 for the left front suspension. The results indicate excellent representation by the analytical model of the actual crash response of the vehicle. The Computer Program B input which provided these results consisted of a Fiat 132 frontal model and test tool model totaling 41 degrees of freedom.

VEHICLE-TO-VEHICLE PREDICTIVE CAPABILITY

The validated Fiat 132 frontal model was duplicated and both model sets were input into Computer Program B, along with the initial crash conditions of a Fiat 132

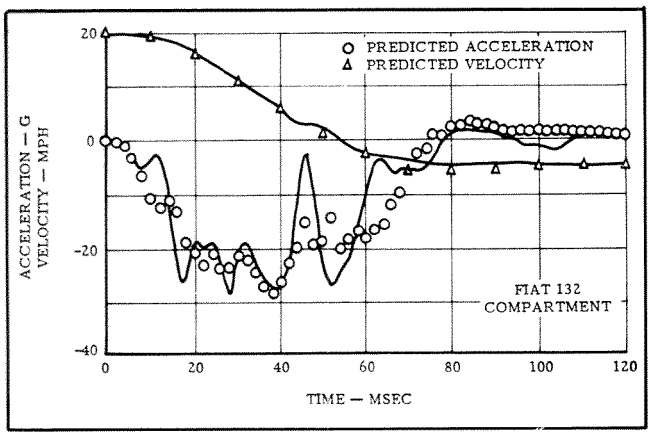


Figure 4. Comparison between predicted and test results for the Fiat 132 compartment—Fiat 132 frontal validation.

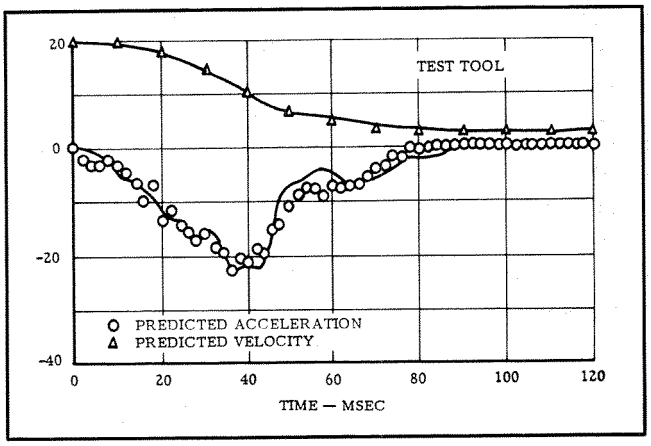


Figure 5. Comparison between predicted and test results for the Fiat test tool vehicle—Fiat 132 frontal validation.

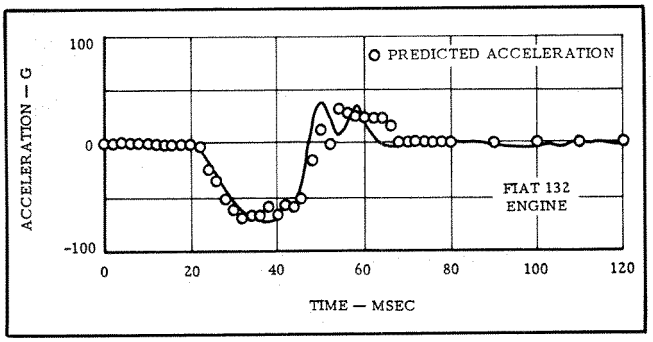


Figure 6. Comparison between predicted and test results for the Fiat 132 engine—Fiat 132 frontal validation.

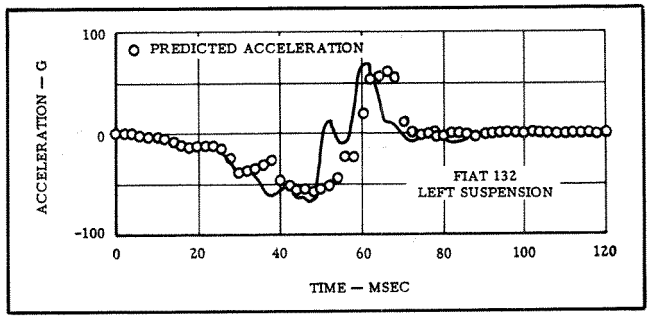


Figure 7. Comparison between predicted and test results for the Fiat 132 left suspension—Fiat 132 frontal validation.

front to Fiat 132 front crash test conducted at a closure velocity of 48.7 mph (78.4 km/hr) (Reference 5). This effort is illustrated in Figure 8. The resulting simulation provided 46 degrees of freedom, including both vehicle representations. Table 3 compares the predicted results to the actual test data. The vehicle analytical models were identical, therefore, producing exactly the same predicted responses. The crash test, however presents two identical

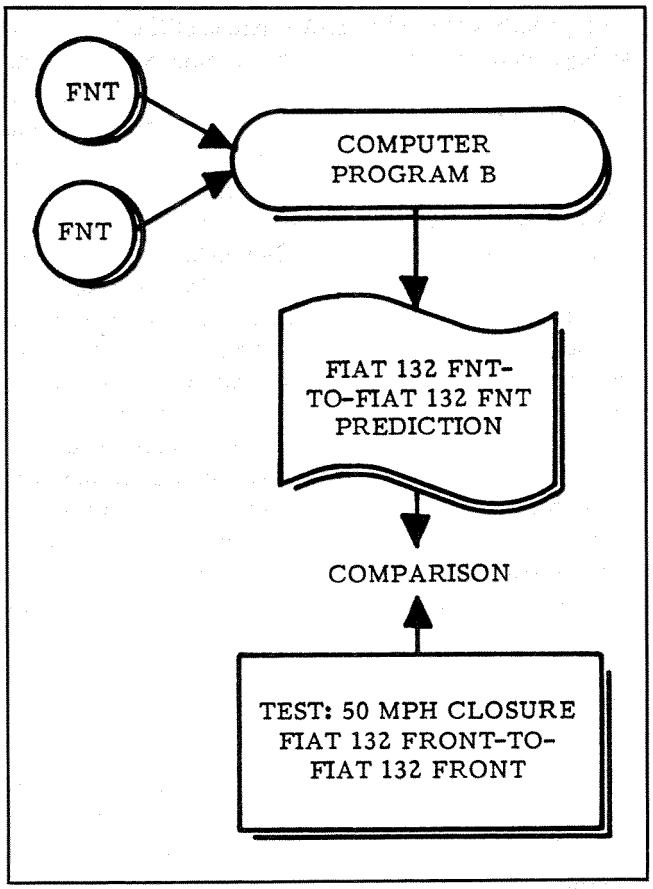


Figure 8. Flow chart for vehicle-to-vehicle prediction.

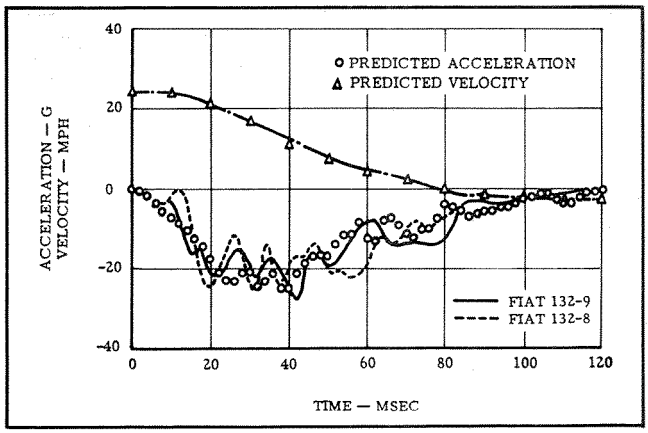


Figure 9. Comparison between predicted and test results for the Fiat 132 compartment.

vehicle models with corresponding responses representative of the real-world manufacturing and data acquisition tolerances. The Fiat 132 frontal model used was identical to that used in the validation analysis without adjustment of total vehicle mass differences.

Figure 9 compares the predicted Fiat 132 compartment response to the response accompanying each of the Fiat 132 test vehicles and Figure 10 compares the predicted engine response to the responses measured on each of the test vehicles. Figure 11 presents the predicted dynamic crush of the Fiat 132 models compared to the measured post-test residual crush for the test vehicles at bumper level.

Table 3. Fiat 132 front to front predicted crash results summary.

Parameter	Simulation	Test Data
Bullet Vehicle Weight (lb)	2798	2820
Target Vehicle Weight (lb)	2798	2826
Bullet Vehicle Velocity (mph)	24.4	24.4
Target Vehicle Velocity (mph)	24.4	24.4
Maximum Dynamic Mutual Crush		
—Integrated Acceleration (in.)	35.0	37.0
—Photography (in.)	N/A	34.0
Velocity Change at 100 msec (From Acceleration Data)		
—Bullet Vehicle (mph)	26.1	26.1
—Target Vehicle (mph)	26.1	27.0

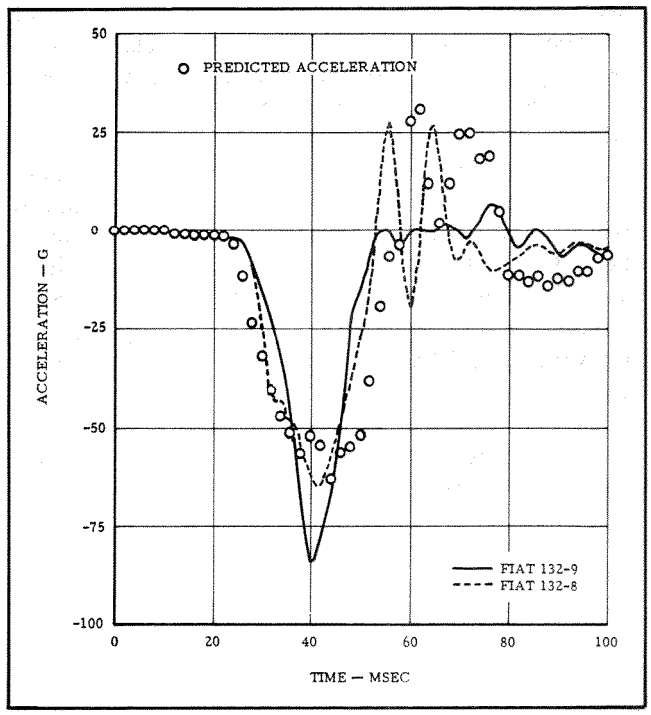


Figure 10. Comparison between predicted and test results for the Fiat 132 engine.

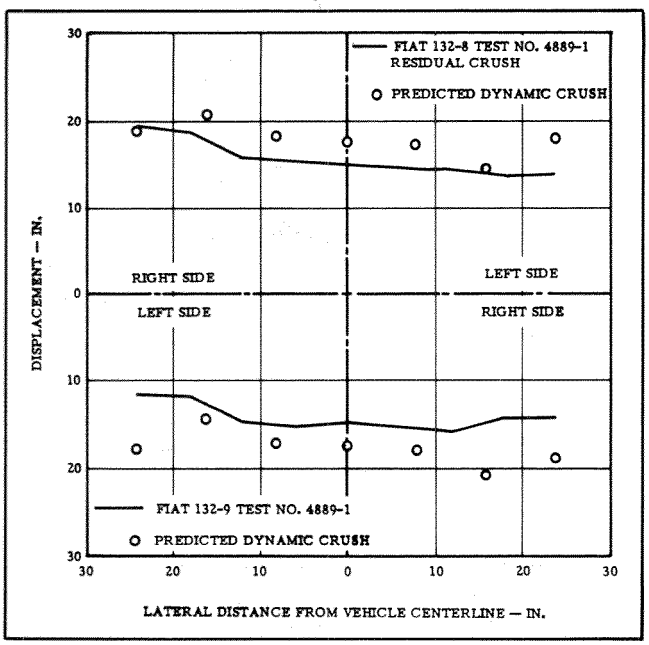


Figure 11. Comparison between simulated and test results for the Fiat 132 exterior crush at bumper level.

CONCLUSIONS

The objective of the Fiat Methodology is to provide a means by which vehicle interactions within a variety of crash environment can be determined with minimal testing. The applicability of the Fiat Methodology, test tool, and computer analysis procedures to the frontal head-on impact problem was demonstrated. The predicted results documented herein were well within the variability which can be expected when production vehicles are tested under identical conditions, using current instrumentation.

Early Fiat Methodology research revealed that the development of the predictive technology was evolutionary in nature—the achievement of a certain level of model sophistication resulted in improved modeling and characterization techniques. A great deal of the capabilities reported herein involved methodologies and upgraded computer programs which are presently proprietary to Fiat Auto S.p.A. Therefore, only the results of these analyses can be presented in this report.

The side impact model development on which the NHTSA program (Reference 1) focussed indicated that considerably more detail and capabilities, over and above the capabilities of the NHTSA versions of the Fiat Methodology, computer programs, were required to provide side impact characterization. Consequently, to maintain compatiblity between the frontal and side characterization programs, the frontal characterization model discussed herein also required this additional refinement.

Accuracy of the electronic test data is critical to the effective application of the Fiat Methodology. Significant time can be saved if the accuracy of the electronic test data is verified prior to its input into Program A. In addition, the vehicle characterization and model predictive accuracies can never be better than the test data used. As a result, the accuracies and refinement of the Fiat Methodology can be improved concurrently with improvements in instrumenation hardware and techniques. Furthermore, the use of the Fiat Methodology to evaluate a vehicle's crashworthiness is not fixed or dependent upon one evaluation condition or compliance environment. It is a methodology which is compatible with changing compliance criteria.

REFERENCES

1. Shaw, L. M., Knight, R. E. and Trudgen, A. C., "Application of the Fiat Methodology to Vehicle Side Impact", Report Number to be Assigned by the National Highway Traffic Safety Administration, Contract Number DOT-HS-8-01933, Modification Number 4, Dated September 1981.
2. Shaw, L. M., Ragland, C.,"Application of the Fiat Methodology for Characterizing Vehicle Structural Responses in Side Impact", Ninth International Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, November 1 through 4, 1982.
3. Franchini, E., "Fiat Technical Presentation", Sixth International Technical Conference on Experimental Safety Vehicles, Washington, D.C., U.S.A., Pages 129 through 157, October 12 through 15, 1976.
4. Franchini, E., "Side Collision", Seventh International Technical Conference on Experimental Safety Vehicles, Paris, France, Pages 456 through 476, June 5 through 8, 1979.
5. "Data Submittal Report Entitled, Excerpts From an Existing Fiat Auto S.p.A. Report of Fiat 132 Front-to-Front Head-On Impact, Test Data for Task 1", Contract Number DOT-HS-8-01933, Modification Number 4.

Influence of Occupant Seating Posture and Size on Head and Chest Injuries in Frontal Collision

TSUYOSHI AIBE, KUNIYUKI WATANABE,
TATSUMASA OKAMOTO and
TAKASHI NAKAMORI
Nissan Motor Co., Ltd.

ABSTRACT

The evaluation of vehicle occupant protection performance in a collision is generally based on the injury criteria. The seat is placed in the standard design position, using a 50th-percentile dummy, as represented in the FMVSS 208.

On the highway, however, vehicles are driven by individuals of various physical sizes and in various seat positions.

In this study, we have examined the relationship between injury level and occupant size or seating posture.

This paper presents examination results concerning forces acting on the chest and also on factors causing injury to the head.

TEST PROCEDURES

Test Equipment

In order to compare occupant injury levels in various conditions, we have conducted tests using a weight-drop type sled tester. This sled tester was considered to be a highly accurate reproduction when combined with a shock absorber, capable of producing a deceleration curve, simulating a 30-mph frontal barrier collision.

Figure 1 shows a schematic drawing of the test equipment. Figure 2 shows a deceleration curve caused by the combination of the weight-drop type sled and the shock absorber. Another deceleration curve produced by a 30-mph frontal barrier collision with a vehicle is also shown. This can be regarded as an actual simulation of the collision.

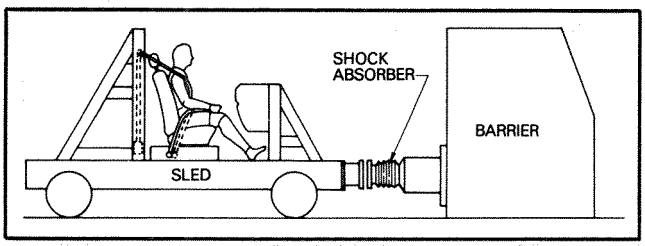


Figure 1. Test equipment.

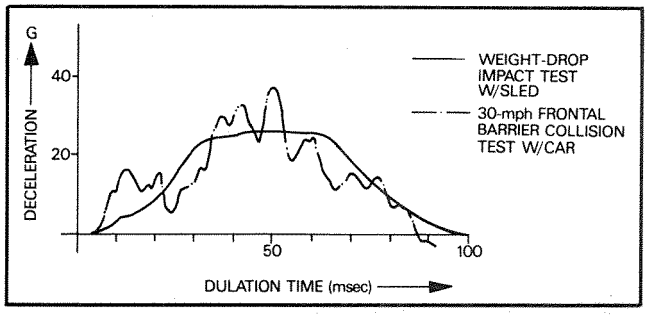


Figure 2. Deceleration curve.

Test Conditions

We conducted all sled tests with the same instrument panel, seats, seat belts, and seat belt anchorage points as found in an actual car.

To consider the influence of occupant body size, we used the following three types of dummies:

Table 1. Types of dummies.

	ABBR.	SIZE	Wt.(kg)	SITTING Ht.(cm)	REMARKS
1	M50	AMERICAN, MALE, 50th PERCENTILE	74.5	90.7	HYBRID II ALDERSON-MADE
2	M95	AMERICAN, MALE, 95th PERCENTILE	97.7	96.5	ALDERSON-MADE
3	F05	AMERICAN, FEMALE, 5th PERCENTILE	47.2	78.0	ALDERSON-MADE

Next, tests were conducted to examine the influence of occupant seating posture by setting up five points as shown in Figure 3. The seat slide was moved forward or rearward by 100 mm from the normal middle position. The seat back angle was set where the seat back was inclined forward or backward by 9 degrees from the normal middle position.

Using three different sized dummies to examine the relationship between injury levels and occupant sizes, a series of tests were carried out under the conditions shown in Table 2.

Next, to see what effect the seat slide positon had on

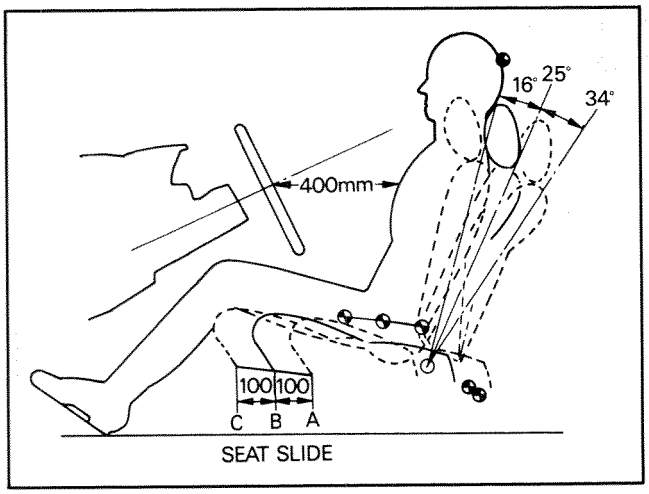


Figure 3. Positions of seat back and seat slide.

Table 2. Test condition (1).

SEAT SLIDE \ SEAT BACK ANGLE \ SEAT POSITION \ DUMMY		F05		M50		M95	
		DRIVER	PASSENGER	DRIVER	PASSENGER	DRIVER	PASSENGER
A	25°	1	2	3	4	5	6
B	25°	7	8	9	10	11	12

Table 3. Test condition (2).

SEAT SLIDE \ SEAT BACK ANGLE \ SEAT POSITION \ DUMMY		M50		M95	
		DRIVER	PASSENGER	DRIVER	PASSENGER
A	25°	③	④	⑤	⑥
B	25°	⑨	⑩	⑪	⑫
C	25°	⑬	⑭	⑮	⑯

Table 4.

SEAT SLIDE \ SEAT BACK ANGLE \ SEAT POSITION \ DUMMY		M50		M95	
		DRIVER	PASSENGER	DRIVER	PASSENGER
B	16°	⑰	⑱	⑲	⑳
B	25°	⑨	⑩	⑪	⑫
B	34°	㉑	㉒	㉓	㉔

injury level, tests were conducted under conditions shown in Table 3.

To determine what effect the seat back angle had on the injury level, tests were conducted under the condition shown in Table 4.

Table 5.

SEAT BELT ELONGATION RATE \ SEAT POSITION \ DUMMY	M50	
	DRIVER	PASSENGER
STD WEBBING	⑨	⑩
15% MORE ELONGATING WEBBING	㉕	㉖

Finally, to determine the effect of the seat belt elongation rate on the injury level, tests were conducted under the same conditions as in Test Nos. (9) and (10), with the belt elongation itself increased by approximately 15 percent, as shown in Table 5.

RELATIONSHIP BETWEEN INJURY LEVEL AND OCCUPANT BODY SIZE

Figures 4 and 5 show the extent of injuries sustained by the head and by the chest, as a result of tests of Test Nos. (1) through (12) under the conditions shown in Table 2.

In Figures 4 and 5,

(1) The head injury level increases as the dummy size decreases, especially with the F05 which shows high injury levels, and

(2) The chest injury level also increases as the occupant size decreases.

Here, force applied to the dummy during a collision is shown in Figure 6. The difference in occupant size does not change the initial restraint caused by the seat belt.

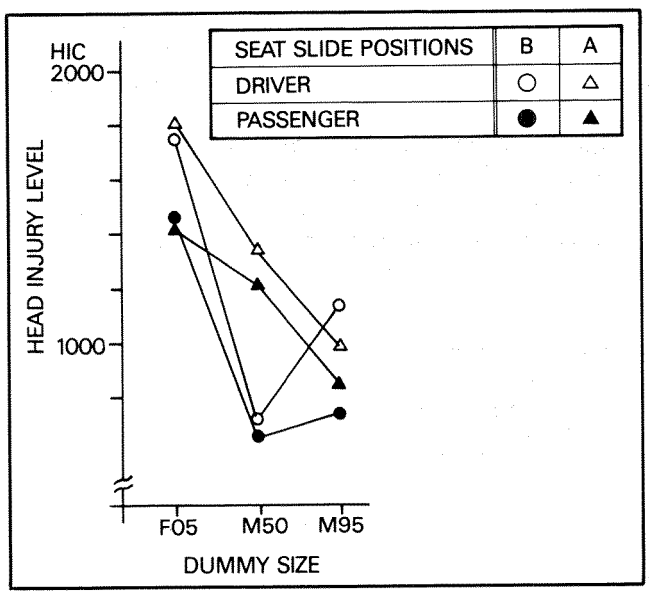


Figure 4. Head injury level.

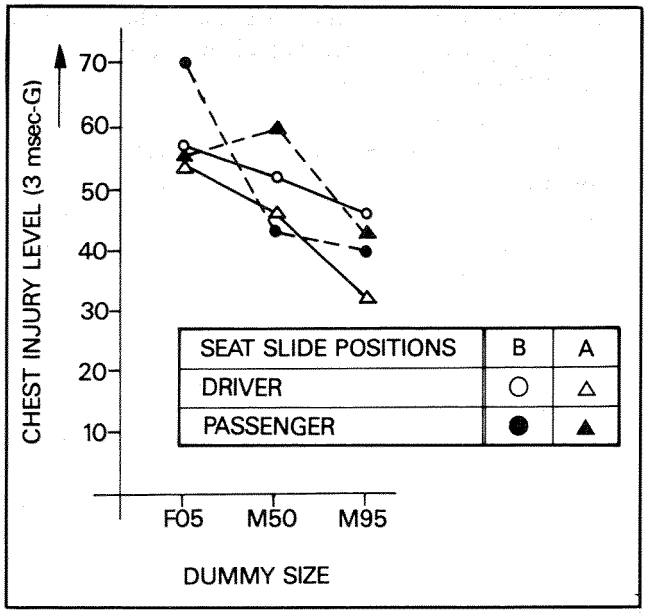


Figure 5. Chest injury level (3 msec-G).

After approximately 40 to 50 msec from the start of the collision, the chest becomes restrained by the shoulder belt, and after another 30 msec, the chest stops moving. Then, the head begins to pivot on the neck, and thus, the phenomenon caused by the collision comes to an end.

We examined the reason why, in a similar phenomenon, the tendencies shown in Figures 4 and 5 occur.

The chest is restrained by the shoulder belt. Our examination revealed, in each test case, that the relationship between the tension on the shoulder belt and the occupant weight was highly correlated as shown in Figure 7. Generally the substantial mass weight applied to the shoulder belt is said to account for 25 percent of the overall weight. The Substantial mass weight figured out from the belt tension and the deceleration G produced on the chest is shown in Table 6. This shows clearly that the substantial mass weight makes up approximately 25 percent of the overall weight.

The force produced on the chest can be calculated by

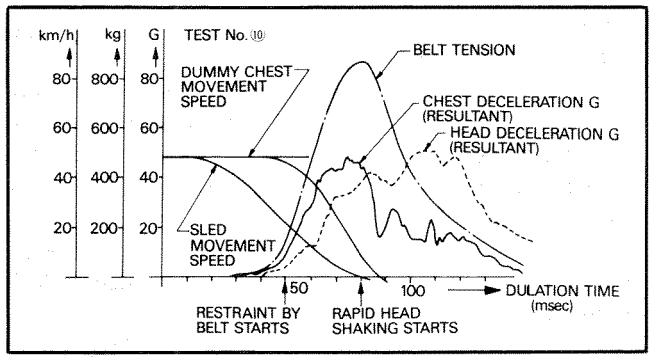


Figure 6. Phenomenon occurring on each part in collision.

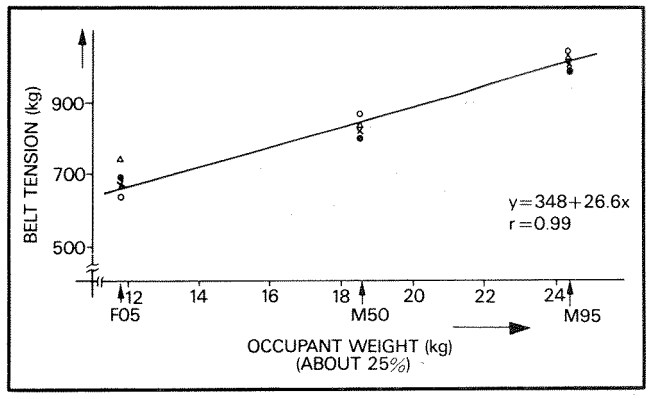


Figure 7. Relationship between occupant weight and belt tension.

using a simple equation. From the correlative equation in Figure 7, the following equation is formed:

$$F = WG \quad \ldots\ldots (1)$$

where F : Shoulder belt tension (kg)
W: Substantial mass weight (kg)
G: Deceleration produced on chest

$$F = 26.6W + 348 \quad \ldots\ldots (2)$$

From equations (1) and (2), the deceleration produced on the chest is expressed by the following equation:

$$G = \frac{348}{W} + 26.6 \quad \ldots\ldots (3)$$

From equation (3), it is found that the chest injury level is lowered in a reciprocal proportion to the dummy size and weight.

Table 6. Substantial mass weight applied to shoulder belt.

DUMMY SIZE	SEAT SLIDE POSITION	DUMMY SEATING POSITION	INITIAL STAGE			PEAK STAGE		
			Dec'n (G)	BELT TENSION (F)	SUBSTANTIAL Wt. (W)	Dec'n (G)	BELT TENSION (F)	SUBSTANTIAL Wt. (W)
F05	B	DRIVER	10	120	12	57	690	12.1
		PASSENGER	10	120	12	54	635	11.8
	A	DRIVER	–	–	–	70	810	11.6
		PASSENGER	10	140	14	57	670	11.8
M50	B	DRIVER	10	120	12	52	820	15.6
		PASSENGER	10	150	15	46	865	18.8
	A	DRIVER	10	180	18	43	840	19.5
		PASSENGER	10	180	18	60	830	13.8
M95	B	DRIVER	10	250	25	46	980	21.3
		PASSENGER	10	310	31	32	1,020	31.8
	A	DRIVER	10	280	28	40	1,010	25.2
		PASSENGER	10	350	35	43	990	23.0

	WEIGHT (kg)	SUBSTANTIAL MASS Wt. Av. (kg)	PERCENTAGE (%)
F05	47.2	12.2	25.8
M50	74.5	16.3	21.9
M95	97.7	25.1	25.7

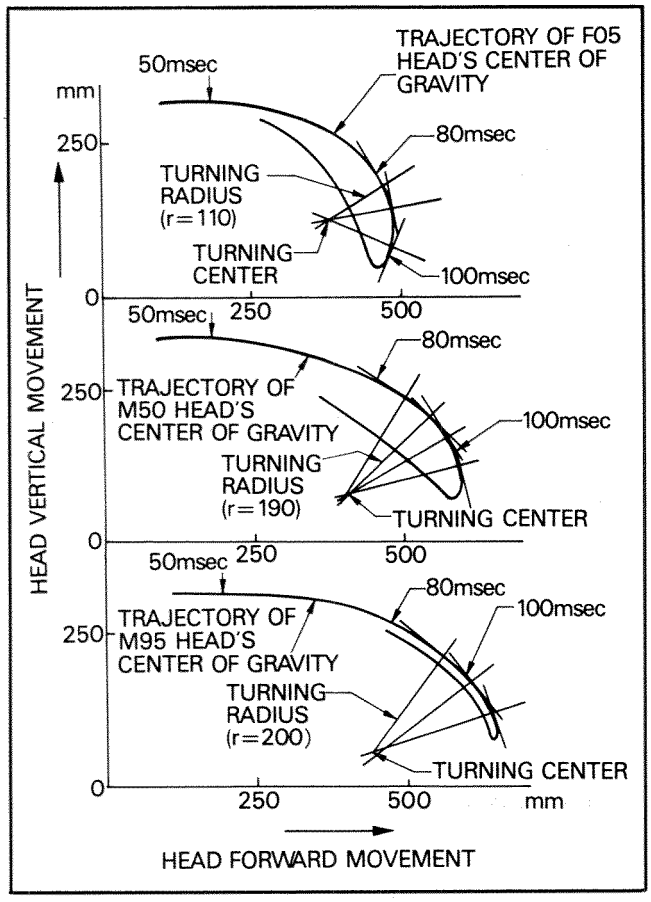


Figure 8. Head behavior by size.

Next, let's consider the influence of the dummy size on the head injury level. It is found that although the aforementioned chest deceleration influences the head injury, the dummy size has a more dominant effect.

That is, when the curve of deceleration produced on the head is looked at after a period of time, we can consider the phenomenon in the following two stages:

According to the deceleration curves in Figure 6,

(1) Approximately 80 msec after the initial collision, the deceleration on the chest reaches a peak. In the meantime, the head, affected by the chest, traces a large circular arc trajectory with the waist as a pivot, and thus, a peak at the first stage is reached.

(2) The chest stops moving after the peak of the first stage. The remaining speed energy on the head is absorbed by the head shaking motion. It has an extremely small turning radius, and uses the neck as a pivot. Centrifugal force generated by the head shaking motion produces the second-stage peak deceleration.

In this study, the level of head injury sustained by the F05 dummy is highly comparable to those cases of the M50 and M95 dummies. This is thought to be due to the second-stage peak mentioned above.

Figure 8 shows head behavior graphed according to dummy size. From the head behavior after the chest ceases to move (approximately 80 msec after the initial collision), the turning radius of the head shaking motion is measured to be equal to the values shown in Figure 8.

The difference of these turning radii of the head shaking motion was caused by the difference in the position of chest restraint by the shoulder belt.

Let's discuss the head turning radius. Changes in the early position of chest restraint by the shoulder belt, which is caused by the difference in occupant size, will have different effects on the attitude of the restrained dummy during a collision. As shown in Figure 9, the difference in restraint ranges from a rapid head shaking motion, with the neck as a pivot (F05 type), to a comparatively gentle head shaking motion with the neck turning with the twisting torso (M50 and M95 types).

As described above, it can be seen that the head injury level is largely influenced by the difference between the chest restraint position and dummy size, namely due to the difference in the head turning radius, even if the occupant compartment has no components to cause a secondary collision to the head.

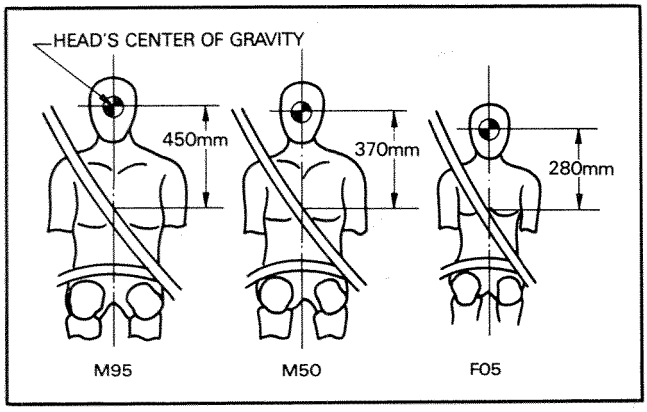


Figure 9. Restraint positions by size.

INFLUENCE OF SEAT SLIDE POSITION ON INJURY LEVEL

Figures 10 and 11 show the chest injury level and the head injury level as they relate to the position of the seat slide, with the following results:

(1) The chest injury level tends to increase as the seat slide is positioned rearward.

(2) The head injury level tends to increase as the seat slide is moved rearward. When the seat slide is positioned forward, a phenomenon can occur in which a secondary collision against the steering wheel, etc. becomes more severe and the injury level increases.

Hereupon, we examined the reason why we see increased deceleration on the chest when the seat slide is moved rearward.

Figure 12 is a comparison graph showing deceleration produced on the chest, belt tension and chest moving

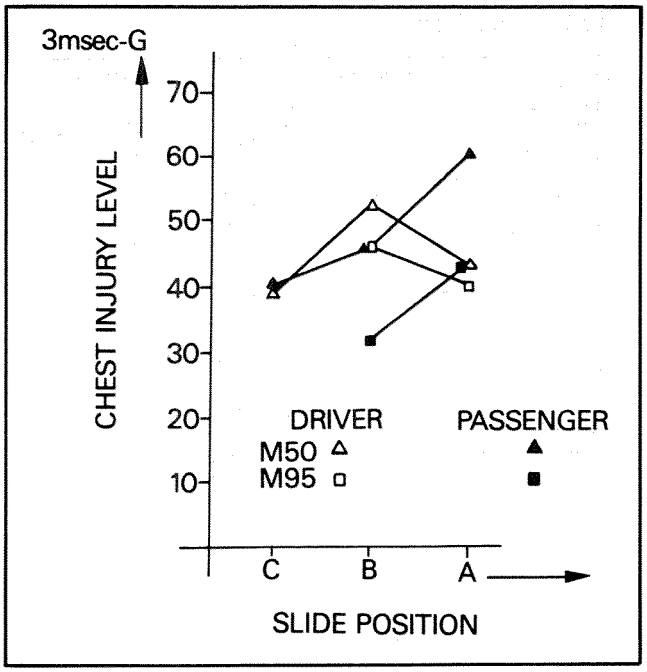


Figure 10. Seat slide position and chest injury level.

speed of Test Nos. (3), (9) and (13), when conducted using an M50 dummy.

The time when the shoulder belt begins to restrain the chest changes by 4 to 6 msec according to the position of the seat slide.

This difference in time influences the amount of tension produced on the shoulder belt and the rise of deceleration produced on the chest. On the other hand, an observation of the relative speed between the occupant's chest and the sled reveals that there is a difference of 4 to 5 km/h in relative speed due to variations in the time when the restraints begin.

It can be considered that a delay in initiating the seat

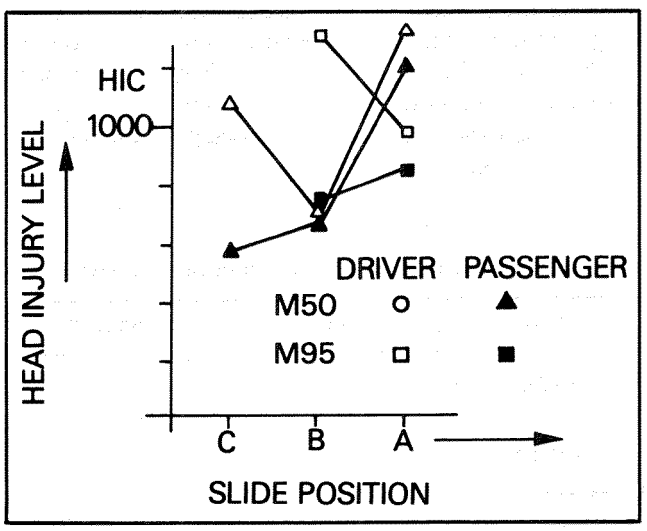


Figure 11. Seat slide position and head injury level.

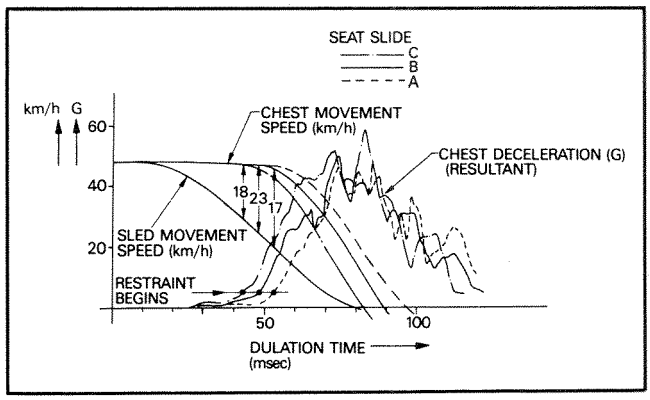


Figure 12. Results of tests by seat slide position.

slide rearward position restraint results in a lowered Ride-Down Effect, and thus leads to an increase in chest deceleration and in injury level.

INFLUENCE OF SEAT BACK ANGLE ON INJURY LEVEL

Figures 13 and 14 show changes in injury level, caused when the seat back angle was changed. The chest injury level rises slightly when the seat is inclined backward.

As clearly seen in Figure 14, the head injury level increases remarkably when the seat is inclined backward.

Figure 15 shows how deceleration acts on each part. The graph shows that a delay in chest restraint by the shoulder belt is caused in the same way as in the test conducted by changing the position of the seat slide.

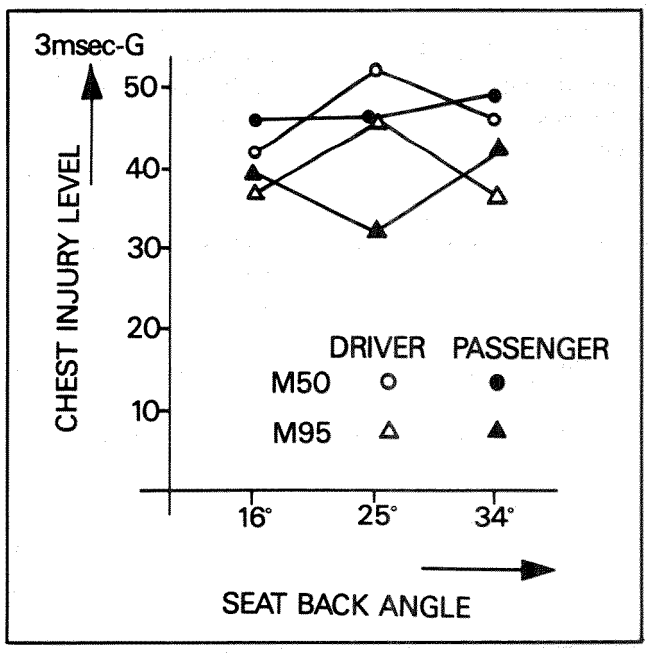


Figure 13. Seat back angle and chest injury level.

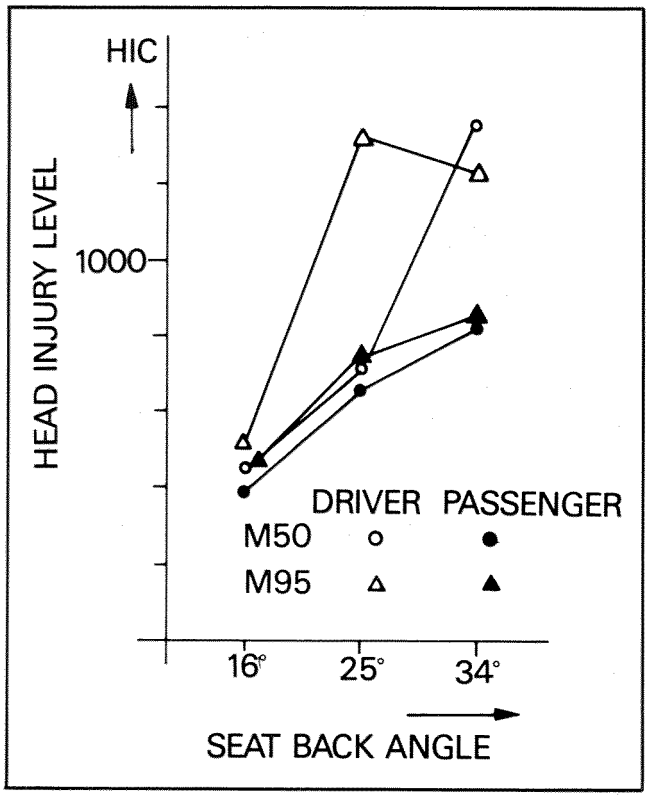


Figure 14. Seat back angle and head injury level.

FEMUR LOAD ACCORDING TO SEAT POSITION

Table 7 shows femur loads obtained in all the tests reported so far. As is clear in this table, even the heaviest femur loads are within 70 percent of the injury criteria provided in FMVSS 208, etc., and have no significant influence.

The level of the femur load is determined by whether or not the knees have collided with the instrument panel or the steering shaft, or by the severity of the knee collision.

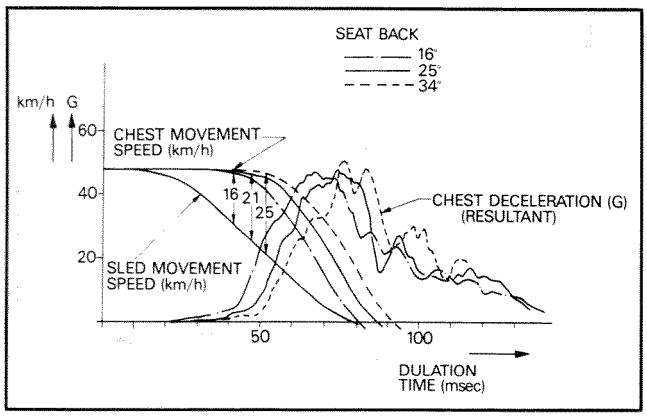


Figure 15. Results of tests by seat back angle.

Table 7. Femur load.

DUMMY	SEAT SLIDE	SEAT BACK ANGLE	DRIVER 0 50% 100%	PASSENGER 0 50% 100%
F05	B	25°		
	A	25°		
M50	C	25°		
	B	16°		
		25°		
		34°		
	A	25°		
M95	B	16°		
		25°		
		34°		
	A	25°		

RELATIONSHIP BETWEEN SEAT BELT AND OCCUPANT INJURY LEVEL

We have conducted an examination to find out the influence of the seat belt webbing elongation rate, when increased by 15 percent over the standard, on the behavior of the occupant.

Table 8 shows the increased amount of movement of each body part of the dummy when the seat belt webbing elongation rate is increased. From this it is seen that an increase in the webbing elongation rate leads to an increase in the amount of chest and pelvis movement, which is directly restrained by the seat belt.

Figure 16 shows the movement speeds of the sled and the dummy chest. It also shows the amount of tension acting on the shoulder belt. When the seat belt webbing elongation rate is increased, the chest movement speed is greatly delayed by 6 to 8 msec. Further, the seat belt gently raises the tension, and causes an 8 to 10 msec delay for the same tension and a 15 msec delay for the tension to reach a peak.

Table 8. Increased amount of movement of each part.

PART	DRIVER	PASSENGER
HEAD	107%	110%
CHEST	120%	136%
PELVIS	119%	123%

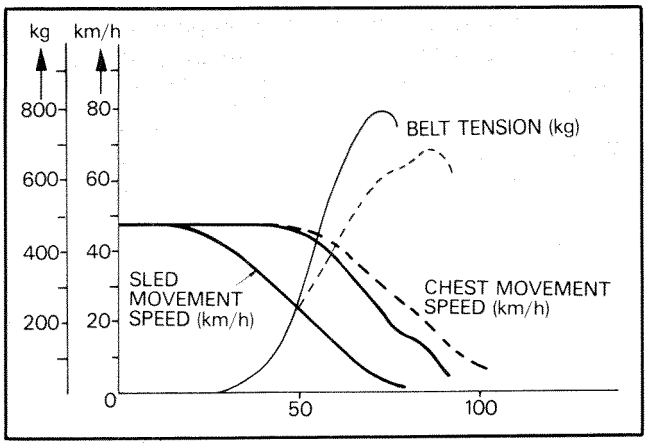


Figure 16. Movement speeds of sled and chest.

It follows from this that an increase in webbing elongation rate will somewhat ease the chest restraint and lower the injury level.

Figure 17 shows the behavior of the head. It is when the chest is restrained by the seat belt that an increase in seat belt webbing elongation rate begins to cause a difference in the head behavior. The head's forward movement is increased by as much as the chest restraint is loosened.

The head behavior in Figure 17 is sharply changed because the top of the head has collided with the upper side of the instrumental panel caused by an increased in forward movement. This phenomenon is very advantageous for decreasing the dummy injury level. It can be decreased by increasing the rate of the seat belt webbing elongation. For the head, however, this signifies that a secondary collision has occurred due to an increase in forward movement.

The length of seat belt webbing left on the retractor spool may cause injury to the occupant. Sufficient webbing is generally wound inside the seat belt retractor, so that the seat belt can be used in any seat position. Further, in order for the belt to restrain the dummy in a collision, a device is installed for immediately locking the retractor mechanism when a collision occurs, that is, Emergency Locking Retractor.

An examination of the movement of a tightly belted dummy in a collision was done. It was found that approximately 40 to 50 msec after the collision, the seat belt starts to restrain the dummy. In the meantime, the dummy moves forward approximately 100 mm.

The cause for this is thought to be that the seat belt webbing in the retractor is spooled out. Therefore, we conducted tests on the amount of spooled out seat belt webbing in the three stages of 400 mm, 800 mm and 1,100 mm. These are the lengths of webbing found on the retractors before the respective tests. Figure 18 shows the amount seat belt spooled out in the process of applying a 1,000 kg load.

Another phenomenon in Fig. 18 is that when 10 percent of the tension acting on the seat belt is produced, the amount of spooled out webbing covers approximately 70 percent of the maximum spooled out amount, and when 20 percent of the tension is produced, the amount of spooled out webbing covers approximately 75 to 80 percent of the maximum spooled out amount.

It follows from this that the amount of spooled out seat belt webbing will lead to a delay in the beginning of occupant restraint.

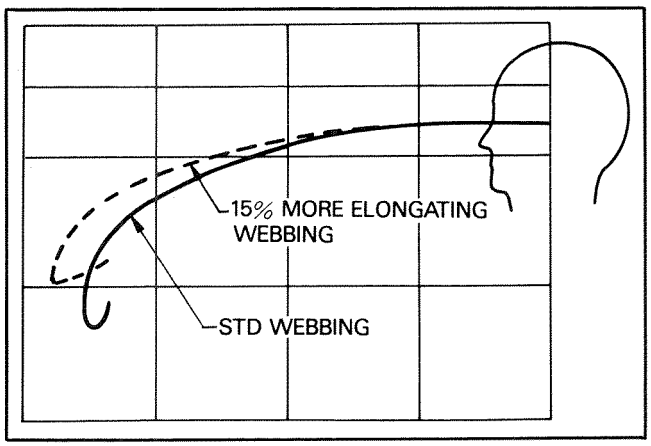


Figure 17. Behavior of head.

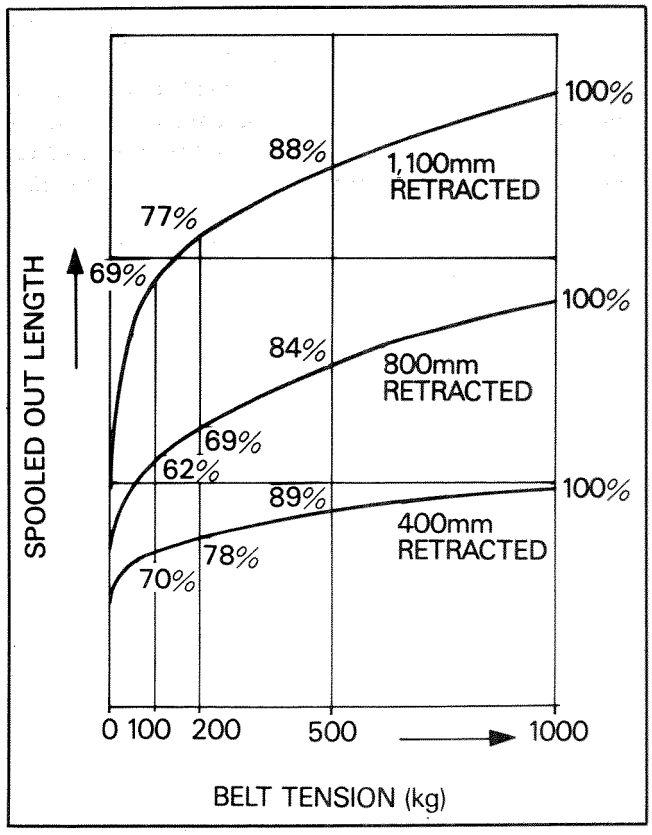


Figure 18. Amount of spooled out seat belt webbing.

CONCLUSIONS

As a result of this study, it is found that the occupant injury level varies largely according to occupant body size, seating posture, and the seat belt. That is,

(1) The larger the occupant body size, the less the injury level. Especially with the head injury level, it is found that when the occupant size is small, the head turning radius becomes small. Thus, the injury level is increased after completion of the chest movement, because the distance between the seat belt restraint point on the occupant and the head's center of gravity is short.

(2) The beginning of the chest restraint is delayed as the seat slide is moved rearward. Due to this lapse in time, the Ride-Down Effect is lowered, and thereby the injury level is increased.

(3) As the seat is inclined backward, the beginning of restraint is delayed as in the case of the seat slide position.

(4) When the seat belt webbing elongation rate is increased, the chest restraint is reduced and the injury level is lowered. However, the head forward movement is increased, and thus the danger of a secondary collision against the instrument panel, etc. is increased.

(5) Furthermore, it is certain that the spooled out webbing length from the seat belt retractor, even under a load equivalent to 100 kg, amounts to approximately 70 percent of the overall spooled out amount, thus leading to a delay in the beginning of restraint.

It is important to conduct evaluations under various conditions on the occupant restraint system used in the market. There are many subjects still to be examined; some of them are mentioned below:

(1) A quick restraint of the occupant by the seat belt immediately after a collision is effective in the sense of reducing the injury level. On the highway, people of various physical sizes are driving in various positions; thus, to cope with this, the seat belt should be improved in its fitting performance, taking its comfort and convenience into consideration.

(2) For evaluation of the occupant protection performance according to size, the performances and specifications of dummies should be realistic. This is a subject of development necessary to solve the present problems. There are some differences even in measurement data obtained by tests carried out in the same conditions. We would like to pursue our study for the development of a better occupant protection system.

(3) All of the tests were conducted using weight-drop sleds, in order to evaluate occupant protection systems in collisions. In actual collisions, however, complicated secondary collisions and various vehicle behaviors will come into play. For this reason, we should continue to analyze various factors affecting the comparison between weight-drop type sled and actual vehicle tests.

REFERENCES

1. Heinrich Hontshik, Egbert Müller and Gert Rüter, "Necessities and Possibilities of Improving the Protective Effect of Three-Point Seat Belts," SAE Paper 770933.
2. Murray Dance and Bert Enserik, "Safety Performance Evaluation of Seat Belt Retractors," SAE Paper 790680.
3. Roger P. Daniel, Kenneth R. Trosien and Burgess O. Young, "The Impact Behavior of Hybrid II Dummy," SAE Paper 751145.
4. L. M. Patrick, N. Bohlin and A. Anderson, "Three-Point Harness Accident and Laboratory Data Comparison," SAE Paper 741181.
5. David C. Herbert, John D. Scott and Christopher W. Corben, "Head Space Requirements for Seat Belt Wearers," SAE Paper 751164.
6. Rüdiger Weissner, "A Comparison of Advanced Belt Systems Regarding Their Effectiveness," SAE Paper 780414.

Technical Session No. 2

Biomechanics and Dummy Development

Mr. Dominque Cesari, Chairman, France

The European Communities' Programme for Promotion of Biomechanic Research

HERBERT HENSSLER
Commission of the European Communities—Brussels

THE SETTING-UP OF THE PROGRAMME

At the end of 1975 the Commission organized an international Symposium in Brussels in order to discuss the future trends in automobile regulations with all interested parties. As far as occupant safety was concerned, the need for a new generation of performance-oriented requirements was clearly defined.

Consequently, the Commission investigated the availability in Europe of the three major elements of any safety regulation: a test procedure, appropriate test tools and protection criteria based as far as possible on objective scientific data. The question of test procedures was already under discussion in the Group of automobile experts (WP 29) at the United Nations' Economic Commission for Europe (ECE) in Geneva. The interest of the EEC therefore focussed on the two other elements: the test tools, which meant essentially the availability of a test dummy, and the knowledge concerning human tolerance of accidental constraints.

The Commission did not, of course, possess the necessary expertise among its staff to deal with such specific matters. Hence, it seemed advisable to take advantage of its good relations with the European Experimental Vehicle Committee (EEVC), the European partner organisation of the United States in the Experimental Safety Vehicle Programme (ESV). A working group of this Committee had drawn the attention of the Sixth ESV-Conference, held in Washington in 1976, to the existence of considerable gaps in the knowledge of impact biomechanics and of the deficiencies of existing test dummies in side impact and car/pedestrian accident modes.

OVERALL OBJECTIVES AND FINANCING

In 1978, the first year in which a budget was made available on this subject, the Commission succeeded, with the efficient help of EEVC and its working group on biomechanics, to establish a coherent programme for the promotion of studies, investigations and experiments in the field of biomechanics.

The programme comprised the following six priority research themes:

Theme 1: Human tolerance and injury criteria concerning vehicle occupants in frontal impact;
Theme 2: Human tolerance and injury criteria concerning vehicle occupants in side impact;
Theme 3: Pedestrian injury mechanisms in impact by vehicle front structures;
Theme 4: Development of a standard dummy for side impact testing;
Theme 5: Mathematical models of impact and injury prediction;
Theme 6: Occupant behaviour and interaction during vehicle impacts.

It is important to mention that the intention of the Commission was not to set up its own spectacular research programme. The objective was to promote and accelerate, by means of decisive financial contributions, ongoing or projected research which was required to complete the necessary knowledge for future safety regulations.

It was also understood from the beginning that the programme should be limited in time in order to keep it manageable and to allow a rapid assessment of its success. Mainly for budgetary reasons, it was initially agreed to run the programme in three phases, starting with the 1978 budget year. Later it appeared necessary to add a fourth phase in order to allow the synthesis of the results of the different projects and comparative testing of the side impact dummy prototypes.

A total amount of 3.16 million of European account units (ECU) (1 ECU equals about 0.95 present US dollars) was made available by the budgetary authorities of the European Communities, divided over the budgetary years 1978 to 1981 and used as follows:

1978: 750,000 ECU; 13 projects covering themes 1 to 4
1979: 750,000 ECU; 19 projects covering themes 1 to 6
1980: 1,000,000 ECU; 28 projects covering themes 1 to 6
1981: 660,000 ECU; synthesis and dummy evaluation (6 projects)

Most of these projects covered more than one phase, so that a total of 37 different projects were promoted. The list of projects and their titles are given in the Annex.

The breakdown of the total amount for the six research themes is as follows:

Theme 1:	345,000 ECU,	7 projects*
Theme 2:	780,000 ECU,	11 projects*
Theme 3:	295,000 ECU,	7 projects*
Theme 4:	935,000 ECU,	12 projects
Theme 5:	175,000 ECU,	4 projects
Theme 6:	270,000 ECU,	2 projects
Coordination and synthesis:	360,000 ECU	

It is recalled that these figures represent only the EEC contribution to the overall costs of the different projects. This contribution was never more than 50 percent—an average of about 40 percent, in fact. It is therefore permissible to estimate the global cost of European biomechanical research for these years at essentially higher figures.

Eleven European research organisations, laboratories or institutes took contracts with the European Communities in the framework of this programme. Most of these passed on subcontracts to other institutes or adopted cofinancing partners, so that it can be assumed that all major biomechanical research bodies in Europe took part in the programme. The list of contracting institutes is also given in the Annex.

It is obvious that the management of such a programme is a tough job for an administration, even that of the European Community. We therefore looked for further help from the outside on two subjects. The scientific coordination between the different projects was assessed by a specialised institution by way of contract. It also appeared necessary to assess periodically the conformity of the current work with the objectives of the contracts and its scientific value. For this purpose a Consulting Expert Committee was created in which personalities from all participating European countries acted as members under the most efficient chairmanship of Professor Aldman from Sweden, who has earned the Commission's wholehearted thanks.

RESEARCH THEMES AND THEIR RATIONALE

As far as the six priority research themes are concerned this paper is limited essentially to a brief explanation of the reasons which caused them to be chosen. More details can be found in the scientific paper distributed later on in this session or in the numerous papers and presentations given by the institutes concerned at previous conferences and meetings.

Occupant Protection in Frontal Impact

The majority of road accidents whereby car occupants are injured occur under this impact condition. This theme is therefore of prime importance to the legislator.

Since several years specific legal requirements exist in Europe relating to occupant protection in frontal accidents, e.g., the EEC directives on approval and installation of safety belts, on interior fittings, strength of seats and headrests, behaviour of the steering system in impact, etc. These requirements have generally proved their efficiency, but they are considered to be somewhat design-restrictive. They do not allow the approval of modern passive restraint systems and thus prevent the car manufacturers from introducing such systems on the European market.

These considerations led the European legislators to envisage a global test which allows the assessment of the quality of occupant protection offered by the vehicle as a whole. The definition of such a global test requires sufficient knowledge of the tolerance of those parts of the human body which are specifically concerned by frontal impacts: head, thorax, femur.

The consultation of the experts showed, however, that despite considerable worldwide research efforts there were still important gaps in biomechanical knowledge. A major participation of the EEC in this field was highly recommended. Consequently, seven projects were promoted which referred, in general, to the demonstration, in accident reconstructions and experiments, of the specific constraints of this impact mode with the help of human substitutes and their comparison with findings of clinical investigations and autopsy of real accident victims.

Occupant Protection in Side Impact

Accidents whereby occupants are injured by lateral impact are far less frequent than front impact accidents. They are, however, of increasing interest to the legislator at a time when the first generation of legal measures related to frontal accidents becomes effective. Some of these individual measures, such as fitting of three-point belts and interior padding, also show advantages in lateral impacts. A decisive improvement of occupant protection in this case can only be expected from a pooling of different technical measures on the vehicle, e.g., structural changes. The assessment of the efficiency of such measures again calls for the definition of a global test.

The gaps in existing knowledge were relatively important and a stronger research thrust seemed necessary. Therefore a major part of the EEC's budget was allocated to this theme. The 11 projects chosen included an inves-

*2 projects cover themes 1 and 2 and 2 projects themes 1, 2 and 3.

tigation of a relevant sample of real-world side-impact accidents and comprehensive accident reconstructions where the accidental constraints of the real victims were compared with those measurable on corpses and dummies. Experimental studies concentrated on the body segments mainly concerned in this impact mode—head, thorax, abdomen and pelvis—in order to understand their injury mechanisms and consequently to allow the definition of appropriate tolerance levels.

Pedestrian Protection

Accidents between motor vehicles and unmotorized road users are traditionally of great importance in the European Community. Their proportion in accident statistics tends to increase due to the current changes in transportation habits in the present economic situation but also due to the positive effect of the legal measures relating to the protection of car occupants.

Hence it is logical that the legislator considers measures to improve this situation. As far as vehicle-related requirements are concerned, however, the scientific and technical basis does not yet seem complete enough to allow the definition of such legal measures. Consequently, the Community deemed it necessary to promote research projects most likely to fill the gaps in knowledge, mainly of the injury mechanisms of pedestrians struck by car fronts. The projects chosen were essentially focussed on the reconstruction of real accidents and on experimental investigations referring to the body segments particularly concerned: head and knee/lower leg. The possibilities for a standard pedestrian test and evaluation methodology have also been examined.

Side Impact Dummy

In contrast with the situation for frontal testing, the experts consulted by the Commission had declared that none of the available dummies could produce representative results under side impact conditions with the degree of reproducibility required for whole vehicle type-approval testing. Consequently high priority was given to this theme, which received the most important financial support of the programme.

In order to save time and costs it was never intended to conceive completely new dummy types. The six projects chosen were concentrated on the construction of dummy components which permit the reproduction of the specific constraints of car occupants in side impact accidents: neck, shoulder, thorax, pelvis and abdomen. These parts were conceived in a way to offer interfaces with the components of the Hybrid II dummy used in the US safety regulations.

Three different sets of the above-mentioned components, based on the concepts of the major contractors, were built and completed with Hybrid II parts in order to form whole dummy prototypes: Peugeot/Renault's "APROD", MIRA's "SID" and ONSER's "50". All three are presented in the exhibition related to this 9th ESV Conference.

These three prototypes, together with an HSRI prototype made available by the NHTSA, have been submitted to a comparative test programme (6 projects in Phase 4). Their performances were also compared with the draft regulatory specifications set up by an ad hoc Group of EEVC specially created for this purpose. It must be mentioned that the objective of these comparative tests was not to set up a hierarchy among the different dummy concepts. The aim was to establish realistic performance criteria with which present dummy concepts can comply at reasonable cost, and which can later be included in a standard European side impact test for type-approval of motor vehicles.

Mathematical Models

Full-scale car crash tests are invariably very expensive. Obviously, it would be advantageous both for researchers and for the car industry to have a tool at their disposal which enables them to predict the influence of the modification of individual parameters on the test results on the basis of theoretical considerations. This aspect is equally interesting for the legislator who could thus keep the costs of type-approval testing down to a reasonable level.

For this reason four projects were promoted which concerned the development of two- and three-dimensional mathematical models simulating the behaviour of car occupants in crash situations and allowing to predict their injury severity.

Occupant Behaviour Interaction

This theme is of particular interest to the European Community, as in most Member States the use of three-point belts on front seats is mandatory, whereas the occupants of other seating positions need not yet wear belts. Hence it is important to establish whether interaction of occupants occur during accidents with different impact directions and whether injury-aggravating effects are observed. The two promoted projects concerned tests with cars of different sizes occupied by Hybrid II dummies submitted to impacts of different speeds and directions. The expected results should help both the car industry and the legislators to find a solution to this problem.

CONCLUSIONS

The EEC study programme on biomechanics which has been briefly outlined in this paper has enabled the experts to compile a great amount of scientific data. It is the Commission's duty towards the citizens of the European Community whose tax money has made the execution of this programme possible to use the results of

the research work to its best advantage for the purposes of a significant mitigating of the consequences of road accidents.

The present standstill of the programme allows us to assess how close we came to the aim of making available to the legislators all relevant scientific data which they need for the definition of the next generation of safety requirements. A synthesis report is currently being made on the results of the different projects and their complementarity to the work carried out in other parts of the world.

The synthesis report as well as the conclusions of the individual projects of each study theme will be presented to the interested parties of research, industry and administrations at a seminar to be held in Brussels on 21 to 23 March 1983.

It is, of course, impossible to anticipate the conclusions of the seminar which hopefully will state a general success of the programme. A partial success can, however, already be seen today.

The EEC support, even if it was limited by budgetary and time factors, has proved to be an important encouragement for biomechanical research in Europe. Researchers from many countries have coordinated their projects, thus avoiding useless redundancy. Many projects have been carried out on a joint basis which would not have been possible on a purely national basis, at least not in such a short period of time.

We hope that this spirit of cooperation will subsist and that if, at a later stage, joint projects would again be defined, this cooperation could be extended even beyond the bounds of the Community.

ANNEXE

List of Contractors and of Study Projects of the European Community Biomechanics Programme

Contractor	Title of the Study	Reference	Phase
Bundesanstalt für Strassenwesen (BAST) Postfach 510530 D—5000 KÖLN 51	Development of a Test Dummy for Investigating Occupant Protection in the Case of Side Impacts	G 2	1
	Interaction of Car Passengers in Frontal, Side and Rear Collisions	G 3	2,3
	Methodology of Developing Accident Protection Criteria	G 4	3
	Biomechanical Investigation to determine Physical and Traumatological Differentiation Criteria, for the Maximum Load Capacity of Head and Vertebral Column with and without Protective Helmet under the Effects of Impact	G 5	3
	Proposed Standardized Pedestrian Test Methodology	G 6	3
	Lateral Dummy Comparison Testing	G 7	4
Organisme National de Sécurité Routière (ONSER) 2, Avenue du Général Malleret-Joinville F—94110 ARCUEIL	Head tolerance to Acceleration (Brain Vulnerability from Real Accidents)	F 1	1,2,3
	An Experimental Study of Thorax Tolerance to Seat Belt Loads	F 2	1,2,3
	Evaluation of the Behaviour of Different Substitutes in Lateral Impact Conditions (Improvement of the ONSER 50 for Lateral Impact)	F 4	1,2,3
	Lateral Dummy Comparison Testing	F 12	4
	Scientific Coordination		1,2,3
Université libre de Bruxelles Unité de recherche de biomécanique du mouvement 28, Av. Paul Héger 1050 BRUXELLES	Characterization of Individual Bone Resistance	B 1	3
Laboratoire de Physiologie et de Biomécanique PSA/RENAULT 147, Av. Paul Doumer F—91500 RUEIL-MALMAISON	Tolerance of the Human Head at Impact; Reconstruction of Head Impacts observed in True Life Accidents	F 6	1,2,3
	Development of a More Convenient Dummy than the Hybrid II Part 572 for Side Collisions by using this as a Basis	F 10	1,2,3
	Lateral Dummy Comparison Testing	F 11	4

Contractor	Title of the Study	Reference	Phase
Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek ten behoeve van Nijverheid, Handel en Verkeer (Nijverheidsorganisatie TNO) Juliana van Stolberglaan, 148 NL—DEN HAAG	Development of Abdominal Injury Detection in Side Impact Dummies (Organization and Administration of Lateral Dummy Evaluations)	NL 3	2,3
	Simulation of Frontal and Lateral Collisions with Mathematical Crash Victim Models	NL 4	2,3
	Madymo-Crash Victim Simulations Optimization and Development to a General Laboratory Tool	NL 6	3
	Lateral Dummy Comparison Testing	NL 7	4
	Lateral Dummy Comparison: Theoretical Analysis	NL 8	4
	Organization and Coordination of Intercomparison Testing Programme		4
Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV) Ridder Snouckaertlaan, 7 NL—VOORBURG	Development of an Injury Prediction Model	NL 5	2,3
Transport Research Delegation (TRD) Sveavägen, 166, 14 tr. S—11346 STOCKHOLM	Experimental Study of Adult Pedestrians in Frontal Impacts—Physical Simulation of Human Leg—Bumper Impacts	S 1	1,2,3
	Development of a Device for Improvement of a Standard Dummy	S 2	1,2,3
University of Birmingham P.O. Box 363 UK—BIRMINGHAM B 15 277	Investigation of a Representative Sample of Real-World Side Impacts to Cars	UK 1	1, 3
Motor Industry Research Association (MIRA) Watling Street UK—NUNEATON CV10 OTU	Lateral Impact Dummy Development	UK 2	1,2,3
	Lateral Dummy Comparison Testing	UK 3	4
Joint Biomechanical Research Project (KOB) Bundesanstalt für Strassenwesen Postfach 510530 D—5000 KÖLN 51	Cerebral Tolerance : Interpretation of Experimental Cerebral Injuries obtained on Cadavers	B 3/ (F 5)	2,3
	Reconstruction of Side Impacts Accidents	G 1	1
	Pelvis and Femur Human Tolerance in Side Impacts	B 2/ (F 3)	1,2,3
	The Prediction of Injuries to the Thorax by Measuring Twelve Accelerations on the Thorax Periphery	B 1/ (F 7)	1,3
	Reconstruction of Pedestrian Collisions	K 5	2
	Rib Cage Deformation in Side Impacts	K 9	2,3
	Overall Behaviour of the Animal with Respect to the Safety Belt and Influence of the Car Driver Posture on his Protection in Frontal Impacts	K 10	2 and 3
	Analysis of Frontal and Lateral Accident Reconstructions Conducted in Europe	K 11	3
	Evaluation of the Influence of Inter-Individual Differences on the Injury Level	K 12	3
	Comparative Pedestrian Test with Side Impact Dummy	K 13	3
FIAT Auto S.p.A. Corso Giovanni Agnelli, 200 I—TORINO	Development of an Occupant's Mathematical Model for a Side Impact Test	I 1	2,3
	Relationship between Occupant's Behaviour and Vehicle Characteristics in Side Collisons	I 2	2,3

Side Impact Data Analysis

R. H. EPPINGER
Head, Biomechanics Group
R. M. MORGAN
Mechanical Engineer and
J. H. MARCUS
Mechanical Engineer
National Highway Traffic Safety Administration

ABSTRACT

As part of a continuing study of thoracic injury resulting from side impact loading, the interrelationships between subject age, various kinematic parameters characterizing the impact, and injury severity were investigated in data from a series of 30 cadaver tests.

These 30 tests include, in addition to the tests previously reported by the authors, sled tests conducted by the University of Heidelberg and car crash tests performed by ONSER. These new data expand the range of subject age to 67 years.

Two propositions are examined in this analysis. The first being: Can mechanical response measures partition side impact injuries into different categories? And the second being: Can a continuous function be constructed that can accurately predict a dependent injury severity variable given the various response variables available?

With regard to the first proposition, it is shown that by using any of a number of kinematic variables the present data can be easily partitioned into two classes consisting of those injuries of an AIS 80 severity of four and greater and those of AIS 80 three and less. For the second proposition, peak acceleration of the struck side rib along with age proved the best in predicting a new injury variable, fatality rate, which is a function of two highest AIS values in the body region. Age was a needed explanatory variable in all cases.

INTRODUCTION

In 1976 Melvin reported on the results of exposing cadavers to controlled side impacts [1].* In that paper, the test conditions were 15-, 20-, and 25-mph rigid-wall impacts and 20-mph padded-wall impacts. Two years later, in a further extension of the Highway Safety Research Institute (HSRI) cadaver work, Eppinger suggested acceleration-versus-time corridors for key thoracic locations and presented a methodology for universal thoracic trauma prediction [2].

During 1979, investigations into side impact dummies and thoracic injury criteria increased. Two advanced dummies, whose design specifications are based upon biomechanical data, were introduced. They were a Side Impact Dummy (SID) designed by the HSRI [3], and the Association Peugeot-Renault (APR) dummy from France [4, 5]. Relative to injury criteria, the B parameter computed from the rib acceleration data [6], power computed from the spine acceleration data [7], and deflection of the thorax [8] were introduced. (The B parameter computed from the upper rib data on the impacted left side is denoted BLUR.)

In 1980, the APR dummy and the deflection criteria underwent further development [9]. The power and B parameter criteria were substantiated by additional cadaver data [10]. Comparisons of the SID and APR dummy began [10, 11].

Cesari [12] concluded, based on eight cadaver pendulum tests, the arm—when positioned along the side of the thorax—distributes forces on the thorax. He also found the BLUR relationship previously established not to be strictly applicable to pendulum impacts. Methods were developed [13] to allow objective judgment of a dummy's magnitude and "signature" response to a test. Ten cadaveric side impact tests under four different conditions were performed to determine the characteristic mechanical response and resulting trauma outcome [14]. A dynamic characterization of the human thorax, in the form of a digital impulsive response signature, was obtained which linked the acceleration response of the struck side with the far side of the thorax under side impact conditions [15].

Early in 1982, a paper [16] discussed the state-of-knowledge of side impact protection. The French team continued their efforts in the development of a protection criteria and introduced a bone characterization factor as an indicator of thoracic body resistance [17, 18].

DESCRIPTION OF TESTS

To date, the National Highway Traffic Safety Administration (NHTSA) has conducted or participated in 45 side impact tests utilizing cadaveric specimens. The present paper shall discuss findings based on an analysis of 30 of these tests. There are several reasons the analysis does not include 45 tests. One significant reason is that some of the tests are still being processed, i.e., the time between the actual test event and when the data becomes resident in the NHTSA computer is still considerable. With other tests, there was a loss of mechanical response data. This loss is indicative of the extremely severe environment that side impact presents not only to the specimen but also to the instrumentation.

Table 1 categorizes the 30 tests by research institution, type of test, and number of tests. As can be noted, there

*Numbers in brackets denote references cited at the end of paper.

Table 1. Data source.

HSRI	
	6 Rigid wall sled
	6 Padded wall sled
	4 Pendulum
WSU	
	1 Padded wall sled
Heidelberg	
	6 Rigid wall sled
	4 Padded wall sled
ONSER	
	1 Baseline car crash
	2 Modified car crash
30 Total Tests	

is a large variation in type of test: from lateral pendulum tests to actual vehicle tests.

In all tests, the physiological consequences were determined by autopsy after each experiment. The injuries produced in the thoraco-abdominal area were the primary focus of this analysis. An interesting dilemma exists when one classifies the observed injuries by the Abbreviated Injury Scale. That is, injuries to the thorax include the rib cage and those organs and structures above the diaphragm as seen in Figures 1 and 2. Abdominal injuries include all structures below and including the diaphragm [19], whether they are within the thoracic rib cage or not as shown in Figures 3 and 4.

Since the experimental measurements consist solely of responses of the rib cage, two types of AIS injury classifications have been made, the first, AIS thorax (AIS_T) includes only those thoracic injuries as defined by the AIS manual. The second classification, AIS hard thorax (AIS_{HT}), includes—in addition to the standard thorax injuries—those injuries of abdominal structures that lie within the rib cage, specifically the liver, spleen, and kidneys.

A third dependent injury variable was also examined

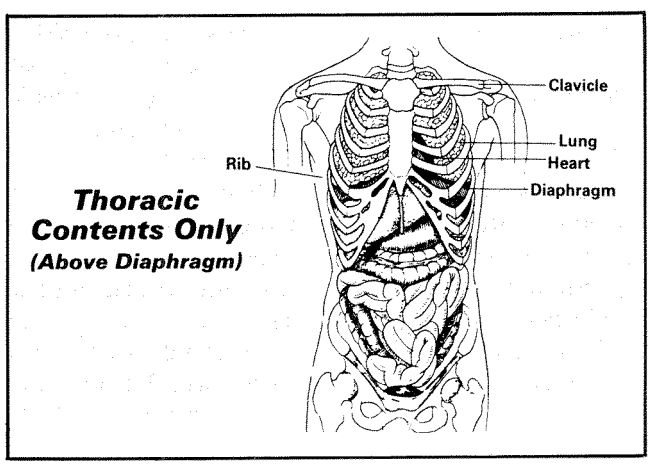


Figure 1.

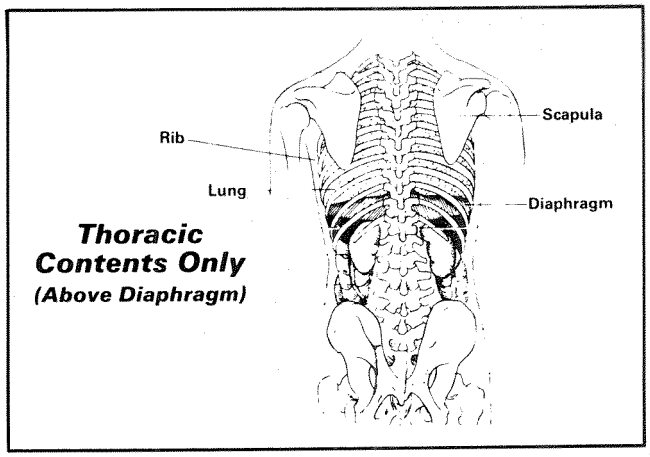


Figure 2.

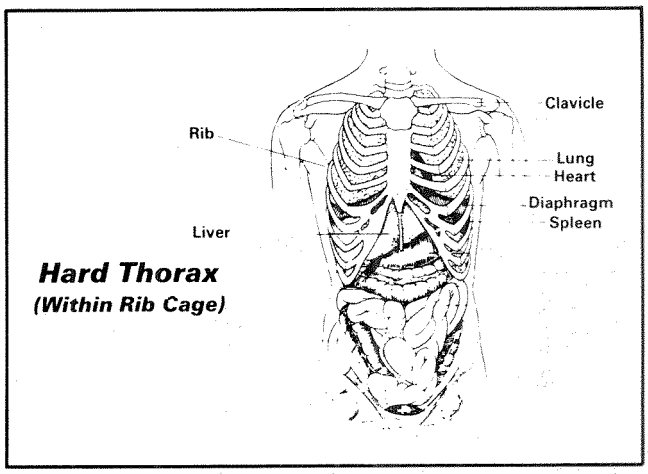


Figure 3.

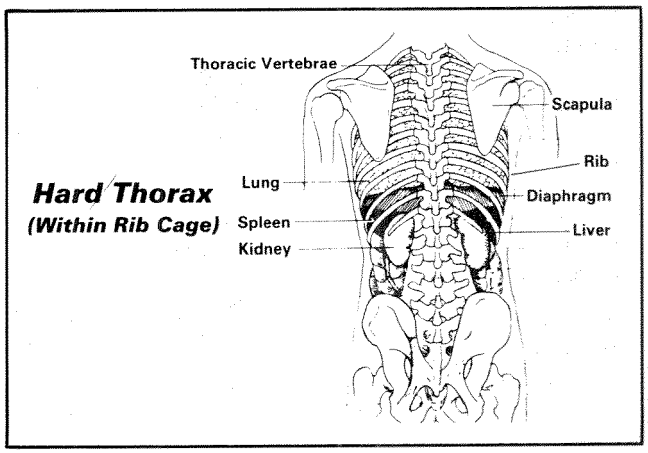


Figure 4.

Table 2. Fatality rate by (AIS1, AIS2).

(AIS1, AIS2)	Fatality rate
(0, 0)	.00000
(1, 0 -1)	.0001131
(2, 0 -1)	.00073
(2, 2)	.00456
(3, 0 -1)	.00434
(3, 2)	.00593
(3, 3)	.02174
(4, 0 -1)	.0392
(4, 2)	.04301
(4, 3)	.10526
(4, 4)	.12821
(5, 0 -1)	.28
(5, 2)	.36667
(5, 3)	.48529
(5, 4)	.58182
(5, 5)	.86364
(6, ANY)	1.00000

Table 3. Comparison of injury values.

Test type	AIS_T	AIS_{NT}	FR_{NT}	Age
Rigid wall	1	1	.0001131	80
Rigid wall	5	5	.0636	75
Rigid wall	4	4	.10526	84
Rigid wall	4	4	.12821	89
Padded wall	2	2	.00073	67
Padded wall	4	4	.04301	62
Padded wall	3	3	.00593	72
Padded wall	4	4	.0392	58
Pendulum	1	1	.0001131	63
Pendulum	3	3	.00434	60
Pendulum	1	1	.0001131	60
Pendulum	3	3	.02174	79
Rigid wall	5	5	.4853	66
Rigid wall	4	4	.1282	45
Padded wall	4	4	.1282	77
Padded wall	4	4	.10526	71
Padded wall	2	2	.00073	54
Rigid wall	1	2	.00456	27
Rigid wall	2	3	.02174	60
Rigid wall	2	2	.00073	38
Padded wall	0	1	.0001131	21
Padded wall	1	1	.0001131	26
Padded wall	0	0	.0	29
Padded wall	2	2	.00073	41
Rigid wall	0	0	.0	24
Rigid wall	4	4	.12821	57
Rigid wall	4	4	.12821	56
Baseline car	4	4	.12821	40
Modified car	2	3	.00593	43
Modified car	4	4	.12821	52

in this analysis. It is called "fatality rate" and is derived using the two highest AIS injuries observed in a particular occupant [20, 21]. That is, each possible pair of AIS values has associated with it a particular fatality rate. This fatality rate was calculated from the National Crash Severity Study by examining each AIS pair category and calculating the percentage of observed fatalities within each subgroup. Table 2 shows each AIS pair and its associated fatality rate. This table appears to allow a reversal of the process, i.e., the ability to transform from a given fatality rate back to the corresponding AIS pair. The only ambiguity to this process occurs between the (2,2) and the (3,0-1) classifications.

Applying the preceding discussion to the 30 side impact cadaver tests, Table 3 illustrates that the AIS_{HT} is higher than AIS_T in four instances and that the fatality rate is different in 17 cases where the highest AIS is the same. (The AIS values use the AIS 80 manual.)

Of the 12 accelerometer channels available [2] from the specimen tests, this analysis concentrated on examination of lateral responses observed on the fourth rib of the struck side of the rib cage and the twelfth thoracic vertebra. Parameters extracted from these signals include peak acceleration (see Appendix A for the procedure followed in preparing each signal) of the rib and spine, a synthetic relative velocity between the left and right side of the rib cage [15], and peak average power which is the maximum incremental velocity change squared divided by incremental time. Age was also utilized as an explanatory variable since a variety of studies have demonstrated the increased susceptibility of the human body to trauma with increasing age [22, 23].

ANALYSIS OF DATA

When performing an analysis of data, it is useful to know what the analysis is going to examine. This analysis examined two propositions. The first being: Can mechanical response measures partition injuries into two categories; those severe or greater (AIS $\geq$ 4) and those from minor to serious (AIS $<$ 4)? The second proposition examined was: Can a continuous function be constructed that can accurately predict the dependent injury variable given the various independent variables available?

Figures 5 and 6 indicate that indeed both peak rib acceleration and peak synthetic relative velocity (feet per second) partition the severe and greater injuries from the lesser ones quite well and—if this were sufficient—additional tests would be necessary only to gain further confidence in the partitioning line for the years from 20 to 40. (The numbers in the middle of Figures 5 and 6 denote AIS_T based on the AIS 80 manual.) For this data set, peak acceleration was found to be highly correlated with peak average power for the same anatomical location and, therefore, in the following discussion, general con-

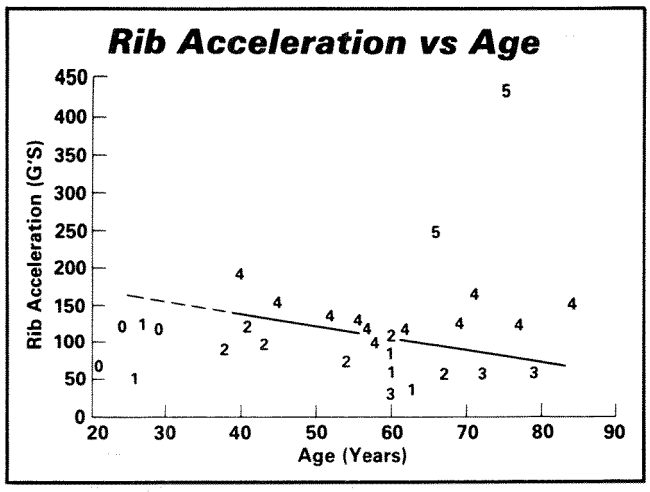


Figure 5.

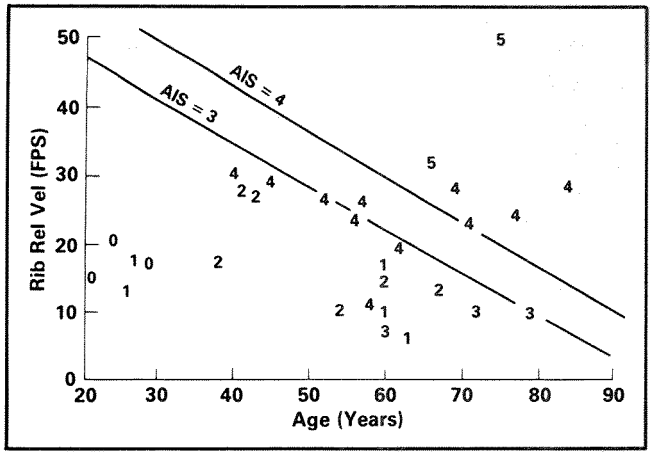


Figure 7. Constant AIS lines on data.

clusions reached relative to peak acceleration also apply to peak average power.

Efforts to predict AIS thorax gave the following results:

$$AIS_T = 0.82\Delta V + .05\ Age - 1.8 \qquad R = .81 \quad (1)$$

$$S.E. = .93$$

$$AIS_T = .0089\ A_{LUR} + .049\ Age - 1.1 \qquad R = .77 \quad (2)$$

$$S.E. = 1.01$$

$$AIS_T = .011\ A_{T12} + .057\ Age - 1.3 \qquad R = .74 \quad (3)$$

$$S.E. = 1.03$$

For this linear regression analysis, the synthetic relative velocity (feet per second) performed the best, but just marginally. A discussion of these equations would not be complete without giving some indication of how the constant AIS lines map onto the data points. Some of the constant AIS lines from equation (1) are mapped onto the data in Figure 7. Note the AIS = 3 line goes through a number of AIS = 4 data points. It appears—due to the lack of severe injuries in the younger age bracket—that the equation has an exaggerated dependence on age. Similar results are seen when examining the other linear AIS regression equations.

Naturally, the regression equations are only good for values of the dependent variables which lie within the region covered by the original data [24]; e.g., the equations are not to be used for a 5-year-old child because children were not included in the original data set. The values of the observed variables are in Appendix B.

Linear regression on AIS hard thorax yields the following results:

$$AIS_{HT} = .081\Delta V + .044\ Age - 1.2 \qquad R = .79 \quad (4)$$

$$S.E. = 92$$

$$AIS_{HT} = .0088\ A_{LUR} + .042\ Age - .5 \qquad R = .74 \quad (5)$$

$$S.E. = 1.0$$

$$AIS_{HT} = .012\ A_{T12} + .049\ Age - .75 \qquad R = .72 \quad (6)$$

$$S.E. = 1.0$$

So when all is said and done, adding abdominal trauma to that which lie within the thoracic rib cage had little effect on the coefficients of the linear equations other than shifting the curves by a constant term of about .6 of an AIS value. Stated another way, when considering the same impact event, the injury severity of the hard thorax is approximately one half of an AIS level greater than when considering injuries to only the thorax.

Age enters all these linear equations with roughly the same coefficient, .05. In other words, in going from 20 years to 80 years—all other things being equal—there is an AIS increase of 3. About 41% of the variation of AIS can be attributed to a linear relationship with age. Again, this appears to be an exaggerated dependence on age, and the use of these equations is not recommended.

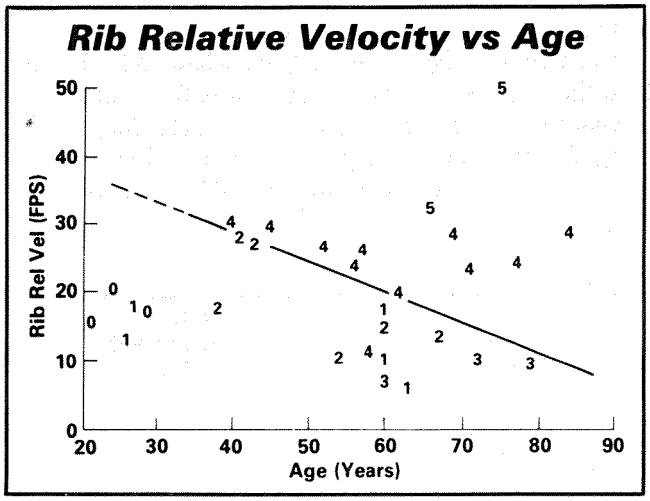


Figure 6.

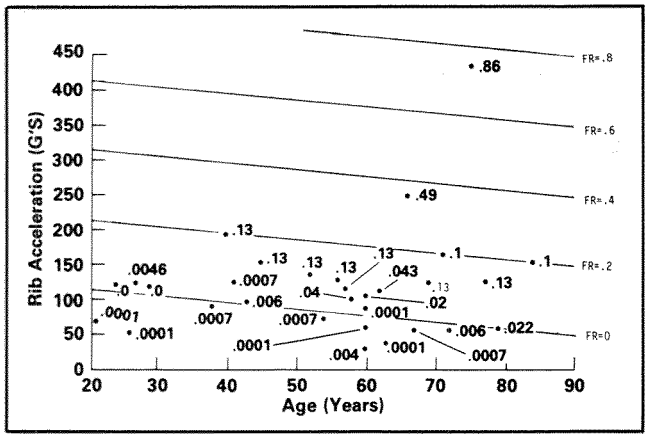


Figure 8. Constant fatality rate lines mapped onto data.

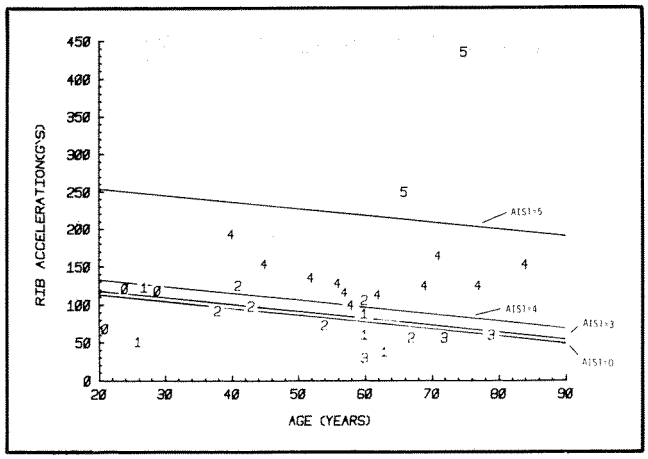


Figure 9. AIS lines derived from fatality rate regression lines.

Examining the results of predicting fatality rate based on the hard thorax injury is shown here:

$$FR_{HT} = .002\ A_{LUR} + .0018\ Age - .25\ R = .94 \quad (7)$$

$$S.E. = .06$$

$$FR_{HT} = .014\Delta V + .0026\ Age - .34 \quad R = .82 \quad (8)$$

$$S.E. = .1$$

$$FR_{HT} = .002\ A_{T12} + .0036\ Age - .28 \quad R = .67 \quad (9)$$

$$S.E. = .13$$

Peak acceleration along with age appears to perform the best. Here the age sensitivity is less and more consistent with the data, i.e., a 60-year increase in age reduces the required peak G's by 54 to produce the same fatality rate. This is quite consistent with the data as can be seen in Figure 8.

For completeness, the fatality rate for the thorax predictive equation with the highest correlation coefficient is presented here:

$$FR_T = .002\ A_{LUR} + .0018\ Age - .26 \quad R = .92 \quad (10)$$

$$S.E. = .07$$

Equation (7) is essentially identical to equation (10).

On Figure 8 the 30 data points have been plotted in fatality rate space. The number beside each data point is the observed hard thorax fatality rate. The constant fatality rate lines are the linear regression prediction based on equation (7).

Based on the family of predicted linear regression lines of Figure 8, it is possible to predict the constant AIS1 lines by using Table 2. For example, Table 2 shows that AIS1 = 3 injuries start at a fatality rate of roughly 0.00434. Substitution of FR = .00434 into equation 7 determines a line on Figure 8. This same line becomes the constant AIS1 = 3 line in the AIS injury space as shown in Figure 9.

There are a number of interesting implications in going from Figure 8 to Figure 9. For one, the linear lines in the fatality rate space (Figure 8) have become nonlinear in AIS space (Figure 9) by virtue of the transformation of Table 2. For another, the constant AIS1 = 1 and AIS1 = 2 lines have been mapped almost on top of the AIS1 = 0 line. (In fact the AIS1 = 1 and AIS1 = 2 lines are not shown in Figure 9 because they are indistinguishable with respect to the AIS1 = 0 line for the given scale.)

A further examination of these various functions was performed by posing the following question: "What injury level could be expected by a 45-year-old victim were he to experience either a 50, 100, or 150 G peak rib acceleration?" Table 4 demonstrates the results.

It can be seen that the directly calculated AIS for the hard thorax does not have as great an AIS variation due to changes in acceleration as does the AIS determined using fatality rate. In other words, the fatality rate model—because the relationship in Table 2 between FR

Table 4. Predicted injury based on three acceleration levels.

Rib Acceleration (G's)	AIS Hard Thorax	Fatality Rate Hard Thorax	AIS1 Corresponding to That Fatality Rate
50	1.83	.0	0
100	2.27	.031	3
150	2.71	.131	4
Age = 45 Years			

and AIS1 is nonlinear—rapidly moves the AIS1 through the 0, 1, and 2 levels up to AIS1 = 3 and then on to AIS1 = 4. When examining the results from these two models against the actual data in Figure 5, the latter process appears to perform the better. (The AIS1 in this example was determined by first calculating the expected fatality rate and then referring to Table 2 to find the AIS1.)

CONCLUSIONS

1. Both peak struck side acceleration and synthetic relative velocity partition injuries into AIS $\geq$ 4 and AIS $\leq$ 3 groups well.
2. Age has a statistically significant effect on injury outcome with every mechanical response parameter examined.
3. Synthetic relative velocity and age were the best predictors of AIS_T and AIS_{HT} when requiring a linear fit through the data. However, the predicted AIS has an exaggerated dependence on the age of the subject and these relationships are not suggested for use.
4. Peak struck side rib acceleration and age predicted fatality rate best.
5. Given a predicted fatality rate, one can reverse the process and determine the maximum expected AIS_{HT}. This process provided the best continuous prediction of AIS that was the most consistent with the data.

DISCLAIMER

The views presented are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

ACKNOWLEDGEMENTS

The figures which illustrate the thoracic and abdominal viscera in their normal positions are from *Kimber-Gray-Stackpole's Anatomy and Physiology*, Sixteenth Edition, published by the MacMillan Company, and are reprinted by permission of the MacMillan Company.

REFERENCES

1. Melvin, J. W., Robbins, D. H., and Stalnaker, R. L., "Side Impact Response and Injury," Sixth International Technical Conference on Experimental Safety Vehicles, October 1976.
2. Eppinger, R. H., Augustyn, K., and Robbins, D. H., "Development of a Promising Universal Thoracic Trauma Prediction Methodology," Twenty-Second Stapp Car Crash Conference, October 1978.
3. Melvin, J. W., Robbins, D. H., and Benson, J. B., "Experimental Application of Advanced Thoracic Instrumentation Techniques to Anthropomorphic Test Devices," Seventh International Technical Conference on Experimental Safety Vehicles, June 1979.
4. Fayon, A., Leung, Y. C., Stalnaker, R. L., Walfisch, G., Balthazard, M., and Tarriere, C., "Presentation of a Frontal Impact and Side Impact Dummy, Defined from Human Data and Realized from a 'Part 572' Basis," Seventh International Technical Conference on Experimental Safety Vehicles, June 1979.
5. Stalnaker, R. L., Tarriere, C., Fayon, A., Walfisch, G., Balthazard, M., Masset, J., Got, C., and Patel, A., "Modification of Part 572 Dummy for Lateral Impact According to Biomechanical Data," Twenty-Third Stapp Car Crash Conference, October 1979.
6. Robbins, D. H., and Lehman, R. J., "Prediction of Thoracic Injuries as a Function of Occupant Kinematics," Seventh International Technical Conference on Experimental Safety Vehicles, June 1979.
7. Burgett, A., and Hackney, J. R., "Status of the National Highway Traffic Safety Administration Research and Rulemaking Activities for Upgrading Side Impact Protection," Seventh International Technical Conference on Experimental Safety Vehicles, June 1979.
8. Tarriere, C., Walfisch, G., Fayon, A., Rosey, J. P., Got, C., Patel, A., and Delmas, A., "Synthesis of Human Tolerance Obtained from Lateral Impact Simulations," Seventh International Technical Conference on Experimental Safety Vehicles, June 1979.
9. Fayon, A., Tarriere, C., Walfisch, G., Duprey, M., and Balthazard, M., "Development and Performance of the APR Dummy (APROD)," Eighth International Technical Conference on Experimental Safety Vehicles, October 1980.
10. Morgan, R. M., and Waters, H. P., "Comparison of Two Promising Side Impact Dummies," Eighth International Technical Conference on Experimental Safety Vehicles, October 1980.
11. Mellander, H., and Bohlin, N., "A Comparison Between Different Dummies in Car-to-Car Side Impacts," Eighth International Technical Conference on Experimental Safety Vehicles, October 1980.
12. Cesari, D., Ramet, M., and Bloch, J., "Influence of Arm Position on Thoracic Injuries in Side Impact." Twenty-Fifth Stapp Car Crash Conference, September 1981.
13. Morgan, R. M., Marcus, J. H., and Eppinger, R. H., "Correlation of Side Impact Dummy/Cadaver Tests," Twenty-Fifth Stapp Car Crash Conference, September 1981.
14. Kallieris, D., Mattern, R., Schmidt, G., and Eppinger, R. H., "Quantification of Side Impact Responses and Injuries," Twenty-Fifth Stapp Car Crash Conference, September 1981.

15. Eppinger, R. H., and Chan, H. S., "Thoracic Injury Prediction via Digital Convolution Theory," Twenty-Fifth Stapp Car Crash Conference, September 1981.
16. Burgett, A., and Brubaker, W., "The Role of the Side of the Motor Vehicle in Crash Prediction." SAE Publication No. 820245, International Congress and Exposition, Detroit, Michigan, February 1982.
17. Walfisch, G., Chamouard, F., Lestrelin, D., Fayon, A., Tarriere, C., Got, C., Guillon, F., Patel, A., and Hureau, J., "Tolerance Limits and Mechanical Characteristics of the Human Thorax in Frontal and Side Impact and Transposition of these Characteristics into Protection Criteria," IRCOBI Conference, Cologne, Germany, September 1982.
18. Sacreste, J., Brun-Cassan, F., Fayon, A., Tarriere, C., Got, C., and Patel, A., "Proposal for a Thorax Tolerance Level in Side Impacts Based on 62 Tests Performed with Cadavers Having Known Bone Condition," Twenty-Sixth Stapp Car Crash Conference, October 1982.
19. "The Abbreviated Injury Scale 1980 Revision," American Association for Automotive Medicine, Morton Grove, Ill. 60053.
20. Eppinger, R. H., and Partyka, S. C., "Estimating Fatality Reductions Associated with Safety Improvements," Eighth International Technical Conference on Experimental Safety Vehicles, October 1980.
21. Partyka, S. C., "A Comparison of AIS and ISS Predictions of Fatality on NCSS," Twenty-Fourth Conference of the American Association for Automotive Medicine, October 1980.
22. Eppinger, R. H., "Considerations in Side Impact Dummy Development," Seventh International Technical Conference on Experimental Safety Vehicles, June 1979.
23. Neathery, R. F., Kroell, C. K., and Mertz, H. J., "Prediction of Thoracic Injury From Dummy Responses," Nineteenth Stapp Car Crash Conference, November 1975.
24. Draper, N. R., and Smith, H., "Applied Regression Analysis," Second Edition, John Wiley and Sons, Inc., New York, 1981, pg. 8.

APPENDIX A

Data processing of the accelerometer signal closely followed that in Reference 2. The steps included: (A) electronic filtering to appropriately band limit the response and minimize aliasing in the A/D process, (B) analog to digital conversion (1600 Hz sampling rate), and (C) digital filtering with a finite impulse response filter having the following characteristics; pass band frequency = 100 Hz, stop band frequency = 189 Hz, pass band ripple = 0.0225 dB, and stop band gain = − 50 dB.

APPENDIX B
Injury Data and Parametric Value Summary

Test No.	Test Velocity (mph)	Test Type	Age (Years)	Sex	Weight (kg)	Height (cm)	Testing Organization	Test No.	$AIS1_T$	$AIS2_T$	$AIS1_{HT}$	$AIS2_{HT}$	NFR	Peak Rib Synthetic Relative Velocity (fps)	Peak Rib Acceleration (G's)	Peak Spine (T12) Acceleration (G's)
76T003	15	RW	60	M	102.1	180.5	HSRI	76T003	1	0	1	0	1	16.7	88.	---
76T009	25	RW	75	F	44.1	155.5	HSRI	76T009	5	5	5	5	20	49.7	435.	207.
76T010	20	RW	84	M	87.8	162.2	HSRI	76T010	4	3	4	3	13	28.6	153.	106.
76T011	20	RW	69	M	74.9	170.2	HSRI	76T011	4	0	4	4	17	28.3	125.	167.
76T029	15	PW	67	M	62.5	167.1	HSRI	76T029	2	0	2	0	3	13.5	56.	54.
76T034	20	PW	62	M	59.	183.5	HSRI	76T034	4	2	4	2	18	19.8	112.	---
76T039	20	PW	72	M	73.9	186.8	HSRI	76T039	3	2	3	2	9	10.3	56.	40.
76T042	25	PW	58	F	64.5	177.7	HSRI	76T042	4	0	4	0	15	11.3	99.	67.
76T065	9.5	P	63	M	94.7	178.9	HSRI	76T065	1	0	1	0	0	6.3	38.	12.
77T071	9.5	P	60	M	80.7	172.2	HSRI	77T071	3	1	3	1	0	7.1	30.	14.
77T074	9.5	P	60	M	54.	176.9	HSRI	77T074	1	0	1	0	1	10.0	61.	15.
77T077	13.6	P	79	M	73.7	175.5	HSRI	77T077	3	3	3	3	3	9.7	60.	20.
77T089	20	RW	66	M	55.1	173.5	HSRI	77T089	5	3	5	3	9	32.0	249.	88.
77T092	20	RW	45	F	58.3	176.7	HSRI	77T092	4	4	4	4	21	29.3	153.	79.
77T095	20	PW	77	M	92.8	183.2	HSRI	77T095	4	4	4	4	11	24.4	125.	59.
77T098	20	PW	71	M	59.	168.2	HSRI	77T098	4	3	4	3	13	23.1	165.	98.
WSU484	15	PW	50	M	78.4	164.	Wayne State	WSU484	2	1	2	1	8	---	---	51.
WSU487	20	PW	54	F	54.4	165.	Wayne State	WSU487	2	1	2	1	5	10.6	73.	57.
WSU488	17	RW	58	M	97	183.	Wayne State	WSU488	4	2	4	2	7	---	---	69.
WSU490	15	RW	50	M	49.9	185.	Wayne State	WSU490	2	1	2	1	10	---	---	38.
H80011	15	RW	27	M	89	180.	Heidelberg	H80011	1	1	2	2	1	17.8	123.	93.
H80014	14	RW	60	F	84	169.	Heidelberg	H80014	2	0	3	3	3	15.0	106.	146.
H80017	15	RW	38	M	70	175.	Heidelberg	H80017	2	0	2	0	6	17.6	92.	76.
H80018	19	PW	21	M	61	166.	Heidelberg	H80018	0	0	1	1	0**	15.3	69.	61.
H80020	19	PW	26	F	67	167.	Heidelberg	H80020	1	1	1	1	3	13.4	52.	---
H80021	20	PW	29	M	63	180.	Heidelberg	H80021	0	0	0	0	0	17.5	118.	56.
H80023	20	PW	41	F	82	159.	Heidelberg	H80023	2	0	2	0	8	27.9	125.	86.
H80024	20	RW	24	M	65	176.	Heidelberg	H80024	0	0	0	0	0	20.2	121.	134.
H81002	20	RW	57	M	65	165.	Heidelberg	H81002	4	2	4	4	14	25.9	116.	130.
H81004	20	RW	56	M	80	165.	Heidelberg	H81004	4	1	4	4	16	23.7	128.	135.
BMD001	40*	BC	40	F	69	167.	ONSER	BMD001	4	1	4	4	11	30.1	193.	138.
BMD002	40*	MC	43	M	70	175.	ONSER	BMD002	2	2	3	2	11	27.1	98.	57.
BMD003	40*	MC	55	M	74	174.	ONSER	BMD003	4	2	4	4	12	26.7	135.	49.

* Velocity of deformable side impact moving barrier.

P = Pendulum
RW = Rigid Wall
PW = Padded Wall
BC = Baseline Crash
MC = Modified Vehicle Crash

AIS values in terms of 1980 manual.
NFR = Number of Fractured Ribs.

Signals processed according to Appendix A.

Synthetic Relative Velocity discussed in Reference 15. The numbers here are slightly changed from Reference 15 due to a slight change in the transfer function.

**Incorrectly reported in Reference 13 as 6 fractured ribs.

Human Head Tolerance to Lateral Impact Deduced from Experimental Head Injuries Using Primates

ATSUMI KIKUCHI, KOSHIRO ONO
Japan Automobile Research Institute, Inc.

NORIO NAKAMURA
Department of Neurosurgery
Jikeikai University

ABSTRACT

Impacts were applied to temporal regions of 23 subhuman primates, while controlling 1) impact velocity, 2) impactor elasticity and 3) impact stroke. Such impacts were repeatedly applied to test primates until they showed symptoms of brain concussion or other brain injuries. As a result, the range of head accelerations, in which brain concussion and pathological brain injuries such as subdural hemorrhage, brain stem hemorrhage, etc. were likely to occur, was clearly indicated on the coordinates represented by the averaged resultant head acceleration and its duration of impact.

This provided a clear indication of thresholds of severe pathological brain injuries as well as the threshold of brain concussion of subhuman primates against lateral impacts. Based on the experimental results using subhuman primates, the extrapolation was done of human head acceleration and its duration, and thresholds of human brain concussion and severe pathological brain injuries were deduced. From results thus obtained it was estimated that the tolerances to brain concussion and severe pathological brain injuries for humans and subhuman primates were higher for lateral impacts than those of frontal or occipital impacts and that the hemorrhage of callosal, cortical and subcortical was often involved at time of occurrence of brain concussion by lateral impact on the head. According to the above, it was concluded that it should be appropriate to determine the tolerance threshold of the lateral impact, using slight skull fracture, minor subarachnoid hemorrhage or other similar head injury for reference.

INTRODUCTION

Doctors who actually engage in clinical treatment feel that a certain pattern exists among head traumas, and there are clearly some rules concerning the relationship between the direction of force and area of brain injury. Nevertheless, only a few quantitative analyses of the relation between the impact region, injury and impact magnitude have been done, (1,2,3) and the tolerance of each region of the head against impacts has not been clearly developed, whereas relatively more qualitative analyses have been performed.

Gurdjian et al. reported the Wayne State Tolerance Curve (WSTC) regarding tolerance thresholds against frontal impacts in 1965, based on data obtained from a number of animal tests, skulls, cadavers, volunteers and clinical cases. (4,5,6) Since then the WSTC has been used extensively not only as a criterion for motor vehicle safety but also as an index to safety against head impacts. The author et al. recently extrapolated the threshold of human brain concussion against frontal or occipital impacts from the results of head impact tests performed using subhuman primates, (7,8,9) which was reported as the JARI Human Head Tolerance Curve (JHTC) (10,11). As a result, it was confirmed that the WSTC developed by Gurdjian et al. employed injuries similar to brain concussion in terms of severity as the index to tolerance thresholds.

In recent years, safety measures for motor vehicle side collisions have been attracting the attention of people concerned, but safety thresholds of head, thorax, pelvis, etc. against lateral impacts are not recognized yet. The author et al., therefore, carried out lateral impact tests using subhuman primates, in an attempt to clarify tolerance thresholds against lateral impacts through the extrapolation of human brain concussion threshold according to experimental results.

EXPERIMENTAL SUBJECTS

Twenty-three subhuman primates which were morphologically, anatomically and physiologically analogous to humans were used as test subjects. The primates were classified as follows; 7 Macaca fuscatas (Japanese monkeys), 12 Macaca mulattas (Rhesus monkeys) and 4 Macaca fasicularises (crab eating monkeys) consisting of 21 male monkeys and 2 female monkeys. Their weights ranged from 4 to 13 kg, presumed ages from 3 to 9 years old.

EXPERIMENTAL APPARATUS AND IMPACT METHOD

The impactor ejection apparatus shown in Figure 1 was used as the test equipment to apply impacts to temporals of test monkeys. The posture of each test monkey was held by subject restraint device shown in Figure 2. The impactor ejection apparatus was capable of colliding the piston, accelerated by the compressed air, against the impact shaft located at the front end of the cylinder, for ejection of the impact shaft. The impact stroke was con-

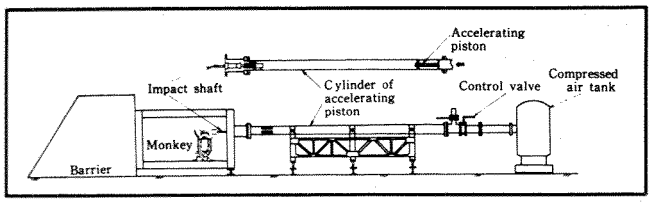


Figure 1. Impactor ejection apparatus.

trolled by the impact shaft stopping position. The maximum capability of the impactor ejection apparatus was 50 m/s where the weight of the impact shaft was 13 kg. The impactor head was made of a solid rubber block of 120 × 80 × 100 mm, and the degrees of hardness of the rubber block were 20, 30 and 70. Elastic characteristics of each impactor head are shown in Figure 3. Each test monkey under light anesthesia was seated on the subject restraint device with its chin held by a urethane foam block, while impacts were applied. The impact direction was vertical to the sagittal plane of the head, with the Frankfurt line of the monkey's head held horizontal (Figure 4). The upper region of the zygomatico arch was selected as the area of impact in order to avoid fracturing of the zygomatico arch. The magnitude of impact was controlled by 1) impactor ejection velocity, 2) impact stroke and 3) impactor head elasticity. After applying impacts, the test monkey's head was held by the supporting net so as to avoid the hyperextension of the neck. At the same time when the body fell against the supporting net, the net started to tilt by 30 to 60° while reducing the velocity, then stopped. Owing to the braking function of the supporting net, the test monkey stopped

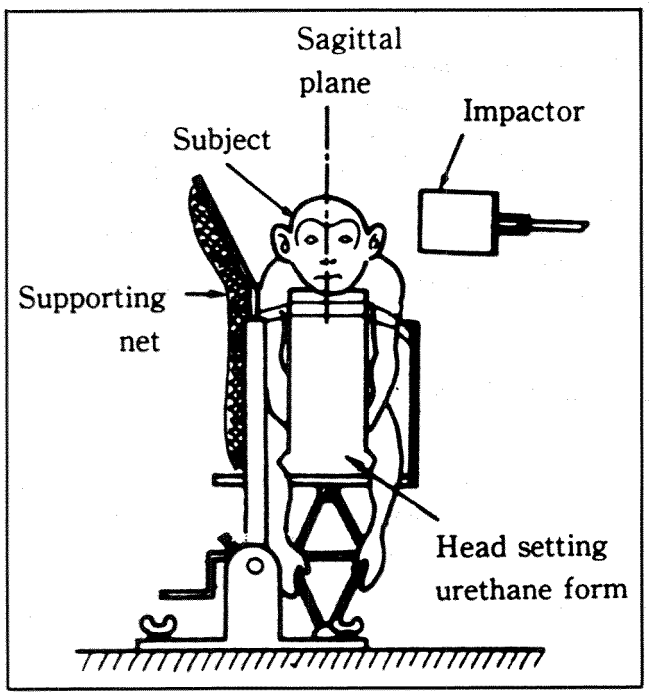


Figure 2. Subject restraint device.

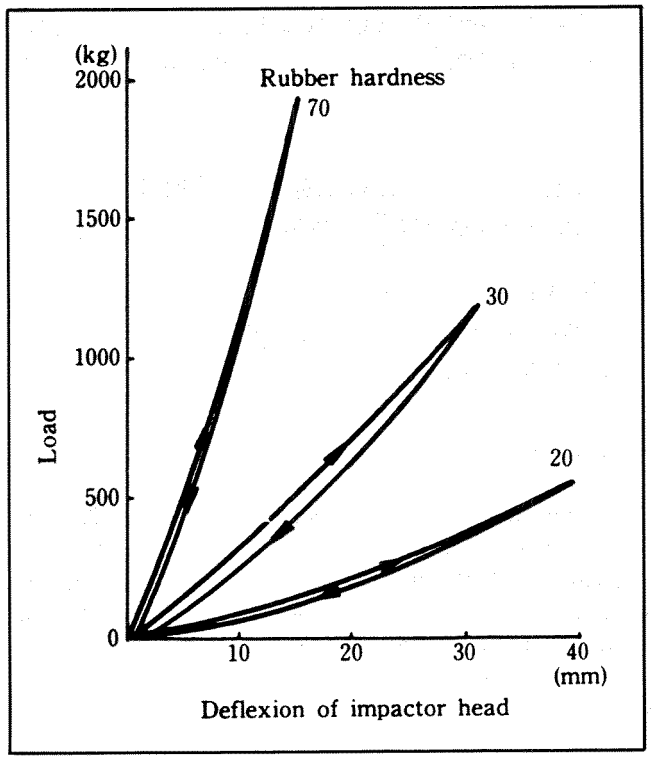


Figure 3. Load-deflexion curve of impactor head.

moving while avoiding secondary collision. At that time, the chair on the subject restraint device did not travel.

PHYSICAL MEASUREMENTS AND BIOLOGICAL OBSERVATION

Ketamin hydrochloride for anesthesia was injected into the muscles of each test monkey about 2 hours prior to the test. Under the anesthesia, the test monkey's physical dimensions and weight were measured and various trans-

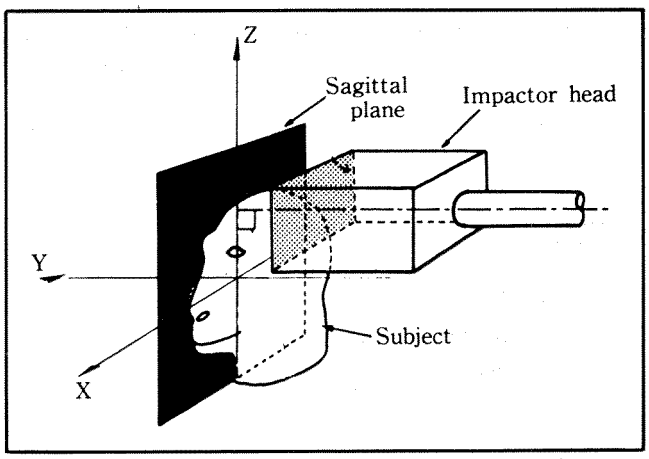


Figure 4. Impact direction; impact direction was set vertical to the sagittal plane, with the Frankfurt line set horizontal.

ducers, electrodes, etc. were installed onto specified locations. The coordinate reference frame of the subject's head was set at the left-hand system. X-axis was set in parallel to the Frankfurt line, while Y and Z axes were set vertical to the X-axis. Head acceleration of each axis was measured by the accelerometer of semiconductor strain gauge type (AH-2000, ST). Values measured by such accelerometers were analyzed and processed through low-path filters by means of a data processing system (NOVA Nihon Minicon). Velocity of impactors was measured optically by laser beams and phototransistors. Behaviors of test monkeys were photographed by high speed cameras at 4000 frames per second (HYCAM, Pedlake) from the direction of X-axis on the head, and the results were studied by a film analyzer (Motion Analyzer, Nack). Electroencephalograms (EEGs) were induced from right and left sides of the frontal-temporal and the parietal scalp, while electrocardiograms (ECG) were induced from the front chest. Respiration measurements were made by means of thermistor-type respiration meters (MTR-2TIS, Nihon Koden). The foregoing biological data were recorded on an electroenceparagraph (EEG-4109, Nihon Koden) and pen-type oscilloscope (RTG-3034, Nihon Koden). Before and after each impact, pupillary light reactions, ciliary reflexes, winks, occular movements, spontaneous movements, etc. were repeatedly observed from time to time. X-ray tests were also done on the head and neck before and after impacts, and skull dimensional measurements were performed and fractures checked, etc. Autopsies were made immediately after death for fatal cases, while surviving monkeys were subjected to euthanasia using nembutal sodium solution 1 hour to 7 days after the impact test, and then given an autopsy. After autopsy, fracture of the skull and cervical vertebra was examined first and extra-intradralle hemorrhage was investigated next. Finally the brain, the cervical spinal cord and upper portion of the thoracic spinal cord were taken out in one, and the skull base duramater was opened to check skull base fractures. After taking photographs and weighing, the brain and spinal cord were held in 10% formalin solution. After 4 weeks or so, they were dissected and studied under an optical microscope.

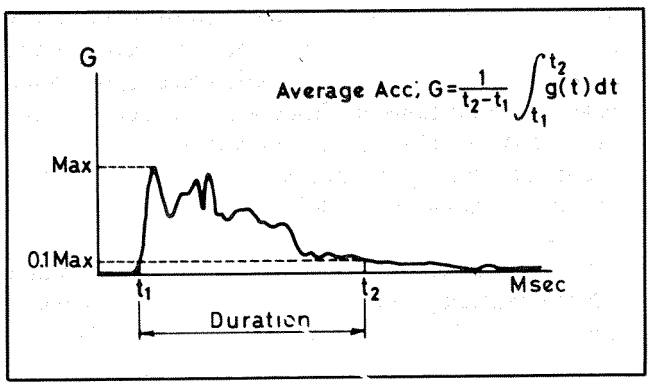


Figure 5. Duration of acceleration; time interval t_1 -t_2 at 10% level of max. acceleration is assumed as acceleration duration.

EVALUATIONS OF IMPACTS AND INJURIES

Magnitudes of impacts on the head were evaluated by head acceleration and its duration, while brain injuries were evaluated by the extent of damage to brain concussion and pathological brain injuries. The methodology and criteria are given in the following.

Magnitude of Impacts

The magnitude of impact from the impactor to the test monkey head is judged by the averaged resultant head acceleration and its duration.

The resultant acceleration is expressed by the absolute value of the sum of vectors of accelerations on X, Y and Z axes. The resultant acceleration is obtained by equation (1), while the duration of the resultant acceleration is expressed by 10% level interval against the maximum of the resultant acceleration (Figure 5).

$$G_R(t) = \sqrt{G_X^2(t) + G_Y^2(t) + G_Z^2(t)} \qquad (1)$$

where, G_R : resultant acceleration
G_X : X-axis acceleration
G_Y : Y-axis acceleration
G_Z : Z-axis acceleration

The averaged value of the resultant acceleration is the value obtained by the integral value of accelerations within the duration by the duration.

Criteria of Brain Concussion

The extent of damage of brain concussion is judged mainly by 3 indices of 1) disappearance of ciliary reflex, 2) apnea and 3) bradycardia, while making reference to test results of neurological reflex and physiological response.

Criteria:

a. Ciliary reflex disappears for 20 seconds or longer after impact
b. Apnea continues for 20 seconds or longer after impact
c. According to the degree and duration of bradycardia, bradycardia is classified by "none", "slight" and "severe", and judged as "severe".

The degree of brain concussion is classified into 3 grades as listed below, according to the criteria mentioned above.

Brain concussion grade 0: does not fall under either one of a, b or c.
Brain concussion grade I: falls under either one of a, b or c.

Brain concussion grade II: falls under two out of a, b and c.

Brain concussion grade III: falls under all of a, b and c.

Criteria of Pathological Changes

Pathological brain injuries differ greatly according to the area and contents of injury. Although it is difficult to make a general classification and grading of pathological brain injuries in terms of morphology, the location of injury, etc., grading is given in this report as listed on Table 1 for injuries found by this experiment. Consequently, pathological brain injuries were classified into 4 grades, including the grade of "intact".

RESULTS OF EXPERIMENT

Impacts were applied 1 to 5 times per test monkey, which totaled 75 times for 23 monkeys, with impactor velocity of 10 to 27 m/s, impact strokes of 20 to 80 mm and impactor head rubber hardnesses of 20 to 70. As a result, significant brain concussions (grade II and III) were found 12 times (16%) out of total impacts of 75 times, some degrees of pathological brain injuries were found in 18 monkeys (78%) out of 23 monkeys, and skull fractures were found in 6 monkeys (26%).

Head Behaviors

According to results of high speed film analysis, details of head behaviors upon impact differ from impact to impact according to differences in impact conditions. For macroscopic behaviors of test monkeys, however, the following common sequential behaviors were found starting from the moment when the monkey head contacted the impactor to the moment when the monkey head stopped.

(1) Initiation of impact: The impactor head surface contacted the temporal region while keeping itself parallel to the sagittal plane of the test monkey. As the impact progressed, the monkey head started moving toward the direction of impact, while crushing into the impactor head.

(2) Progression of impact: As the impactor further progressed, the monkey head started falling to one side with the neck acting as the fulcrum, while crushing further into the impactor head.

(3) Impactor stop: The impactor stopped with the preset stroke. In some cases, the monkey head was accelerated due to the rebound of the impactor after its stopping, while in other cases the head was not accelerated.

(4) Termination of impact: Even after the monkey head left the impactor head, it fell sidewise further with the neck still acting as the fulcrum, then stopped as the inclination angle became 90° to 100°, and was held by the side net.

(5) Finale: The body fell toward the direction of impact as it was pulled by the head through the neck, then held by the side net. The side net in turn inclined by 60° or so while braking down the speed, then stopped. As mentioned above, nearly reproducible macroscopic head behaviors were obtained throughout the experiment.

Table 1. Classification of pathological brain injury of nofractural case.

Injury Severity	Injury
0	Intact
I	Subarachnoid hemorrhage
II	Cortical or Subcortical Hemorrhage Callosal hemorrhage Thalamus or Basal ganglia hemorrhage
III	Brain stem hemorrhage Subependymal hemorrhage Subdural hemorrhage

Head Accelerations

Measurements of effective head acceleration for all of X, Y and Z axes were obtained in 56 cases. In the 56 effective measurement cases, accelerations occurred in all directions of X, Y and Z axes. For the processing of acceleration data, a low-pass filter with a cut-off frequency of 1650 Hz was used. Typical examples of time histories of head accelerations are shown in Figure 6. In every impact, the Y-component head acceleration which coincided with the direction of impact showed the maximum acceleration. In case of the time history of Y-component head acceleration, the standard pattern of waves was that a triangular wave with a sharp peak appeared initially, and was followed by a half sine wave or flat wave. The peak value of the sharp triangular wave which appeared first tended to become greater as the impactor velocity increased or the impactor head hardness become harder, ranging from 190 G to 2800 G. The head acceleration wave of Y component that followed the first sharp wave varied its form according to impact conditions. Under conditions where the impactor was soft (rubber hardness 20) and the impact stroke was long (60 to 80 mm), the duration of head acceleration tended to become long, while the duration of head acceleration tended to become shorter where the impactor head was hard (rubber hardness 70) and the impactor strokes were short (20 mm).

Head accelerations of X and Z component were smaller than the Y-component acceleration, but the duration of acceleration was longer for the Z component in most cases. This was due to the rotation of the head around the X axis centering about the neck, and the Z component acceleration continued even after the head had left the impactor head. The acceleration of the X component was smaller than Y and Z components in every case.

The wave form of the resultant acceleration obtained from each component of acceleration in X, Y and Z axes

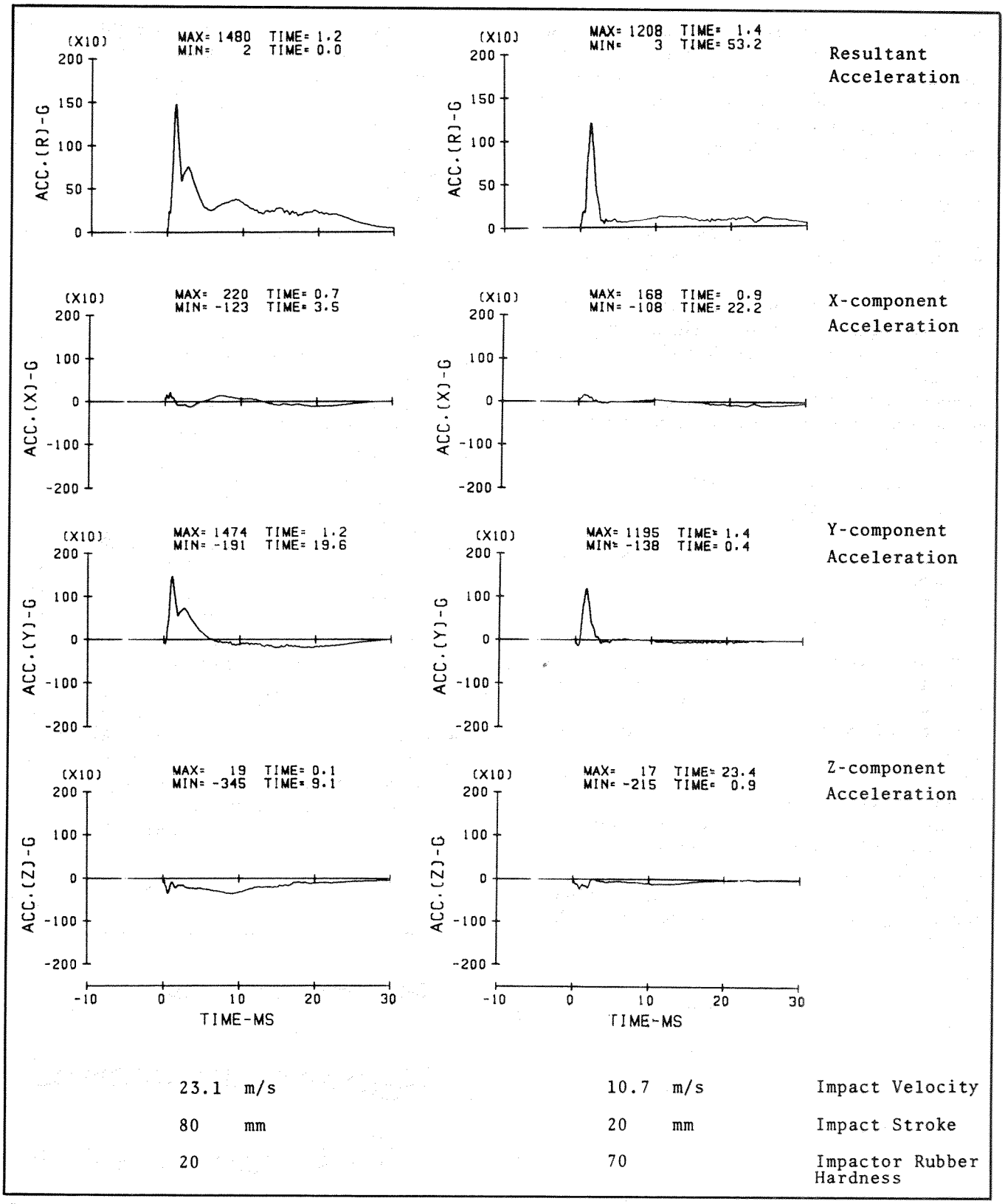


Figure 6. Time histories of head acceleration.

had wave form approximate to the sharp peak wave of the acceleration of the Y component which was the principal component, and it also appeared in the initial stage of impact, and the effect of the Z component on the duration of the resultant acceleration was significant. The averaged resultant head acceleration of 56 effective measurements ranged from 70 to 1310 G, and the duration was in the range of 2.2 to 43.0 ms.

Head Injuries

Physiological and neurological observations: Some physiological and neurological changes were observed in every case. Respiration stopped initially after impact, then resumed as time went by in many cases. In cases where the injury was slight, however, the respiration cycle hardly changed, whereas test monkeys died without recovering from apnea in cases of severe injuries, showing significant variations in respiration. Nevertheless, respiration patterns may be roughly classified into the following 5 types (Fig. 7).

a. No changes in respiration cycle
b. Respiration stopped initially rapidly resumed after a certain time
c. Respiration stopped initially resumed gradually
d. Stopped respiration was initially resumed but deteriorated again
e. Stopped respiration was not resumed

Of 5 types listed above, cases that fell under b and d often showed irregular an weak breathing, but all of them were considered as recovered cases. Therefore, out of 56 effective head acceleration measurements, cases that required more than 20 seconds (a criterion for brain concussion) to recover from apnea were 12, and 10 cases of no-skull fractures were found.

Correlationship was found between blood pressure and heart rate. That is, in many cases, the greater the blood pressure fluctuation, the greater became the variation in heart rate. Blood pressure variation patterns after impact may be classified into the following three types, as shown in Figure 8. Normally, during the fluctuation of blood pressure, bradycardia also appeared, and as the blood pressure resumed its original level, bradycardia also disappeared. Therefore, bradycardia was nearly nil or slight when the blood pressure fluctuation was Type I, but it became more significant for Type II and Type III. The case with the most significant bradycardia showed Type III blood pressure fluctuation and the R-R interval on the ECG was 0.5 sec before impact and 5.6 sec after impact, showing an increase rate of 11 times or so, the original interval then resuming within 5 minutes or so. The recovery time in most cases was between 1 and 5 minutes. Damages appearing in heart rate were judged as "none", "slight" and "severe" using R-R interval and its duration as criteria. Consequently, 17 cases out of 56 impacts of head acceleration effective measurements were judged as "severe", which means that at least one of our criteria for brain concussion, out of 15 cases of non-skull fractures, was found. In most cases ciliary reflex and light reaction were found to be lost, and cases in which ciliary reflex was resumed within 10 sec amounted to 17 cases out of 56, accounting for 30% of the total effective measurements, and those which recovered within 20 sec accounted for 70% or so. The longest recovery time was 154 sec. As for light reaction, on the other hand, 16% were less than 10 sec, and 57% less than 20 sec, with the longest recovery time being 190 sec. The number of cases requiring more than 20 sec (a criterion for brain concussion) for the recovery of ciliary reflex was 17, out of which 12 cases had no-skull fractures.

Using respiration, heart rate and ciliary reflex mentioned in the foregoing as indices, brain concussion judgments for the 56 effective head acceleration measurements were done as follows; brain concussion 0: 30 cases, brain concussion I: 16 cases, brain concussion II: 6 cases, and III: 4 cases. Thus significant brain concussion was observed in 10 cases (18%), out of which 3 monkeys had skull fractures.

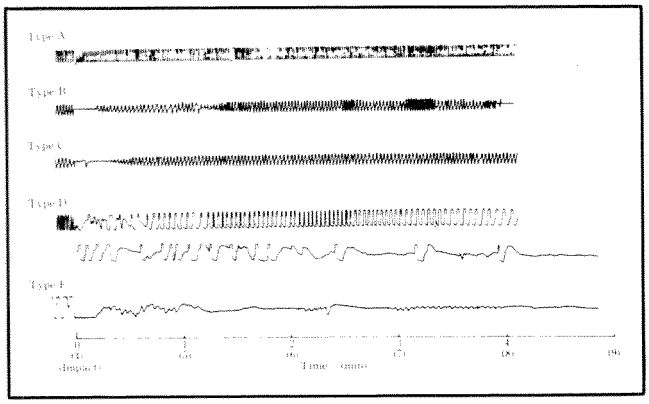


Figure 7. Respiration pattern after impact.

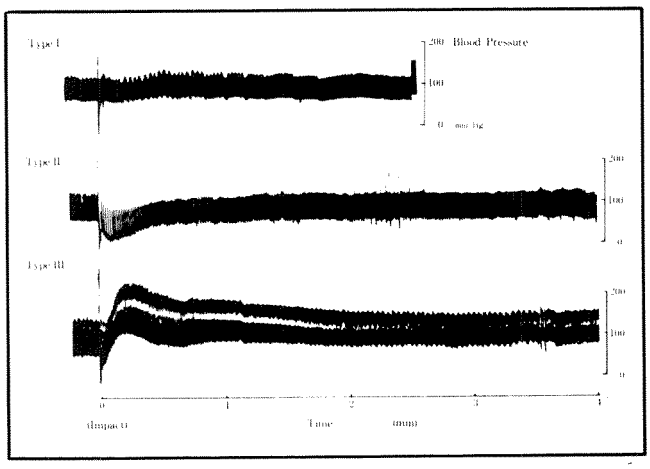


Figure 8. Blood pressure pattern after impact.

Pathological observations: Skull fractures were found in 6 monkeys, out of which one monkey did not have pathological brain injury due to the fact that the fracture was only orbital. The remaining 5 monkeys had skull base fractures, all of which except one were comminuted depressed fractures. This type of fracture caused very serious injuries of brain contusion, brain crush, subdural hemorrhage, etc. as compared with non-fracture cases, and such monkeys died within 15 minutes. Neurological reflex and physiological response of two monkeys of the above resumed within 1 minute, but two other monkeys resumed neither of them.

Of 17 monkeys that had no-skull fracture, on the other hand, one died within 15 minutes and two others died in 6 to 7 days. The 15 minute fatal case had extensive subdural hemorrhage and subarachnoid hemorrhage, and judged as "brain concussion III". Two fatal cases that died in 6 to 7 days did not show any visible injuries, and their brain concussions were below "brain concussion I". Pathological brain injuries of total 18 monkeys consisting of 17 no-fracture cases and 1 case of orbital fracture without any effect to the brain are shown on Table 2. Of the above, subarachnoid hemorrhage was found in 9 monkeys and callosal hemorrhage in 9 monkeys. Cortical hemorrhage and subcortical hemorrhage were also found in 10 monkeys, respectively. Brain stem hemorrhage was observed in 4 monkeys, and subdural hemorrhage was observed in 5 monkeys, out of which 1 fatal case occurred. Moreover injuries were both to the impact side and opposite side of impact, in combinative or separately. No-cortical contusion was found directly beneath the impact.

The classification of pathological brain injury to such no-skull fracture is as follows, according to the injury grades shown on Table 1; pathological injury severity (abbreviated to patho. injury severity) 0: 5 monkeys, severity I: 0, severity II: 7 monkeys and severity III: 6 monkeys. Of these monkeys, effective measurement cases of head acceleration were 3, 0, 4 and 6 monkeys, respectively.

DISCUSSION

Since the mechanism of injuries accompanying skull fractures differs substantially from that of no-fractural cases, the relationship between severity of the no-fractural head trauma and the magnitude of impact will be discussed in this report.

Head Acceleration and Brain Concussion

Assuming that the case of orbital fracture is a no-skull fracture, impacts that did not produce skull fracture were 70 cases, of which 53 cases were effective head acceleration measurements. For the 53 cases, relationship between head acceleration/duration and the severity of brain concussion is shown in Figure 9.

Table 2. Pathological brain injuries no-fractural cases.

monkey No. / Patho. brain injury	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
injury severity	0	II	III	II	III	II	III	0	II	0	III	III	0	III	II	0	II	II
subarachnoid hemorrhage			I.L.	C.L.	I.L.		B.L.		I.L.		B.L.	C.L.			B.L.		C.L.	
cortical hemorrhage		I.L.	I.L.		B.L.	I.L.			I.L.						I.L.		C.L.	C.L.
subcortical hemorrhage			B.L.	I.L.	I.L.	C.L.			I.L.		B.L.				B.L.			C.L.
callosal hemorrhage			I.L.	B.L.	I.L.	B.L.			B.L.		B.L.			C.L.	I.L.			B.L.
hemorrhage of thalamus or basal ganglia											I.L.							
brain stem hemorrhage			B.L.		C.L.		I.L.				B.L.							
subependymal hemorrhage			B.L.		I.L.													
subdural hemorrhage			I.L.		B.L.						C.L.	C.L.		C.L.				

I.L.: ipsilateral to the impact side, C.L.: contralateral to the impact side, B.L.: bilateral

The head acceleration is represented by the mean of the resultant acceleration of X, Y and Z components, while the brain concussion is expressed as brain concussion grades of 0 (intact), I (slight) and II or III (significant). In Figure 10, concussion grades 0 and I incidence, and concussion grades I and II or III incidence distributions are partially overlapped, but respective regions of brain concussion grades 0, I and II or III are nearly clarified. In particular, incidence regions of concussion grade 0 and II or III are clearly separated by the boundary which is approximate to the hyperbolic curve, without any overlap. The inclination of the boundary is nearly approximate to inclination of the brain concussion threshold curve on the frontal impact or occipital, and furthermore, the boundary also constitutes approximately the center of the incidence region of brain concussion grade I. From the foregoing findings, it may be deduced that it is necessary to have greater acceleration/duration than the boundary between concussion grade 0 and II or III shown in Figure 9, in the head of a subhuman primate subject to lateral impact in order to induce significant brain concussion in them. It may thus be said that the boundary between brain concussion grades 0 and II or III is the threshold of brain concussion against lateral impact for subhuman primates.

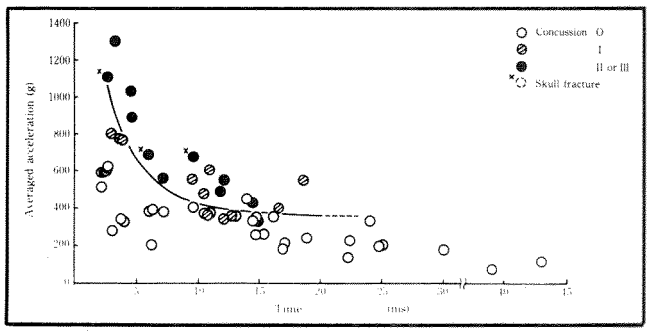


Figure 9. Correlation between averaged head acceleration-duration and grade of concussion in lateral impact.

Head Acceleration and Pathological Brain Injuries

The relationship between the head acceleration/duration and pathological brain injury was investigated, assuming that organic injuries had occurred in impact in which the neurophysiological responses had been the severest in a series of impacts for the same monkey (Fig. 10). In most cases, the severest damage was observed in the final impact. Cases of no-fractural injuries for which head acceleration measurements were effective are as follows; pathological injury severity 0, 4 monkeys; severity I, none (0); severity II, 3 monkeys; and severity III, 6 monkeys, totaling 13 monkeys. As the severity of injury declines from severity III to II and 0, the level of head acceleration/duration also tends to drop. At less than 15 ms of head acceleration's duration in Figure 10, as well as the case of concussion, the pathological injury severity 0 and III incidence distributions are not overlapped, but the underpart of pathological injury severity III incidence and grade II incidence distributions are overlapped. According to the above, the incidence lower limit of pathological injury severity III in Figure 10 which is obtained from these experiment results is the threshold of the subdural hemorrhage, the brain stem hemorrhage and the subependymal hemorrhage, and this threshold is higher than that of the brain concussion by lateral impact on the head as well as the case of frontal and occipital impact. However, it is suggested that the threshold of patho. injury severity II which is the hemorrhage of callosal, cortical or subcortical nearly agrees with or is lower than the threshold of brain concussion.

Extrapolation to Humans

In order to deduce the relationship between the impact and injury of human heads from the relationship between the impacts and injuries of subhuman primates stated above, the dimensional analysis method employed by Stalnaker et al. was applied to extrapolate human brain con-

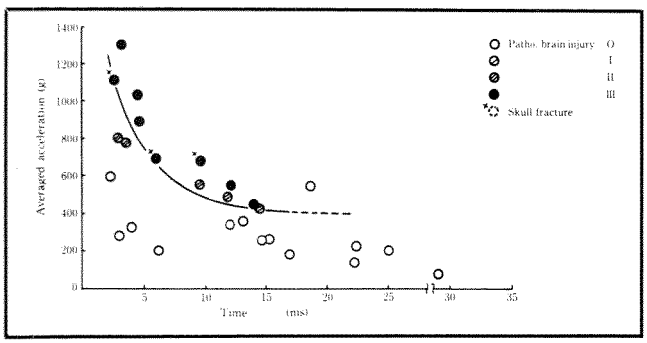


Figure 10. Correlation between averaged head acceleration-duration and grades of pathologica brain injury in lateral; on the patho. brain injury severity O, datas of all impact other than final impact of same subject were contained.

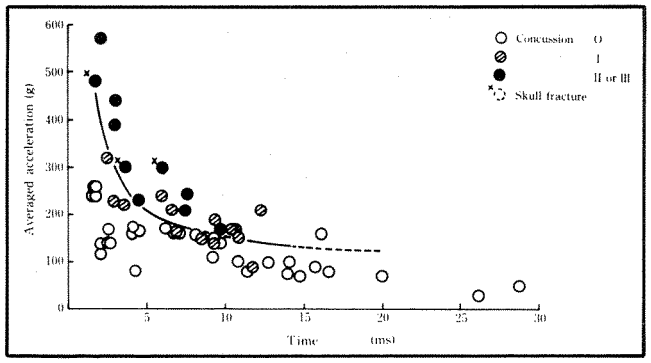


Figure 11. Threshold of concussion in human extrapolated from averaged acceleration-duration by dimensional analysis in lateral impact of the monkey head.

cussion threshold and pathological brain injury threshold. Assuming, therefore, that shapes of subhuman primates and human heads were analogous, and further that physical characteristics of biological tissues of their brains, skulls, etc. are the same, the head acceleration and duration, which would cause human head injuries equivalent to those of subhuman primates upon lateral impacts, were extrapolated. Parameters necessary for the dimensional analysis were the following five items: 1) head acceleration, a; 2) head acceleration duration, t; 3) impact speed, v; 4) average radius of skull, ℓ and 5) average thickness of skull, h.

Non-dimensional quantity π is expressed as $\pi_1 = 1/h$, $\pi_2 = vt/h$ and $\pi_3 = a \cdot h/v^2$. The relationships among π_1, π_2 and π_3 were determined by using the data (12,13) Stalnaker et al. obtained from subhuman primates of various sizes (sucioroid monkeys, Macaca mulattas, chimpanzees, etc.). The ratio between the average radius and average thickness of human heads in expressed at ℓ /h, and the average weight is assumed to be 1.35 kg.

Human head acceleration and its duration extrapolated from 54 cases of effective measurements of conversion parameters upon lateral impacts of subhuman primates are listed together with the relationship between brain concussion and pathological brain injuries in Figures 11 and 12. Similar to the case of subhuman primates, regions of brain concussions of grades 0 and II or III are also separated for humans, and brain concussion threshold based on grade II or III is also clearly indicated. This brain concussion threshold is represented by the hyperbola passing through 400 G — 2.2 ms and 160 G — 10.0 ms.

Lateral Impact Tolerance Threshold

It was believed from clinical experience, etc. that lateral impact tolerance was lower than the frontal and occipital impact tolerances. However, a comparison between the brain concussion threshold of subhuman primates obtained through this experiment and the results of frontal

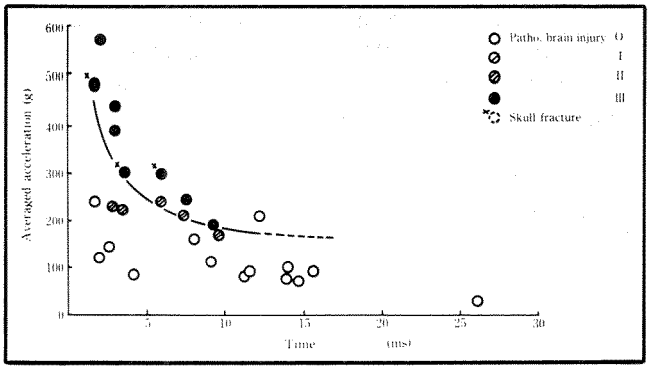


Figure 12. Threshold of pathological brain injury in humans extrapolated from averaged acceleration-duration by dimensional analysis in lateral impact of monkey head.

impact or occipital impact experiment previously reported by the author et al. reveals that the former has markedly higher tolerance than the latter. Gurdjian et al. suggested the WSTC employing brain concussion as the index to the human frontal impact safety threshold, while the author et al. reported the JHTC as the human brain concussion threshold upon frontal or occipital impact, extrapolated from subhuman primates. The comparison between the brain concussion threshold upon frontal or occipital impact indicated by the WSTC and the JHTC and the human brain concussion threshold extrapolated from the results of this experiment shows a clearly high tolerance for lateral impacts.

As regards the threshold of pathological brain injuries, a comparison was also made between the results of frontal or occipital impact already reported by the author et al. and the results of this experiment, which show that the tolerance is higher for the latter as compared with the former similar to the case of brain concussion stated above. According to the results of this experiment described so far, the temporal blow has much higher impact tolerance than the frontal and occipital in terms of brain concussion as well as pathological brain injuries, which agrees with the report published by McElhaney et al., (14) which stated that the impact tolerance to lateral impacts is much higher than that of occipital, according to a head impact experiment performed on primates using the criterion of "whether after effects would remain or not" as the indicator. McElhaney et al., however, reported at the same time that the frontal impact tolerance was higher than the lateral impact tolerance.

As for indices for frontal or lateral impact tolerance threshold, brain concussion is often used as the indicator, as in the JHTC cases and the WSTC. The reasons are that: 1) brain concussion is a transitory and recoverable injury, and 2) brain concussion is likely to occur at the lowest impact level as compared with brain injuries upon frontal or occipital impact. Impacts in the vicinity of the JHTC were such that "at most, subarachnoid hemorrhage might occur (15) (patho. injury severity I)", and it would have been necessary to apply more intense impact to produce skull fracture, subdural hemorrhage, brain stem hemorrhage, etc. (patho. injury severity III). However, the following symptoms were observed upon occurrence of brain concussion of subhuman primates by lateral head impact: 1) subarachnoid hemorrhage (patho. injury severity I) was found in nearly all cases, 2) cortical hemorrhage, subcortical hemorrhage, etc. (patho. injury severity II) were found in more than half the monkeys, and 3) even the concurrence of severe injuries such as subdural hemorrhage, brain stem injury (patho. injury severity III) was found in some cases.

On the other hand, it is reported that the lateral bone fracture load is lower than the frontal bone fracture load according to the studies on skull fracture by head impact, and that lateral bone fracture load is approximately 50 to 80% of the frontal bone fracture load according to a number of experiments. (14,16,17) It is thus deduced, from those studies and skull fracture threshold on frontal or occipital impact as shown in the appendix, that the skull fracture threshold of lateral head impact for humans is the impact level equivalent to or below those of WSTC or JHTC; also it is lower than the threshold for brain concussion on the lateral head impact.

From findings mentioned so far, it was deduced that the thresholds of subdural hemorrhage, brain stem hemorrhage and subependymal hemorrhage (patho. injury severity III) were highest, followed by brain concussion (grade II or III) and cortical hemorrhage and subcortical hemorrhage, etc. (patho. injury severity II) were next, while the threshold of subarachnoid hemorrhage and skull fracture were the lowest for lateral impact, different from frontal or occipital impact. This deduction agrees with a clinical fact that skull fractures are likely to occur in many cases by lateral impacts". Furthermore, this is considered to be one of the reasons for the common belief that the lateral impact tolerance is lower than the frontal impact tolerance due to the difference in the orders of thresholds of injuries as compared with frontal or occipital

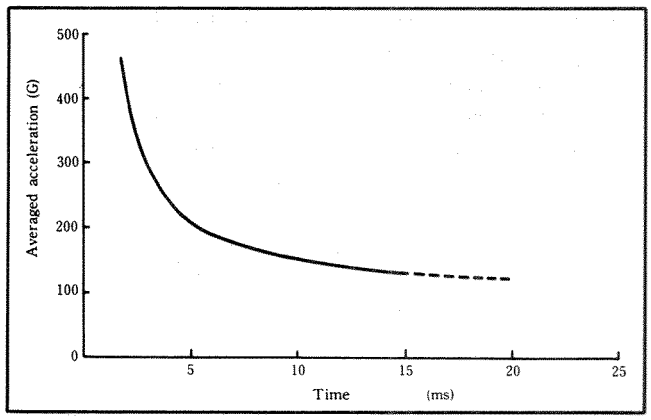


Figure 13. Human brain concussion threshold curve of lateral impact on the head.

impact. The human brain concussion threshold curve of lateral impact on the head extrapolated by the result of this experiment is shown in Figure 13. This is one indicator of judgment on lateral head impact safety. However it was estimated by this experiment that cortical and subcortical hemorrhages and callosal hemorrhage were often involved at time of the occurrence of brain concussion by lateral impact on the head. Consequently it is considered appropriate to determine the safety threshold of lateral impact by referring to skull fractures or subarachnoid hemorrhage of which the tolerance level is deduced to be lower than the tolerance level of brain concussion, brain stem hemorrhage, subdural hemorrhage, etc.

SUMMARY AND CONCLUSIONS

1) In order to clarify thresholds of brain concussion and pathological brain injuries, impacts were applied 75 times to temporals of 23 subhuman primates under various conditions. Of 56 cases of effective measurements, averaged resultant head accelerations of 70 to 1310 G with durations of 2.2 to 43.0 ms were produced, and brain concussion (grade II and III) was found in 10 cases. Of 23 test monkeys, some pathological brain injuries were found in 18 monkeys.

2) For skull fracture cases, the relationship between the head acceleration and brain concussion, and the relationship between head acceleration and pathological brain injury were investigated in order to clarify brain concussion threshold and thresholds of subdural hemorrhage, brain stem hemorrhage, etc. upon application of lateral impact. Extrapolation was also made from data of subhuman primates to humans.

3) Brain concussion threshold of lateral impact, and thresholds of subdural hemorrhage, brain stem hemorrhage, etc. for humans and primates showed higher values than those of frontal or occipital impact.

4) In lateral impact on the head, threshold for hemorrhage of brain stem, subependymal and subdural is higher than that of concussion, and threshold for hemorrhage of cortical, subcortical and callosal nearly agrees with or is lower than the threshold of brain concussion. Comparing these thresholds with JHTC and the skull fracture threshold it is deduced that the threshold of skull fracture is lower than the threshold of brain concussion and cortical hemorrhage, etc.

5) It has been believed from the clinical point of view in craniocerebral injury that the tolerance to lateral impact is lower than the tolerance to frontal impact. It is deduced that one of the reasons for the above concept is that the relationship of skull fracture threshold, brain concussion and various pathological brain injuries threshold differs between the case of frontal or occipital impact and the case of lateral impact.

6) Various pathological brain injuries are often involved at time of occurrence of brain concussion by lateral impact on the head. Therefore slight skull fracture or subarachnoid hemorrhage is an adequate indicator of tolerance by lateral impact on the head.

ACKNOWLEDGEMENTS

The authors received generous assistance from many research and laboratory staff members of the Neurosurgery Departments of the Tokyo Jikeikai University School of Medicine, the University of Tokyo, and Tokyo Women's Medical College and Engineering Department of the University of Tokyo.

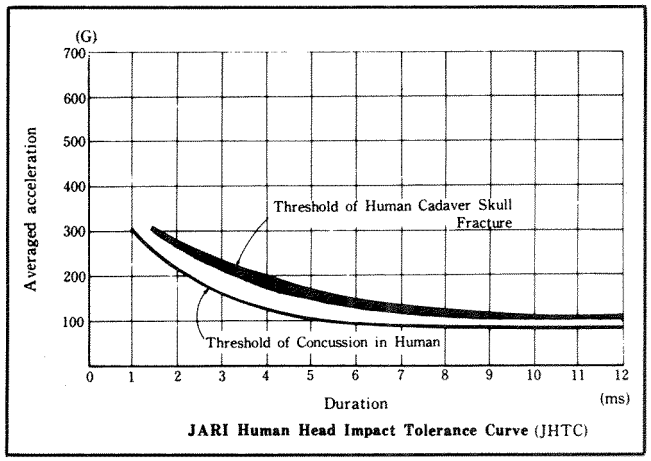
REFERENCES

1. K. Sano, N. Nakamura, K. Hirakawa, H. Masuzawa, et al.; Mechanism and dynamics of closed head injuries (preliminary report). Neurol. Medicochir. (Tokyo) 9:(1967)
2. C. B. Courville; Coup-contrecoup mechanism of craniocerebral injuries. Some observations. Arch. Surg. 45:(1942)
3. R. Hooper; Patterns of Acute Head Injury. Edward Arnold Ltd., London (1969)
4. E. S. Gurdjian, H. R. Lissner and L. M. Patrick; Protection of the head and neck in sports. JAMA 182:(1962)
5. E. S. Gurdjian, V. R. Hodgson, W. G. Hardy, L. M. Patrick and H. R. Lissner; Evaluation of the protective characteristics of helmets in sports. J. Trauma 4:(1964)
6. L. M. Patrick, H. R. Lissner and E. S. Gurdjian; Survival by design-----Head protection. Proc. 7th Stapp Conference 7:(1965)
7. H. Sekino, N. Nakamura, A. Kikuchi, K. Ono, et al.; Experimental Head Injury in Monkey Using Rotational Acceleration Impact. Neurologia medico-chirurgica Vol. 20, No. 2: 1979 (Japanese)
8. H. Kohno, N. Nakamura, M. Matuno, et al.; Experimental Head Injury and Concussion—Morphologic Change and Pathophysiologic Following Translational Acceleration in Primates. Neurologia medico-chirurgica Vol. 19, No. 8; 1979 (Japanese)
9. R. Kanda, N. Nakamura, A. Kikuchi, K. Ono, et al.; Experimental Head Injury in Monkeys-Concussion and its Tolerance Level. Neurologia medico-chirurgica, Vol. 21, No. 7:1981
10. K. Ono, A. Kikuchi, M. Nakamura, H. Kobayashi, N. Nakamura; Human Head Tolerance to Sagittal Impact Reliable Estimation Deduced from Experimental Head Injury Using Subhuman Primates and Human Cadaver Skulls. Proc. 24th Stapp Conference 24: 1980

11. A. Kikuchi, K. Ono, H. Kobayashi, N. Nakamura, M. Nakamura; Evaluation of Head Tolerance to Sagittal Impact by Head Acceleration and Duration, and Head Velocity, JSAE Review, No. 3:1980
12. R. L. Stalnaker, V. L. Roberts and J. H. McElhaney; Side Impact Tolerance to Blunt Trauma. Proc. 17th Stapp Conference 17:1973
13. R. L. Stalnaker, J. H. McElhaney, R. G. Snyder and V. L. Roberts; Door Crashworthiness Criteria. U. S. Dept. of Transportation Report No. HS-800-S34; 1971
14. J. H. McElhaney, V. L. Roberts and F. Hilyard; Handbook of Human Tolerance. Japan Automobile Research Institute, Inc.: 1976
15. H. Sekino, N. Nakamura, et al.; Brain Contusion Detected by CT Scan in Minor Head Injury. Neuro Traumatology: 1979
16. J. W. Melvin and P. M. Fuller; Effect of Localized Impact on the Human Skull and Patella. SESA Paper No. 70-491: 1970
17. A. M. Nahum, J. D. Gatts, C. W. Gadd and J. Danforth; Impact tolerance of the skull and force. Proc. 12th Stapp Conference 12: 1968

APPENDIX

It is a figure that shows the threshold of concussion and cadaver skull fracture in human on frontal or occipital impact. (10)



JARI Human Head Impact Tolerance Curve (JHTC)

Tolerance of Human Pelvis to Fracture and Proposed Pelvic Protection Criterion to be Measured on Side Impact Dummies

D. CESARI, M. RAMET and R. BOUQUET
O.N.S.E.R. France

INTRODUCTION

The problems of side impact protection have been extensively analysed in several countries in the world.

To make the evaluation of protection offered by cars against side impact, proposals of side impact tests using a mobile deformable barrier have been made as well in the United States (1) as in Europe (2).

The evaluation of car behaviour in side impact would be made through the values of injury parameters recorded on dummies. These injury parameters would be related to injury mechanisms of real side impact accidents.

This paper analyses the results of 60 cadaver tests conducted to determine the pelvis tolerance and to propose a protection criterion of pelvis in side impact.

TEST METHODOLOGY

All the tests were performed using a device especially designed to reproduce impacts similar to those observed in real accidents. The procedure we used has been described in a previous paper (3) but it is briefly described hereafter. The device is made of a fixed frame and a mobile impactor, horizontally guided in order to hit a human subject seated on a rigid seat locked with the frame end.

The mobile part is propelled by rubber extensible springs and the system is tightened through a small trolley guided on the same axis as the impactor and attached to a steel cable. It is possible to pull on the cable through a winch and then to move the trolley and the impactor back by tightening the rubber extensible springs. A bolt located between the trolley and the impactor releases the impactor which is then accelerated by the rubber extensible springs and hits the human subjects.

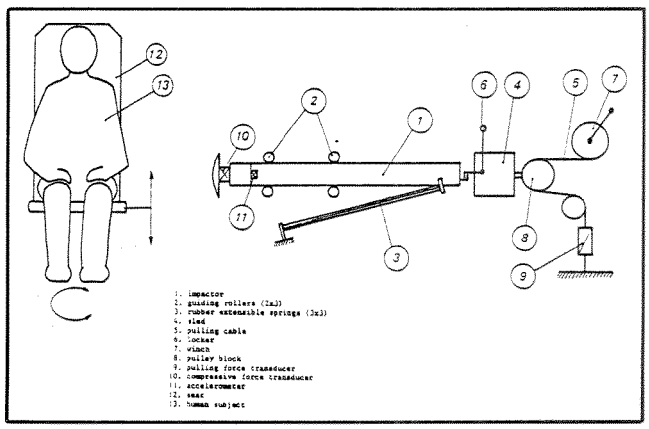


Figure 1. Impactor diagram.

The impactor mass is 17.3 kg and the impacting system is the portion of a sphere (r = 600 mm, R = 175 mm). The impact force and impact acceleration are measured on the mobile system through transducers.

All the tests were performed with fresh human cadavers. They were incised along the iliac crest to expose the internal face of the wing of ilium. Three strain gauges were applied on this internal face : 2 below the iliac crest and 1 behind the acetabulum. These gauges were plastic sheathed, which made their fitting simpler.

Then, the incision was sutured. A fourth gauge was placed on the same side on the upper face of the ilio-pubic ramus. Then, the cadaver was dressed up, weighted, measured and placed on the seat. The seat was centered on the trochanter major tuberosity.

The seat used gave the cadaver a posture identical to that of a car driver. The subject was unbelted and without lateral support.

In order to reach the pelvic fracture at a level as close as possible to the tolerance, several tests at increasing impact speed were conducted on the same cadaver. However, we performed only one impact test on 5 cadavers because the fracture happened at this first test. The results of these 5 tests would also allow to verify the influence of following tests on the same cadaver.

An X ray picture is taken after each test to verify whether it produced a fracture or not. Moreover, an X ray picture is taken before the tests to verify that there was no previous fracture or important osseous decalcification.

We decided to perform tests with unbelted subjects, because the analysis of car-to-car collisions shows that the safety belt is generally not solicited in lateral impact, at least during the main phase of the impact.

Sixty impact tests on pelvis were performed for this study, using 22 cadavers. All the tests, excepted five which were performed with a padded impactor, were conducted using a rigid impactor described previously. Additional static tests have been conducted on five half pelvis in order to determine the force distribution inside the pelvic bone. Cortical area and inertia momentum of the two rami have been calculated for the pelvis of 10 cadavers.

RESULTS

The results of impactor tests reported here are analysed in different directions:

—Injuries found by the autopsy,
—Dynamic test results,
—Static test results and bone mechanical properties.

Table 1.

Test N°	AIS	Injuries
A4	3	Fracture of the right ilio + ischio-pubic rami sacro iliac disjunction non complete fracture of sacrum
B3	3	Fracture of the right ischio-pubic ramus Fracture of the right femoral neck and collapse of the femoral head
C4	3	Fracture of the right iliac wing Fracture of the right femoral shaft
D2	3	Fracture of the right ilio and ischio-pubic rami, fracture of the right femoral neck, sacro iliac disjunction
E2	3	Fracture of ilio and ischio-pubic rami Sacro iliac joint disjunction
H4	2	Right femoral shaft fracture
I5	2	Fracture of the right iliac wing
J3	3	Fracture of the right ilio and ischio-pubic rami. Pubic symphisis disjunction
M3	2	Fracture of the right iliac wing
N7	3	Fracture of the right iliac wing. Fracture of the right ilio and ischio-pubic rami. Right sacro iliac disjunction
O6	3	Fracture of the right ilio and ischio-pubic rami and right sacro iliac disjunction
R5	2	Fracture of the sacrum
S4	3	Collapse of the head of the right femur through the acetabulum. Fracture of the right and left ilio and ischio-pubic rami
T2	3	Fracture of the right acetabulum. Fracture of the right ilio and ischio-pubic rami
V2	3	Multiple fracture of the right ilio and ischio-pubic rami. Fracture of the right femoral neck
W2	2	Fracture of the right femoral shaft
X2	3	Fracture of the right and left ilio and ischio-pubic rami. Bilateral sacro iliac disjunction
Y2	2	Fracture of right ilio and ischio-pubic rami
Z2	3	Fracture of the right ilio and ischio-pubic rami. Right sacro iliac disjunction

RESULTS CONCERNING THE INJURIES

The injuries sustained by the cadavers during the impactor tests were carefully recorded by an autopsy made after the tests. During this autopsy the pelvis was removed and the pelvic fractures carefully analysed. This procedure allows us to set up a complete list of pelvic injuries sustained by the cadavers during the tests. The injuries recorded during autopsies are listed on Table 1.

Pelvic injuries sustained in side impact real accidents are not generally described in details; however, an in-depth study of pelvic fractures in side impact accidents gives a description of injuries sustained by impacted side accident victims (4). The distribution of these injuries and those recorded on cadavers are listed in Table 2.

Comparison of accident and test injuries shows a good correlation with nevertheless some minor differences. In both samples the fracture of pelvic rami is the most frequent injury (13 among 19 in tests and 12 among 14 in accidents). However the pelvic rami fractures are mainly on one side in tests whereas they involve both sides in accidents: these differences seem to depend from the severity of impact; the tests were made at increasing speed until a pelvic injury was found, which limits the extension of injuries, whereas in accidents the energy dissipated by the impact between the occupant and the side parcel can be higher than the energy necessary to produce injuries, and then this impact can make extensive fractures.

The pubic rami fractures seem to be a typical injury of direct lateral impact in the sitting position (which corresponds to the position of car occupants). In tests conducted in similar conditions, but with cadavers having legs in line with the torso, i.e., like in standing posture, (5) the injuries found were completely different: they were mainly acetabulum (hip) fractures: but the energy to produce these injuries was in the same order of magnitude as the energy amount necessary to produce side impact pelvic injuries.

The other differences concern mainly the number of femoral neck fractures and of sacroiliac disjunctions.

The femoral neck fractures are very rare even if we have found more in tests than in accidents. The femoral neck mechanical resistance decreases with age (the spontaneous femoral fracture of elderly is well known) and the cadavers used in these tests were older than the victims of car accidents.

The sacroiliac disjunctions seem also more frequent in tests than in real accidents. These injuries have never been found isolated, but always associated with pubic rami fractures.

In two tests these disjunctions were very minor and were not found by X ray pictures analysis but only at the autopsy; such injuries could be forgotten on human living.

In a general way cadavers sustained on an average, less pelvic injuries than human people involved in side accidents (51 pelvic injuries for 19 cadavers against 47 injuries for 14 accident victims). This increasing of the number of injuries can be associated with the higher severity of impacts in accidents compared to the tests.

Table 2.

	Number of fractures	
Location	Tests (19)	Accidents (14)
Femoral shaft	3	4
Femoral neck	3	1
Acetabulum	2	1
Iliac wing	5	3
Pubic symphisis	1	1
Sacro-iliac symph.	6	3
Sacrum	1	1
One ramus	1	1
Two rami	10	5
Three rami	0	3
Four rami	2	3
Pelvic crush	1	1

DYNAMIC TEST RESULTS

For the purpose of this study 60 tests have been conducted: 55 of them were performed with a rigid impactor and 5 with a padded impactor. For all the tests the impactor was centered on the right great trochanler. They are analysed separately in this paper.

RIGID IMPACTOR TESTS

The results of the 55 tests performed with a rigid impactor are listed in Table 3. These tests were made with 19 cadavers. Six of them are female cadavers whose age varies from 59 years old to 84 years old with an average value of 71 years old. The age of the 13 male cadavers varies from 54 years old to 85 years old with an average value of 72 years old.

The cadavers used in this study were carefully selected according to their antecedents and the medical treatment that they followed; however, one cadaver (M) had very poor bone conditions, and the results of this cadaver should be cancelled.

Analysis of results shows that there is a large scatter of the results. The 3 ms impact force corresponding to pelvic fracture varies from 4880 N to 12920 N for male cadavers and from 4440 N to 8200 N for female cadavers.

If we consider the tests in which injuries occurred, i.e., tests with an AIS 2 and AIS 3, the average value of the 3 ms impact force is 5600 N for female cadavers and 8600 N for male cadavers. This value of 8.6 KN is higher than the acceptable limit proposed by TRRL to be measured on a side impact dummy (the proposal was 6 KN) (6). The tentatives to correlate the impact force with other parameters did not give interesting results except the correlation between the impact force and anthropometric parameters such as cadaver height or weight. The an-

Table 3.

Test N°	Speed KM/H	Force Peak/3MS N	Accel. 3MS g	Impulse N.s	AIS
A1	21	4170/3355	—	63	0
A2	25.3	5800/4355	—	122	0
A3	30.0	6960/5220	—	163	0
A4	41.0	11140/8200	—	209	3
B1	21.0	5100/3240	—	71	0
B2	30.0	6260/5575	—	131	2
B3	34.9	8120/6200	—	161	3
C1	25.6	5620/5375	—	113	0
C2	32.0	10120/8070	—	136	0
C3	39.4	10140/8080	—	162	2
C4	47.5	13780/12920	—	232	3
D1	25.0	4410/3330	34	88	0
D2	30.8	5240/4720	45	115	3
E1	25.2	5520/4330	45	88	0
E2	31.1	5520/4440	34	112	3
F1	28.3	5610/4430	33	89	0
F2	31.1	3890/3330	24	90	0
F3	35.0	5610/4430	24	110	0
H1	25.5	6620/6390	27	82	0
H2	30.2	10760/10000	42	99	0
H3	34.6	11110/10440	40	128	0
H4	38.2	12690/10555		140	2
I1	25.5	10210/7330	39	77	0
I2	30.2	11040/7890	49	97	0
I3	35.5	11590/8440	49	115	0
I4	39.8	12690/8780	35	139	0
I5	40.1	13240/8935	80	157	2
J1	25.5	7730/6835	34	79	0
J2	30.6	6440/6110	30	124	0
J3	35.5	8270/6945	62	131	3
K1	25.0	5520/4665	34	73	0
K2	30.8	7170/4720	35	85	0
K3	35.0	8280/6720	40	102	0
L1	29.7	8330/8220	60	118	0
L2	35.0	11660/10275	60	130	0
L3	39.6	13330/11330	80	142	0
L4	44.6	15550/12770	120	174	0
M3	22.1	4330/3780	32	79	2
N5	33.0	8610/8390	59	110	0
N6	37.7	10000/9500	62	148	0
N7	41.1	10278/9580	72	163	3
O4	32.9	5695/5580	48	126	0
O5	37.8	6140/5890	51	142	0
O6	42.2	6830/6670	53	151	3
R1	36.5	9440/9280	68	163	0
R2	39.6	10694/10440	74	166	0
R3	43.4	10972/10750	81	168	0
R4	47.1	11806/11580	90	173	0
R5	50.6	12306/12080	95	177	2
S2	36.1	7083/6640	54	126	0
S3	40.7	6670/6500	60	137	0
S4	44.4	7140/6890	65	143	3
T2	34.6	4611/4445	33	107	3
V2	27.7	5740/4880	40	75	3
W2	30.0	7490/7165	56	98	2
X1	45.7				
X2	53.2	7620/7220	52	172	3
Y2	53.9	11130/10750	65	225	2
Z1	45.5	7360/7150	25	158	0
Z2	52.0	9120/8760	79	180	3

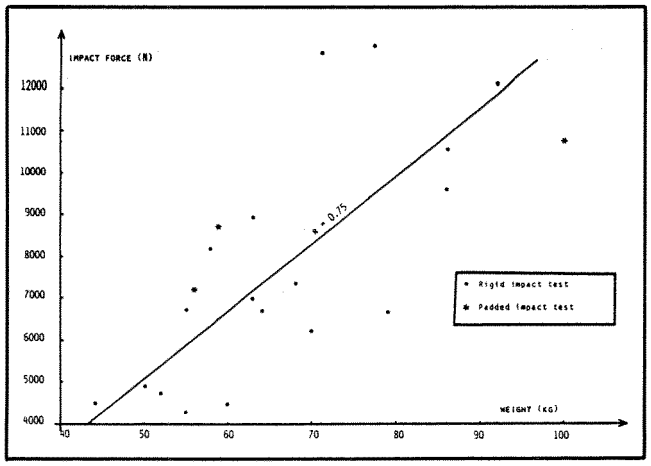


Figure 2. Cadaver weight versus 3 ms injury producing impact force.

thropometric parameters are correlated with bone sizes: taller and stronger persons have bigger bones, and the correlation found between impact force and height and weight seems to indicate a possible correlation between impact force and pelvic bone dimensions.

Figure 2 gives the value of 3 ms fracture producing impact force.

The corpulence of the subjects can be evaluated by the use of the Livi index which is defined by:

$$\text{Li} = 10\,\frac{\sqrt[3]{\text{Weight}}}{\text{Height}}$$

with weight in kg and height in m.

Based on statistical data the corpulence is defined as follows:

$\text{Li} \leq 22$: the subject is very thin,
$22 < \text{Li} \leq 23$: the subject is thin
$23 < \text{Li} \leq 24$: the subject is normal
$24 < \text{Li} \leq 25$: the subject is stout
$\text{Li} > 25$: the subject is obese.

The values of Li are listed in Table 4.

These values can be used to correct the values of weight of cadavers. The proposed correction is:

$$W_c = W_a\,\frac{23.5}{\text{Li}}$$

in which W_c is the corrected weight, W_a is the actual weight, Li is the actual value of the Livi index. The coefficient 23.5 is the value of Livi index for a normal person.

The values of weight corrected according to Livi index values are also listed in Table 4.

If we draw the relationship between the 3 ms impact force of fracture producing tests, and the corrected weight we find a better linear correlation than with actual weight values, as indicated on Figure 4.

The correlation coefficient is .89 instead of .75 on Figure 3.

This better correlation confirms that the pelvic tolerance depends on the bone geometry which is linked to the anthropometry.

The value of impact force as a function of weight is given by the formula: impact force = 193.85 weight − 4710.6.

Table 4.

Cadaver	Sex	Age	Height cm	Weight kg	Livi Index	Corrected Weight kg
A	F	70	167	58	22.9	59.5
B	F	84	154	70	26.4	62.3
C	M	69	173	78	24.3	75.4
D	F	63	160	52	23.0	53.0
F	F	59	152	55	24.7	52.3
H	M	69	175	86	24.9	81.0
I	M	65	181	63	21.7	68.2
J	M	75	177	63	22.2	66.7
K	M	75	171	55	21.9	59.0
L	M	71	175	85	25.1	79.6
M	M	68	165	62	24.0	60.7
N	M	54	184	86	24.0	84.2
O	M	70	160	79	26.8	69.5
R	M	80	180	82	25.1	86.1
S	M	79	164	64	24.4	61.6
T	F	79	144	44	23.7	43.6
V	M	61	162	50	22.7	51.8
W	M	85	170	68	24.0	66.6
X	F	54	162	56	23.6	55.8
Y	M	74	175	100	26.5	88.6
Z	M	67	167	58	23.2	58.8

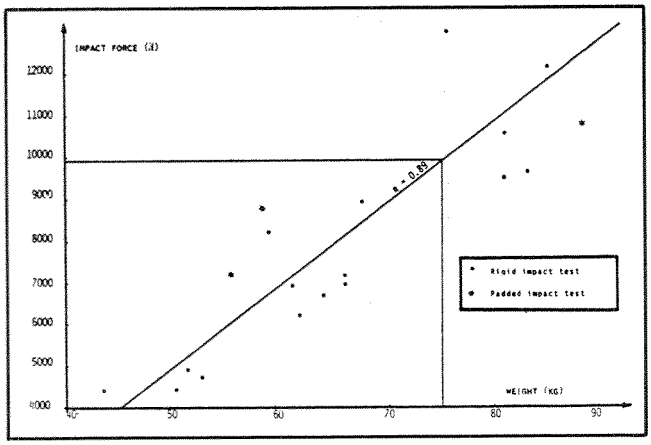


Figure 3. Corrected cadaver weight versus 3 ms injury producing impact force.

The value of impact force calculated for a weight of 75 kg, which is the weight of the 50th percentile male, is 9830 N, which is higher than the mean value for the cadavers used in this study.

During the test we recorded also pelvic acceleration; the values of 3 ms pelvic acceleration are listed in Table 2. All the values recorded are low and much under the proposed tolerance of 100 g's (7). This is probably due to the test methodology: in the impactor test only the pelvis is impacted and no other part of the body is restrained, whereas in drop tests and in sled or car tests, several areas of the body are involved by the impact.

The value of impact speed necessary to produce fractures is in the same order of magnitude as the door velocity change in car-to-car tests in which pelvic fractures occur (8). In these tests, the impact speed producing pelvic injuries varies from 22 km/h to 50 km/h.

Nineteen cadavers sustained following impacts at increasing speed, until five of them got a pelvic fracture at the first impact. Comparison of results shows that several following tests at increasing speed do not change the capability of the cadaver to sustain impacts: the traces of recorded parameters are not changed after the first impact. The value of impact force always increases until the fracture occurs, and, in fact, the value of fracture impact force was lower for cadavers which sustained only one impact than for cadavers which got a pelvic fracture after several tests.

PADDED IMPACTOR TESTS

Five tests with a padded impactor were performed on three cadavers. For these tests the impactor extremity was covered by a polyurethane foam parallelepipedic block (14.5 cm thick, 24.7 cm long, 14.5 cm wide, density 130 kg/m^3). These blocks were developed by APR as paddings for side impact protection. Two of them sustained an AIS 3 pelvic fracture after the second test, whereas the third one sustained only one test which produces an AIS 2 injury. The impact force values recorded on the impactor were in the same order of magnitude as those recorded during rigid impactor test. But the impactor speed necessary to produce pelvic fracture is undoubtedly increased by the padding; all the cadavers in padding tests sustained more than 52 km/h whereas the average value of impact speed in rigid impactor tests in which the injuries occurred in 37.1 km/h. These results are summarized in Table 5.

Table 5.

	Rigid	Padded	Gain
Average impact speed (km/h)	37.1	52.6	40%

PELVIC BONE CHARACTERISTICS

For 10 of the 22 cadavers used in impactor tests, we have determined the value of parameters related to the bone structure. For this we have cut a slice of the 2 rami of half a pelvis. We took macro pictures of these bone slices and from the scaled pictures we determined the total and cortical bone sections and the inertia momentum of these sections.

This was made with a computer which was used to digitize the outlines of the section and to make the calculations. The results of these parameters are included in Table 6.

The pubic rami are mainly involved in a bending process during a lateral impact; the stress at the fracture is defined by:

$$\sigma = \frac{P.L.Y}{Ix}$$

in which P is the force applied to the ramus, L the length of the ramus, Y the distance between the center of mass and the external surface of the ramus, and Ix the inertia momentum of the cortical area. As P is proportional to the impactor force and the variation of L is small the stress and the fracture could be written:

$$\sigma = KF \frac{Y}{Ix}$$

and then it would exist a linear relationship between F and $\frac{Y}{Ix}$. This relationship is drawn on Figure 4 which shows a good correlation.

However the values of geometrical parameters of the iliopubic ramus of the 50th percentile male have to be known to determine the human tolerance of this percentile. The geometry of human pelvis have been measured recently (9). The specific points for which coordinates

Table 6.

TBF	Ramus	S_t mm2	S_c mm2	I_x mm4	I_y mm4	Ymini mm	I_x Ymini mm3
C	ilio	311.5	98.6	3349.8	4946.7	8.41	398
	ischio	281	85.3	1417.6	7175.7	5.64	251
H	ilio	250.2	86	2145.4	3193.3	7.32	293
	ischio	136.4	47.6	417.7	1713.4	4.30	87
K	ilio	217.5	66.7	1306.7	3048.9	5.65	231
	ischio	160.1	42.6	359.8	2615.5	3.58	100
N	ilio	256.5	96.7	2286.2	4496.2	7.82	292
	ischio	202.4	65.2	564.8	1170.6	5.59	101
O	ilio	159.3	53.3	1199.8	1530.4	6.32	190
	ischio	112.3	32.4	248.2	1013.3	3.44	72
S	ilio	265.8	66	1748.2	3505.4	8.32	210
	ischio	165.6	43.3	687.5	1466.03	5.66	121
T	ilio	139.9	45.5	672.1	1105.3	5.91	115
	ischio	100.2	32.7	193.2	1093.4	3.20	60
X	ilio	178.4	61.7	1166.9	1722.3	5.91	204
	ischio	148.7	43.4	381.8	1856.7	3.32	115
Y	ilio	248.4	94.5	2450.4	4284.8	7.93	309
	ischio	137.1	49.7	600	1288.1	5.66	106
Z	ilio	225.9	67.3	1790.5	3006.1	6.86	261
	ischio	167.3	44.9	761.6	2382.3	4.82	159

were measured were on the exterior surface and thus it is not possible to determine the inertia momentum of the ramus section but by comparing the external dimensions, the inertia momentum of the iliopubic ramus cross section can be evaluated. The found value is Ix = 2300 mm^4 and the distance between the center of mass and the external surface y = 7,8 mm, for the 50th percentile. The corresponding value of Ix/y would be 295 mm^3, which corresponds to approximately 10 kN for the 3 ms impact force.

PROPOSED PROTECTION CRITERION

On the basis of the test results described behind the tolerance for a cadaver weighing 75 kg would be about 10 KN 3 ms impact force. This value would be the base for a protection criterion applied to a 50th percentile dummy. The use of such a protection criterion implies that the side impact dummies are able to be fitted with a pelvic lateral force transducer. At the present time only one side impact dummy type, manufactured by the MIRA, is fitted with pelvic force transducers.

This pelvis is equipped with 3 force transducers needing 5 measurement channels and the use of this dummy in several test environments (car-to-car tests, sled tests, impactor tests) have shown the feasibility of the measurement of pelvic lateral force in side impact; but as most of the injuries are located on the pubic rami it seems possible to simplify the force measurement device, and to use only one force transducer located in the anterior part of the pelvis.

CONCLUSIONS

Analysis of these test results allows to conclude as follows:

—impactor tests reproduced realistic pelvic injuries at realistic impact speed
—these injuries are mainly impacted side ischio and ilio-pubic rami fractures
—the impact force seems more correlated to injury than other parameters
—the value of the tolerable impact force varies greatly with anthropometry
—there is a correlation between the geometry of the ischio pubic ramus cross section and the tolerable impact force
—the use of a padding can protect efficiently by increasing the acceptable impact speed. A gain of 40% has been found
—the value of the tolerance is close to 10 KN of 3 ms impact force for the 50th percentile male subjects
—a protection criterion for pelvis based on the 10 KN tolerance could be used on a dummy fitted with a pelvic lateral force transducer.

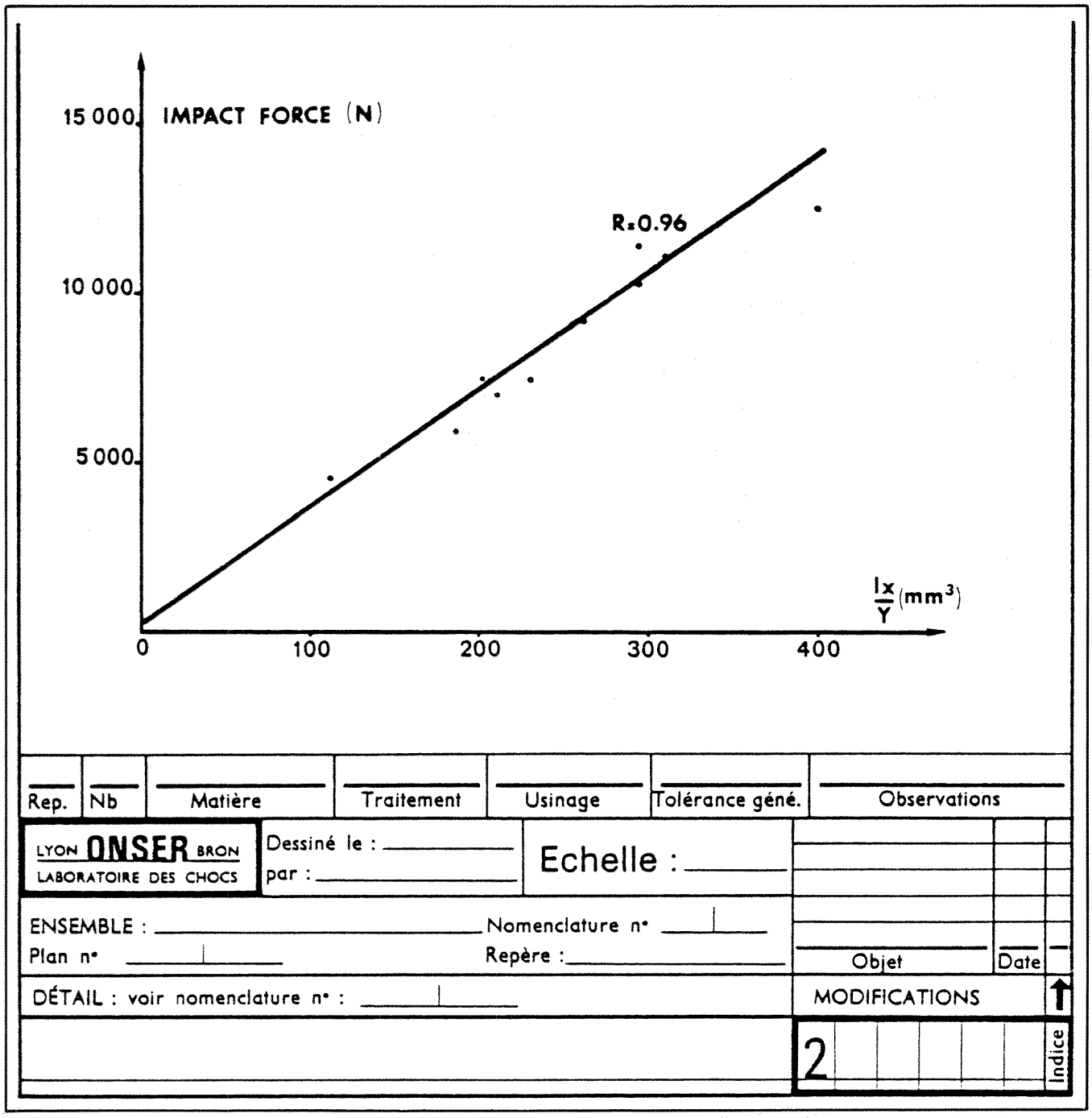


Figure 4. Injury producing impact force versus Ix/y of the ilio-pubic ramus.

REFERENCES

1. Davis, S., Ragland, C. Development of a deformable side impact moving barrier 8th International Conference on ESV, Wolfsburg 1980.
2. EEVC WG7 report-structures. Improved side impact Protection in Europe. 9th ESV Conference Kyoto—Nov. 1982.
3. Cesari, D., Ramet, M., Clair, P. Y. Evaluation of pelvic fracture tolerance in side impact 24th Stapp Car Crash conf., 1980.
4. Dejeammes, N. Fractures du bassin au cours des chocs latéraux automobiles. Thèse LYON 1978.
5. Creyssel, J., Schnepp, J. Fractures tanscotyloïdiennes du bassin, MASSON Ed, 1961.
6. Harris, J. The design and use of the TRRL side impact dummy 20th Stapp Car Crash conf. Oct. 18–20, 1976, 77–106.

angular velocities of 32 rad/s. However, Ommaya claims that angular acceleration greater than 1,800 rad/s^2 and change in angular velocity above 60–70 rad/s will result in cerebral concussion and Löwenhielm suggests tolerance levels of 4,500 rad/s^2 and 50–70 rad/s for bridging vein rupture. Hypotheses put forth to explain the mechanical reactions of various parts of the brain have been examined in physical and mathematical models, but so far authenticated explanations to the mechanisms of injury have been offered for just a few, albeit common, injury types. The mechanisms of concussion has, for example, not been possible to explain, probably due to the fact that the geometry in the vicinity of the brain stem is particularly complex. It is a specific purpose of this paper to shed some light on the motion of the central parts of the brain under rotational acceleration.

A thorough understanding of brain injury can of course not be obtained without studies on the cellular level. Only by piecing together information from different kinds of research will it be possible to gain an insight into the relations between outer load, inner mechanical events and cellular damage.

ASSESSMENT OF MATERIAL PROPERTIES

To enable studies of the influence of anatomical structures during linear and angular motions it appeared advantageous to have a model material which was transparent and in which the material properties could easily be changed within certain limits. After a series of tests it was found that a silicone gel (Dow Corning dielectric gel Q3 6527) best fitted the requirements. The gel is produced by mixing two components and cures in about 24 hours at room temperature. By varying the proportions of the two components the material properties change within certain limits.

A series of cylindrical vessels with tight fitting lids were made of acrylic plastic in such a way that they could easily be fastened on a rotor. The radius of the vessel, 95 millimetres, was chosen to be not too far from that of the skull in different planes. The height of the vessel was 80 or 120 millimetres.

For the assessment of the material properties the two components of the gel were mixed and poured into the vessel to cure at room temperature. A few hours before the curing was completed photographic targets—consisting of confetti-like pieces of black paper—were carefully placed in a straight line on the surface of the gel. When cured, the gel sticks to the sides and the bottom of the vessel. The distance from the surface to the bottom—90 millimetres—was chosen big enough to ensure that the influence from the bottom on the displacement of the targets under angular acceleration of the vessel was negligible. In order to prevent the gel from getting in contact with the lid during rotation the vessel was filled up with water and closed in a careful way so as to avoid having air bubbles trapped under the lid.

The rotor used in these experiments consisted of a circular wooden table fixed to a hub and brake drum taken from the front wheel of a motor car. The brake drum was connected to an electric motor by a belt and the brake could be actuated by a pneumatic cylinder. Accelerometers were fitted under the wooden table and via a slip-ring device and cables connected to amplifiers, the signals were recorded on tape. The vessel could be rotated at a pre-chosen velocity and stopped by applying the brake. The deceleration pulse used was a ramp function which from the peak rapidly dropped to zero. The film from a high-speed camera operating at 500 f/s and placed vertically above the center of the vessel was analyzed with respect to the tangential displacement of the targets relative to the surrounding vessel. The set-up is shown in Figure 1.

In a previous study by Ljung (7) mathematical models were developed for a Kelvin-Voigt viscoelastic material contained in cylindrical and spherical rigid shells subjected to sudden rotational motion. The two material parameters of a Kelvin-Voigt material are in such cases shear modulus and kinematic viscosity. In order to determine those parameters for brain tissue, experiments were performed using brain matter from human cadavers. The temporal lobe was inserted in a cylinder which was then subjected to an angular acceleration of a magnitude which ascertained that the experiment was realistically simulating an injurious situation. The two material parameters of the mathematical model were then chosen so as to minimize the model and experiment displacement response differences in a least squares sense.

In the present investigation the above procedure has been repeated in the opposite direction. Given the material properties of brain matter (as expressed by shear modulus

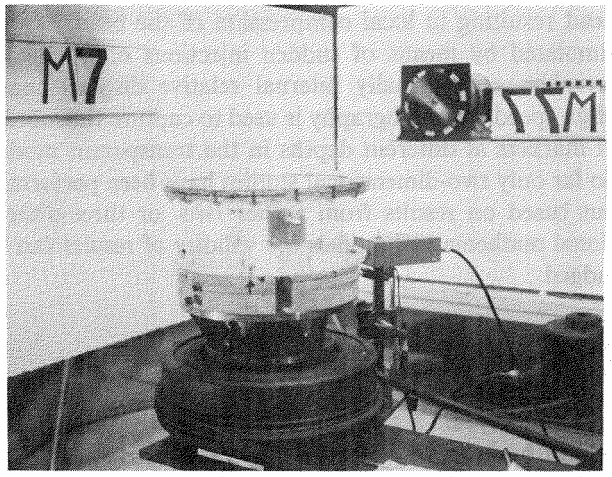


Figure 1. The cylindrical vessel containing silicone gel and water fitted on the rotor for the assessment of the material properties of the gel.

7. Joint biomechanical research project KOB. Unfall-und Sicherheitsforschung Strassenverkehr. N° 34, BAST 1982.
8. Cesari, D., Ramet, M., Herry-Martin, D. Injury mechanism in side impact. 22nd Stapp Car Crash conf. Oct. 24–26, 1978, 429–448.
9. Reynolds, H. M., Snow, C. C., Young, J. W. Spatial Geometry of the Human Pelvis. Unpublished.

Intracranial Deformation Patterns Due to Impulsive Loading—A Model Study

B. ALDMAN
C. LJUNG
L. THORNGREN
Department of Traffic Safety, Chalmers University of Technology, Göteborg, Swedish National Institute for Testing, Borås, Sweden

ABSTRACT

Presently used head injury criteria have lately been questioned for several reasons, and there is much evidence to show that a deeper understanding of the injury-producing mechanisms is needed. It is discussed what kinds of research are needed, and a specific model study is described. The model is intended to provide a better understanding of the skull-brain system when subjected to different kinds of trauma, thus facilitating the planning of research specifically aimed at producing better tolerance criteria.

A series of progressively more refined models of the skull-brain system has been used to qualitatively study the effect of different head impact directions and locations. The model can be subjected to sudden linear and/or angular accelerations. Localized trauma to the head resulting in local compression of the brain can be simulated by means of sudden injections of fluid. Observables are normally internal relative displacements. High speed cinematography is used to capture the motion of markers at different depths in the transparent model. So far only two-dimensional studies have been performed but based on results from earlier two- or three-dimensional mathematical models the validity of results can be judged.

INTRODUCTION

Over the years a great number of investigations in the field of brain injury research have demonstrated the importance of sudden motions of the head. These could be caused by either direct impact to the head or by forces transmitted to the head through the neck region, but it is widely agreed that the latter situation is hardly likely to produce brain injury before extensive injury to the neck occurs. At direct impact to the head the brain tissue is obviously sustaining a multitude of mechanical excitation including local compression of brain matter due to the deformation of the skull bone at the impact site, pressure waves travelling through the brain and deformations of the brain inertially produced through the acceleration of the head. It is still a topic of considerable bewilderment how brain injury, reversible or irreversible, is produced. It is indeed probable that all the above mentioned mechanisms do participate in injury production, and in order to provide a better knowledge of means to prevent injury, methods to determine the relative importance of different mechanisms are of interest. The present study on a physical model of the skull-brain system is meant to provide a better qualitative understanding of deformation pattern development in the brain. It is intended to make progressively more refined models of the skull-brain system, but so far attention has been focussed on how rotational accelerations to the head develop strains within the brain matter. It has an advantage over mathematical models of the brain in that fairly complex geometries and materials can be studied, whereas the main disadvantage is the limited number of observables in each experiment. Like in other fields of complex dynamic systems it would seem feasible to combine experimental and mathematical modelling in the future.

ROTATIONAL CEREBRAL INJURIES

As mentioned earlier it was decided to restrict attention to pure rotational motion to begin with. The ability of rotational head accelerations to produce brain injury has been demonstrated clinically by the nature of post mortem findings by, among others, Lindenberg and Freytag (1), Unterharnscheidt and Higgins (2), and Voigt et al., (3). It has also been demonstrated experimentally by, e.g., Ommaya et al. (4), Ommaya and Hirsch (5), Löwenhielm (6), Ljung (7), and Ono et al. (8). The experimental work suggests that angular accelerations can produce cerebral concussion and brain injuries if the angular velocity change exceeds a certain value. In human volunteer tests performed by Ewing et al. (9) no obvious damage occurred at angular accelerations up to 1,700 rad/s^2 resulting in

and kinematic viscosity), the correctly mixed silicone gel is sought by comparison of experiment and model displacement responses. An example of the kind of responses obtained is shown in Figure 2, where the deformation pattern of the gel is reproduced from the high-speed films.

It is true that in this way care is only taken to ensure that material properties of brain matter and silicone gel match in problems of rotational symmetry where shear modulus and kinematic viscosity suffice in describing the material. It is, however, maintained that the comparison of material properties made will give a reasonable result for the present study. The material properties of the brain under rotational motion have been studied previously by Schuck and Advani (10) and at West Virginia University (11), and in the latter report is also suggested possible substitute materials for experimental use. The determination of material properties were, however, made under sinusoidal excitation, a fact which casts doubts on the applicability of the data to transient problems. One has to bear in mind that if a simple material model is employed, its field of application does not extend far away from the circumstances under which it was established.

PROCEDURE

The deformation of the gel at angular deceleration was studied by recording the displacement of strategically arranged photographic targets by high-speed cinematography. The targets were not placed on top of the gel but in the substance itself at approximately the same distance from both horizontal surfaces. They were placed in a pattern which was thought to give the best information about the deformation of the simulated brain substance in each test.

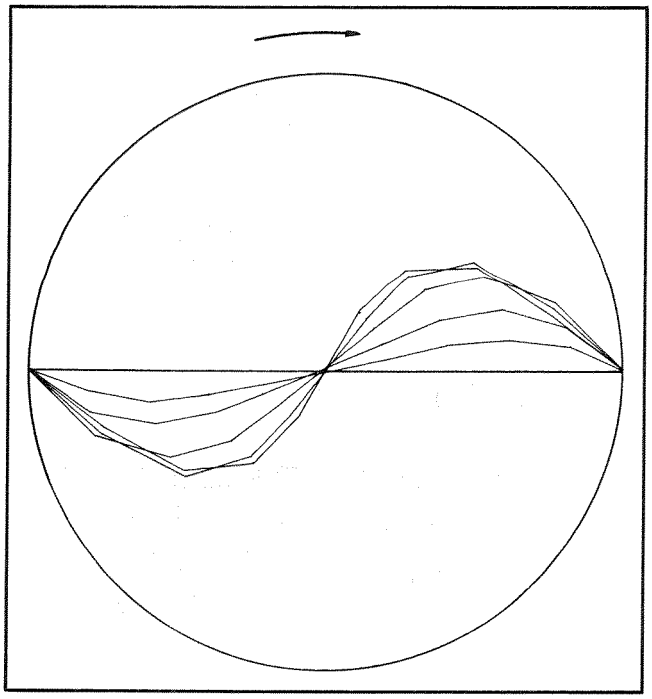


Figure 2. The initially straight line across the cylindrical model is deformed in several stages as a result of the sudden rotation of the cylinder in the direction of the arrow.

For practical purposes it seemed better to decelerate the model from a preset angular velocity by actuating the brake rather than to accelerate it to the desired velocity. The rotation about the centre of the cylindrical vessel in these tests would roughly represent rotation about the centre of gravity of the head in the projections chosen. Two different velocities were chosen for these experiments: 30 rad/s and 60 rad/s. Two pressure levels, 3 and 5 bar, in the pneumatic cylinder resulted in approximately the following peak values of deceleration at 30 rad/s: 1,500 rad/s^2 and 2,600 rad/s^2 and at 60 rad/s: 2,200 rad/s^2 and 4,700 rad/s^2. These values were used throughout these tests since they range from well below and up to what has been suggested as injury producing levels.

In a previous investigation of oblique impacts of a dummy head wearing different types of approved crash helmets by Aldman et al. (12) peak angular accelerations ranging from 4,500 to 14,500 rad/s^2 and peak angular velocities from 20 to 55 rad/s were recorded during the impact sequence in drop tests. The vertical velocity component in these tests was 5.18 m/s (drop height 1.37 m), the horizontal velocity component 8.33 m/s (30 km/h) and the helmeted dummy head impacted different types of simulated road surfaces. In these tests the peak linear accelerations ranged from 90 to 135 g's and peak angular and linear accelerations occurred simultaneously.

It would seem therefore that the angular accelerations used in these experiments are not unrealistically high but could occur in many accident situations.

THE EVOLUTION OF THE MODEL

It was decided early in the planning of these experiments that one essential feature of the series should be a step-wise refinement of the model, such that it would always be possible to distinguish the contribution of the latest model change. For the same reason it is then of interest to briefly relate the history of the model.

A cylindrical vessel like the one used for the assessment of material properties was divided in two halves by rigidly fitting a plate of acrylic plastic across the center. Each half cylinder would then roughly resemble a lateral projection of a middle portion of the skull where the flat plate represented a straight approximation of the skull base and the tentorium. The resulting pattern of deformation is shown in Figure 3. The displacement now takes place round a new centre situated approximately half way between the cylinder wall and the newly inserted plane wall. The extent to which the gel is sheared can be judged from the local slope of the lines as compared to their

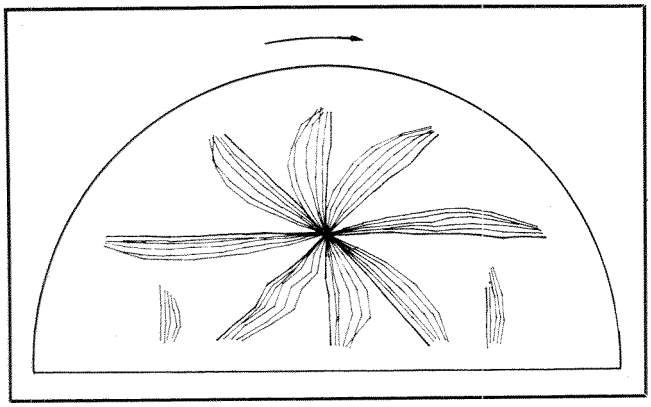


Figure 3. Resulting deformation pattern after insertion of a plane wall roughly simulating the skull base and the tentorium.

original position. The shear deformation is obviously most pronounced along the symmetry line of the half cylinder.

In one of the two half cylinders a shorter plate was fitted to the concave wall at approximately right angles to the longer plate. This new plate was intended as a simulation of the falx cerebri in a frontal projection of the skull. The two quadrants joined in their central parts could then approximately represent cross sections of the two cerebral hemispheres and the mid brain. The resulting pattern of deformation is shown in Figure 4. This time motion occurs round two distinct centres, and the motion will be directed in opposite directions each side of the sagittal plane. Obviously then, local strains could become very high in this region, but the number of markers is not big enough to get a detailed picture.

It would also be of interest to simulate displacements in the brain matter in a horizontal plane (x-y). In order to do so a rigid plastic mould and three soft and transparent vinyl bags were made to fit the base of the skull. The rigid mould was secured inside a cylindrial acrylic vessel by means of a rigid polyurethane foam. The three soft vinyl bags were placed inside the rigid mould. In the inner bag a transparent tentorium and parts of the falx cerebri were welded in position. It was then filled with silicone gel which was left to cure when photographic targets had been placed in the cerebellar as well as in the cerebral parts. These were in both of these structures placed in a middle plane which means at two different levels. The spaces between the rigid mould and the vinyl bags were then filled with water, air bubbles removed and the acrylic lid fitted on top of the cylindrical vessel.

In this horizontal projection of the brain deformation of the model brain material occurred in a similar pattern (cf. Figure 5) at both levels. Thus, large displacements of the targets were seen in the forward half and the rearmost part of the mould, while little or no displacement was recorded in the brain stem area. It should be pointed out, however, that the simulated parts of the falx in this experiment were not fixed to the mould at their upper ends but could move a little with the vinyl bag containing the gel.

With the exception of the last simulation of deformations occurring in a horizontal plane, all studies performed have been two-dimensional in the following sense. Motion is studied in one plane only and the distance of this plane to the bottom and lid of the container was big enough to make sure that they did not disturb the pattern.

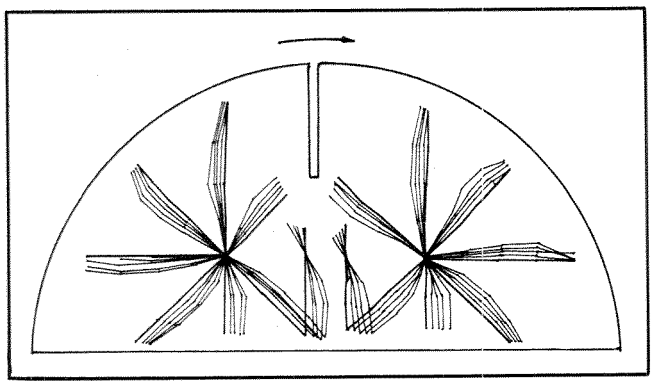


Figure 4. Deformation pattern in a model roughly simulating a frontal section through the skull. The projection at right angles to the cylindrical wall represents the falx.

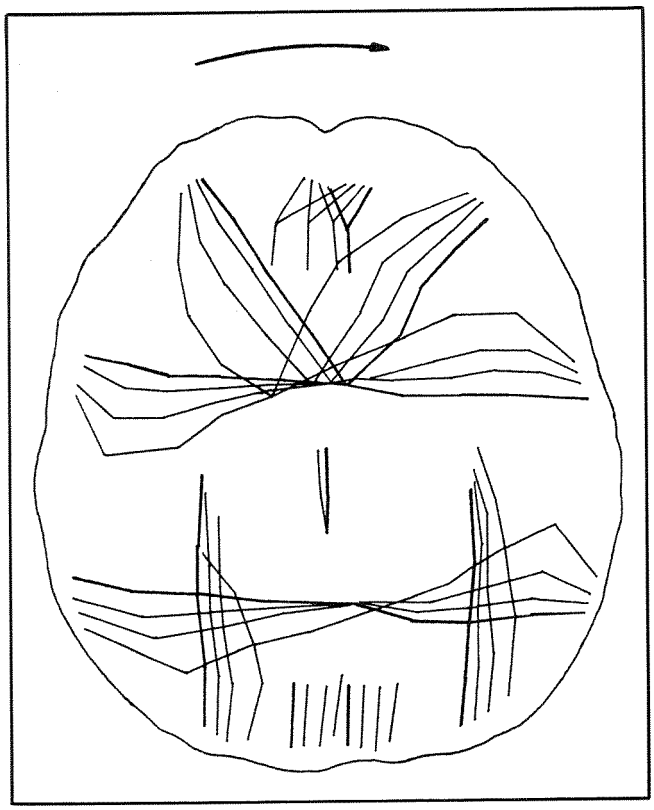


Figure 5. Deformation pattern in a horizontal projection of the head. The back of the head is pointing downwards in the figure which means that the foramen magnum is situated very close to the apparent centre of deformation at this level.

Mathematical simulations of this problem have been performed previously by Ljung (9). The next section deals with a more refined, but similarly two-dimensional model of a lateral projection of the brain.

REFINED LATERAL VIEW MODEL

In this step a more elaborate system of plates was fitted in a cylindrical vessel in order to simulate a mid-sagittal section including brain, brain stem, cerebellum and upper spinal cord. The skull base and the tentorium are still represented by an approximately straight plane but with an opening simulating the tentorial opening. The geometry of the model can be seen in Figure 6 which also shows the resulting deformation pattern in one of the last experiments. Earlier experiments have been presented in greater detail by Aldman et al. (13) and will be only briefly mentioned here.

A comparison has been made between the deformation patterns if the gel sticks to the side walls of the container or if the outer surface of the gel can move freely relative to the wall. In the human skull the brain is anchored more firmly to the dura with age, a fact also reflected in the kind of injury produced (Voigt et al. (3)). The only significant change in pattern between the two experiments was, however, that the direction of rotation of the gel below the tentorium was reversed. This is probably a result of little consequence, since the deformations are quite small in this region anyway. The overall pattern of deformation is otherwise the same although it seems as if the more relaxed conditions in the latter case permit larger displacements to occur. Throughout the series of experiments with this model high values of shear can be detected in the vicinity of the tentorial opening.

In the last experiments the gel was again allowed to stick to the walls and an attempt was made to simulate the influence of the ventricles, since it was anticipated that the reduced shear stiffness of the ventricular fluid could permit greater deformations to develop especially in the vicinity of the tentorial opening. For this purpose a pocket in the gel, approximately 10 mm high, 40 mm long and 40 mm deep, was filled with liquid paraffin. The pocket was terminated above and below with a gel layer so that the paraffin was completely enclosed in gel. Thus, no substantial volume changes were to be expected. The deformations in the model were recorded in a plane situated approximately at the middle of the pocket, far enough from its ends to ensure that the idea of looking at a two-dimensional problem was not disturbed.

In reality the geometry of the ventricles is very complicated and far from two-dimensional, but it is still believed that the essence of the ventricles is maintained in this crude model. The resulting deformation pattern is shown in Figure 6. It is interesting to note the change of shape in the fluid-filled pocket. This means that although

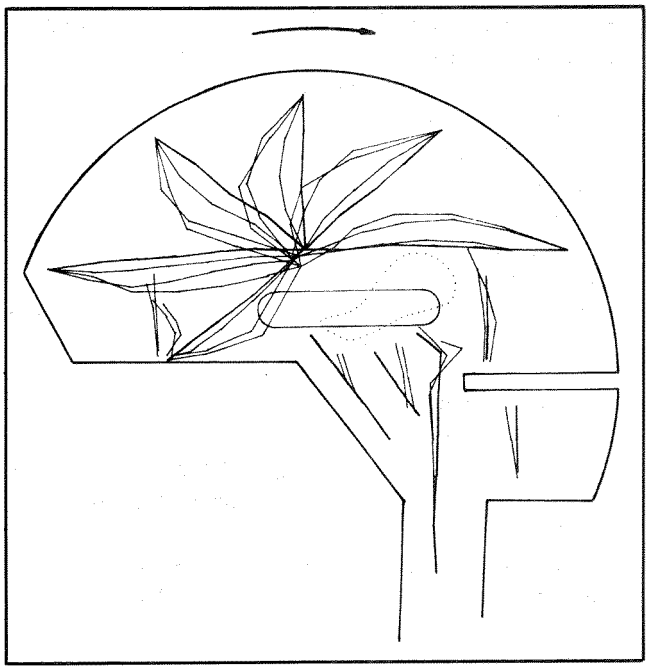


Figure 6. Pattern of deformation in a lateral view model incorporating simulated ventricles. The dotted shape represents the ventricles at maximum deformation.

the overall deformations, as measured by the markers, is not very much changed in relation to the earlier experiments, there may still be significant local changes in the shear strains.

CONCLUDING REMARKS

There is not any dramatic change in the deformation pattern present in the series of experiments with the lateral view model. This gives rise to several conclusions regarding future research.

First of all, the overall pattern of deformation is quite well described by the model at its present stage of development. This means that it might be feasible to try to formulate mathematical models for small parts of the brain, where the overall behaviour of the model coincides with the results found here.

Secondly, the methods for analysis have to be refined for future experimental work with this model. Markers must be placed in such a way as to permit a direct evaluation in terms of local shear strain for example. Once this is achieved further studies in the influence of material inhomogeneities can be made, e.g., studies using simulated brain matter of different stiffness at different sites. It would also be interesting to see the effect of allowing some motion of the upper spinal cord in the direction of the spine.

A more rugged aluminium model is being constructed presently. This model has the same principal features as

the lateral view model and is intended to be used in experiments where translational accelerations are also present. It is obviously of great interest to see if the deformations will be changed to any significance when translational accelerations are introduced. It is also intended to make pressure measurements in the gel in these experiments.

Finally, in order to be able to express the results in quantitative form the two-dimensional approach has to be abandoned and methods for building and studying three-dimensional models are being investigated.

REFERENCES

1. Lindenberg, R. and Freytag, E. (1960). The mechanisms of cerebral contusions. Arch. Path. 69, 440-469.
2. Unterharnsheidt, F. and Higgins, L. S. (1969). Traumatic lesions of brain and spinal cord due to non-deforming angular acceleration of the head. Tex. Rep. Biol. Med. 27, 127-166.
3. Voigt, G. E., Löwenhielm, C. G. P. and Ljung, C. B. A. (1977). Rotational Cerebral Injuries near the Superior Margin of the Brain. Acta neuropath. (Berl.) 39, 201-209.
4. Ommaya, A. K., Yarnell, P., Hirsch, A. E. and Harris, E. H. (1967). Scaling of Experimental Data on Cerebral Concussions in Sub-Human Primates to Concussion Threshold for Man. Proceedings of 11th Stapp Car Crash Conference Oct. 10-11, 1967. SAE, N.Y. USA.
5. Ommaya, A. K. and Hirsch, A. E. (1971). Tolerances for Cerebral Concussion from Head Impact and Whiplash in Primates. Journal of Biomechanics, 4, 13, 1971.
6. Löwenhielm, P. (1975). Brain Susceptibility to Velocity Changes. Relative and absolute limits for brain tissue tolerance to trauma and their relation to actual traumatic situations. Proceedings of an International Interdisciplinary Symposium on Traffic Speed and Casualties held at Gl Avernaes, Funen, April 22-24, 1974, Denmark.
7. Ljung, C. (1975). A Model for Brain Deformation due to Rotation of the Skull. J. Biomechanics, 1975, Vol 8, pp 263-274.
8. Ono, K., Kikuchi, A., Nakamura, M., Kobayashi, H. and Nakamura, N. (1980). Human head tolerance to sagittal impact reliable estimation deduced from experimental head injury using subhuman primates and human cadaver skulls. 24th Stapp Car Crash Conf. Troy, Mich., Oct. 1980, 101-160.
9. Ewing, C. L., Thomas, D. J., Lustick, L., Becker, E., Willems, G. and Muzzy, W. H. (1975). The Effect of the Initial Position of the Head and Neck on the Dynamic Response of the Human Head and Neck to $-G_x$ Impact Acceleration. Proceedings of the 19th Stapp Car Crash Conference, November 17-19, 1975, SAE, Warrendale, USA.
10. Schuck, L. Z. and Advani, S. H. (1977). Rheological response of human brain tissue. ASME paper 72-WA/BHF-2 presented at ASME Winter Annual Meeting, 1972.
11. West Virginia University (1970). Determination of the physical properties of tissues of the human head. Report from the Biomechanics Laboratories. College of Engineering, West Virginia University, Morgantown, West Virginia.
12. Aldman, B., Lundell, B., and Thorngren, L. (1978). Oblique Impacts—A Parametric Study in Crash Helmets. Proceedings of the 3rd International IRCOBI Meeting 1978, Lyon, France.
13. Aldman, B., Thorngren, L., and Ljung, C. (1981). Patterns of deformation in brain models under rotational motion. Consensus Workshop on Head and Neck Injury Criteria, NHTSA, Washington, March 1981.

Automotive Neck Injuries

A comparative study of neck injury mechanisms in frontal collisions in the U.S. and in the Federal Republic of Germany

AYUB K. OMMAYA, M.D., S. BACKAITIS, W. FAN, and S. PARTYKA
National Highway Traffic Safety Administration

K. LANGWIEDER, Ph.D.
HUK-Verband

In an earlier report by K. Langwieder et al. we presented the results of coordinated studies on neck injuries in which it was shown that it was possible to obtain useful information by such comparative evaluation of two large scale accident files in two different countries. (1) Similar proportions of accident types and distributions of injuries to car occupants with a few differences related to data sampling techniques were found. Thus the U.S. data set (NCSS file) contained a higher proportion of uninjured people compared to the German (HUK-Verband) data set because the NCSS data are based on tow-away of at least one of the involved accident vehicles whereas the HUK data are based on the presence of at least one minor injury to accident victims. This and other differences could be controlled by techniques described in the above referenced report. In this paper we summarize our pre-

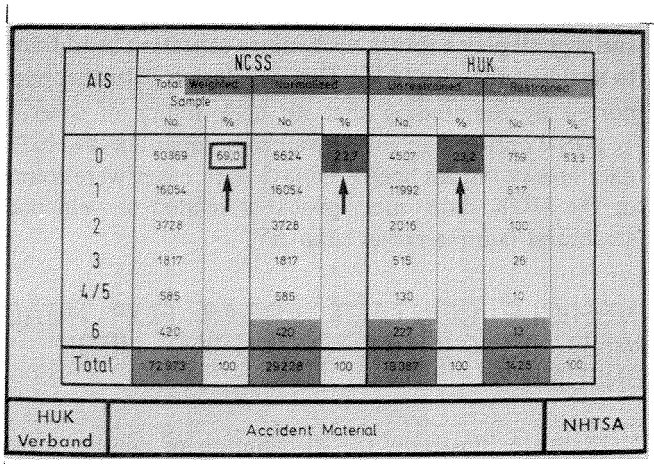


Figure 1. Accident material.

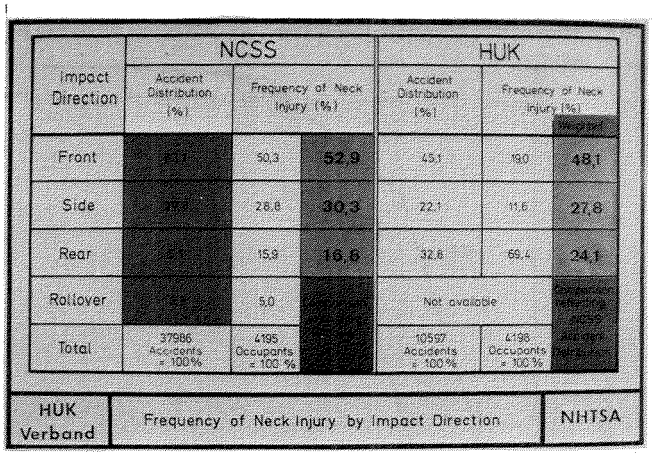


Figure 3. Frequency of neck injury by impact direction.

vious findings and present the results of that analysis combined with a review of the files of 222 cases of AIS-3 to -6 injuries which constitute all of the more severe neck injuries in the N.C.S.S. files with adequate medical data. Although the vast majority of automotive neck injuries are of the minor cervical strain, "whiplash" or hyper-extension/ flexion variety, the more disabling minority of cases produce devastating consequences in terms of human, social and economic costs. In recent studies by Smart and Sanders it was estimated that 5500 cases of AIS-5/6 occurred in 1974 of which 3000 died at the accident site due to the neck injuries and 2500 were admitted to hospitals. Of these only 133 made functional recoveries, 1091 remained quadriplegic and the remainder died. Since automotive neck injuries constitute over 50% of all neck injuries the mounting annual costs are highly significant. (2) It should also be emphasized that even the approximately 95% of all neck injury cases at the AIS-1 and -2 levels often entail loss of work and medical care costs which are out of proportion to the seeming "lesser" severity of these injuries.

The accident material is summarized in Figure 1 which shows a comparison of the weighted and normalized samples from the NCSS file (unrestrained) with the cases from the HUK file for varying levels of the AIS. Note that when the NCSS data are normalized by reducing the uninjured category that the percentages of injured and uninjured necks at the various AIS levels are fairly comparable. The numbers of neck injuries in the two data sets related to different impact directions are shown in Figure 2. Note the greater number of more severe neck injuries in the NCSS file data with more comparable numbers at AIS-1 to -3 levels. The frequency of neck injury by impact direction distribution is more clearly seen in Figure 3. Note the clear predominance of frontal impacts with side and rear collisions following in a similar sequence in both data sets.

The severity distribution of neck injury between minor (AIS-1), moderate (AIS-2 and -3) and severe (AIS-4 to -6) is shown with reference to impact direction in Figure 4. This clearly brings out the fact that although frontal impacts produce neck injuries most frequently, AIS-1 or whiplash type injuries are more often due to rear end collisions.

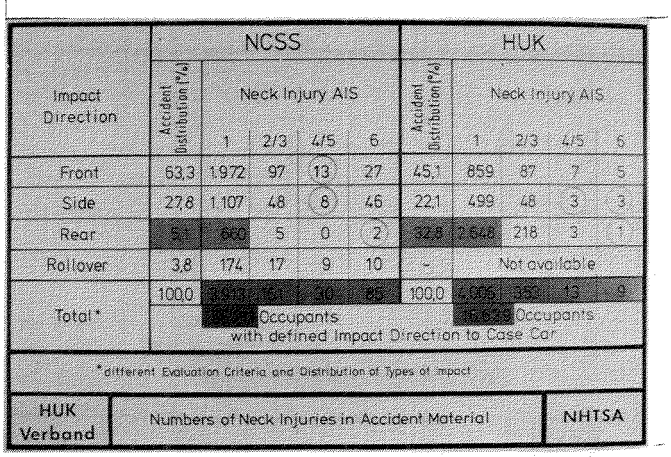


Figure 2. Numbers of neck injuries in accident material.

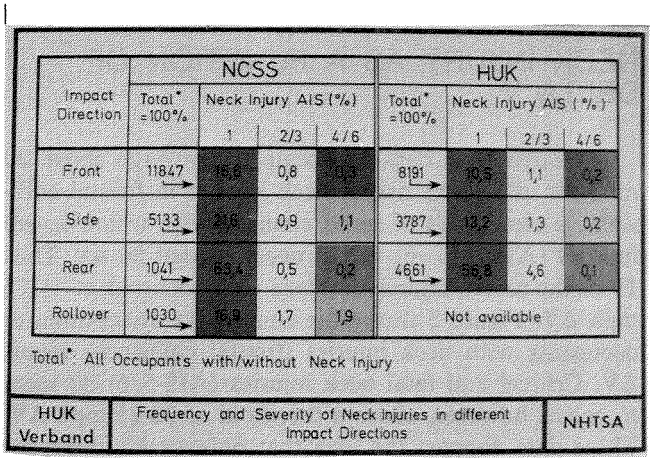


Figure 4. Frequency and severity of neck injuries in different impact directions.

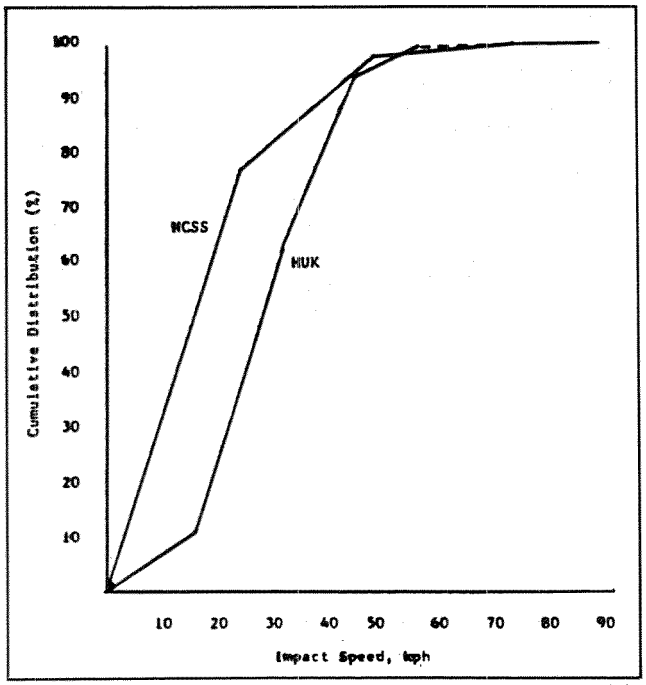


Figure 5. Cumulative distribution of occupants involved in frontal collisions versus change in impact speed (ΔV).

EFFECT OF SEX AND AGE ON NECK INJURY

This study confirmed previous observations by Langwieder on HUK data that females are at a higher risk for AIS-1 and -2 neck injuries (but at equal risk with men for AIS-3 and above injuries) and that children up to 10 years old have about 1/6 the risk of neck injuries as compared to adults. This finding was also supported by the observation made in both NCSS and HUK data in this study that shorter people (below 152 cm/5 ft) have a risk of neck injury about 40% less than taller occupants. Significantly higher risk also exists for occupants aged 30 + as previously also shown in HUK data. (3,4,5)

NECK INJURY AS A FUNCTION OF DELTA V

Although both data sets begin to converge above 20 mph for increasing risk of neck injuries in frontal collisions, a clear limit of speed change above which severe injuries (AIS-3 to -6) would occur cannot be set. Thus 18 of the severe injuries in these data occurred at < 15 mph ΔV. Figure 5 shows the cumulative distribution of occupants with neck injuries (frontal collisions) versus ΔV. Critical and fatal neck injuries (AIS-5/6) do seem to occur, however, above a threshold of 20-25 mph ΔV. These data support the idea that unfavorable occupant kinematics, relation of head and neck to car interior surfaces and its intrusions and the characteristic of contact surfaces all play a role in neck injury causation in addition to accident severity (ΔV). This conclusion is further supported by the finding that no neck injury of severity > AIS-3 occurred in any restrained occupant in the NCSS data at any impact speed. Only 2 such cases were found in the HUK data, most probably related to vehicular structural failures rather than ΔV.

VEHICLE CONTACT AREAS FOR HEAD AND NECK IMPACTS CAUSING NECK INJURIES

Figure 6 illustrates the distribution of contact areas versus neck injury severity for all the frontal collision cases. These include 1569 cases with known contact and injuries at all AIS levels of which 973 were related to 6 main contact areas, i.e., windshield, steering wheel, instrument panel, A-Pillar, Mirror-Sunvisor and glove compartment/hardware. Critical and fatal neck injuries were related primarily to the A-Pillar contacts.

RESTRAINT EFFECTS ON NECK INJURY OCCURRENCE

The majority (82.6%) of neck injuries to unrestrained occupants do not involve direct impact to the neck although 58.2% of these are related to *head* impacts leaving only 30.4% caused by inertial forces on the neck. Figure 7 shows the overall frequency of neck injuries related to head contacts in belted and unbelted occupants in frontal collisions. These data clearly indicate how restraints apparently reduce the frequency of head contact related neck injuries. The distribution of neck injury severity for belted occupants in both the NCSS and HUK data is shown in Figure 8. Note the absence of AIS-4 through -6 injuries in the NCSS data and only 2 injured drivers in the HUK data. The interaction between restraint systems and presence or absence of head contact in the NCSS data is shown in Figure 9. The majority (88.6%) of neck injuries

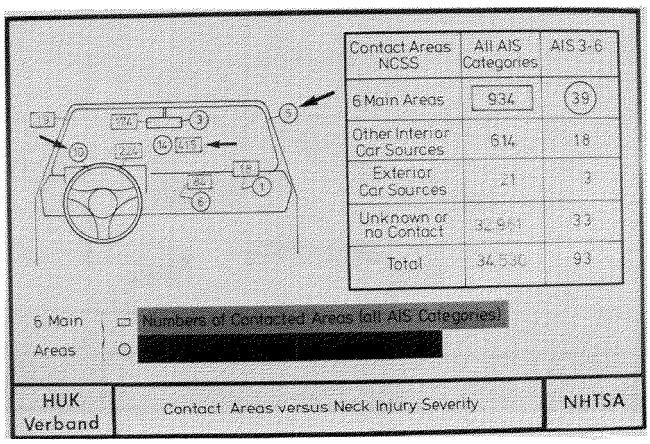


Figure 6. Contact areas versus neck injury severity.

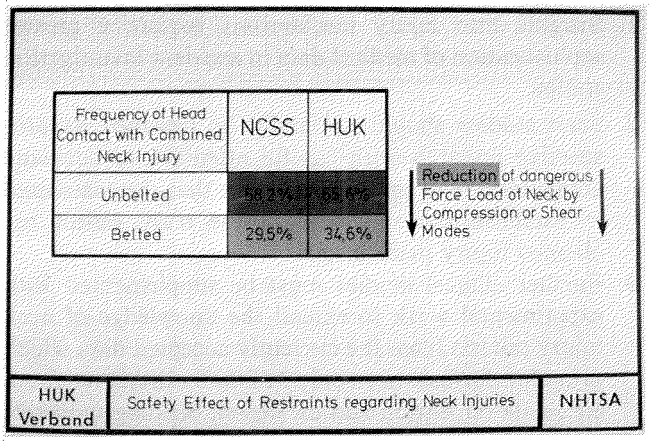


Figure 7. Safety effect of restraints regarding neck injuries.

to *unrestrained* occupants do not involve neck impacts. Of these 58.2% are produced by direct head impacts and 30.4% by inertial forces. Only 11.4% of all neck injuries occur via direct neck contact. For *restrained* occupants the rate of neck injury is reduced because of lower incidence of head impacts. However the rate of neck injury via direct neck contact is doubled and inertial force injury rate increases by 50%. However, no injuries higher than AIS-3 occurred in the restrained occupants and neck injury rates for unrestrained occupants at the AIS-2 and -3 levels are more than twice that of restrained persons. Only at the AIS-1 level do restrained occupants show a slightly larger proportion of neck injuries. These data are very similar to the HUK data shown in Figure 10. In this data set most of the serious neck injuries are combined with an independent head injury for unrestrained occupants, further supporting the conclusion that the most frequent type of severe neck injury (AIS-3 and above) for unbelted occupants consists of an initial force loading the head by contact which results in compressive and shear strains followed by severe flexion or extension of the cervical spine. This figure shows a nearly 3-fold reduction of combined head/neck injuries when they occur with

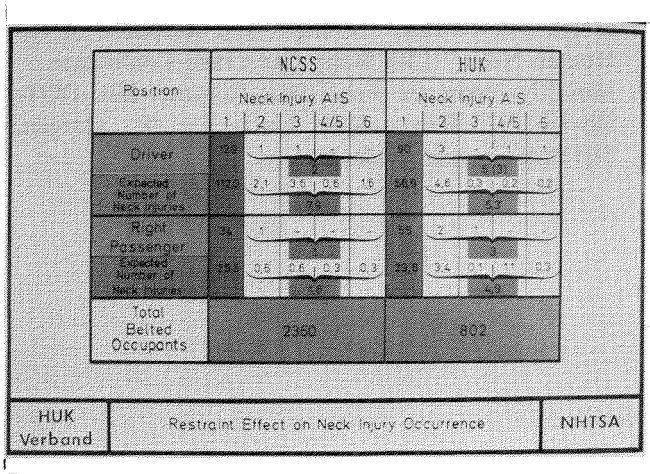


Figure 8. Restraint effect on neck injury occurrence.

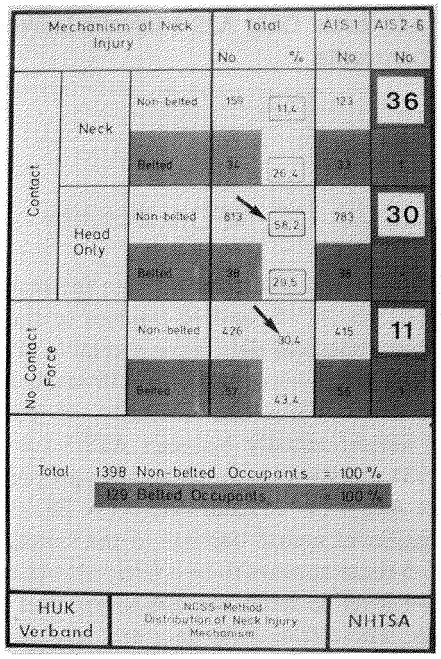


Figure 9. NCSS-Method distribution of neck injury mechanism.

concussion with or without soft tissue damage in 5.2% belted versus 16.5% unbelted occupants. This protective effect of restraints is not seen when more serious head injuries occur (2.6% versus 2.9%) most probably because of structural intrusions into the occupant compartment. In sum, both data sets show a more than 2-fold decrease of occupant injury rates at the AIS-2 and -3 levels by the use of seat belts and a significant decrease of injury at

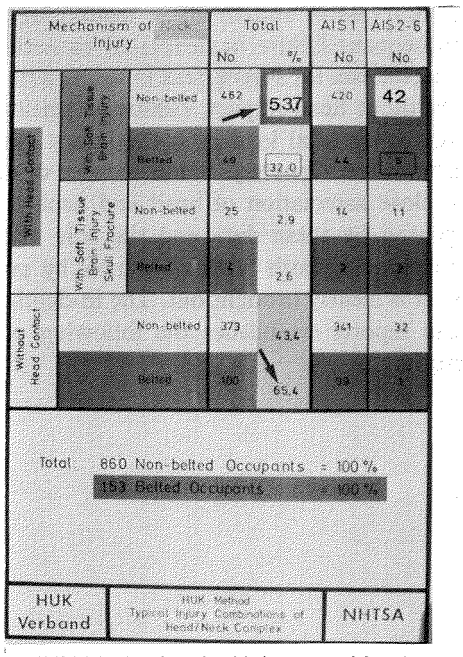


Figure 10. HUK-Method typical injury combinations of head/neck complex.

the higher AIS levels. Only AIS-1 injuries increase in the restrained occupants.

MECHANISMS OF NECK INJURY

A computer search of the NCSS data file revealed 222 cases with AIS-3, -4, -5, and -6 injuries to the neck in which adequate medical data were available. The distribution of these cases between these AIS levels is of considerable interest. Thus the majority of cases were distributed almost equally between AIS-3 (= 86) and AIS-6 (= 93) cases with a much smaller proportion falling into the AIS-4 (= 15) and AIS-5 (= 28) categories. Because significant neural damage to the spinal cord begins at AIS-5 there appears to be a fairly abrupt transition at the AIS-4 level between the less severe and the most severe cases. These transition data are very reminiscent of the findings collected by NHTSA staff member J. Marcus from two sources[6,7] which showed that if the putative levels of injurious moments (M) at the occipital condyles in flexion are listed for increasing severity of neck injury, a sharp transition is seen between AIS-2 injuries at 140 ft lb and AIS-5 injuries at 150 ft lb. This small moment increase for catastrophic neck injuries could be due to methodologic causes, but it is certainly supported by the accident date reviewed above.

Statistical study of NCSS and HUK files shows that a major cause of critical and fatal neck injuries in frontal collisions are head impacts with the interior surfaces of the vehicle. Inertial loading of the head and neck without head impact is significantly less noxious. With head impact, the compressive and/or shear loading of the neck and its subsequent failure in flexion or extension is the putative mechanism for severe neck injuries causing quadriplegia. Without head impact, flexion/extension (whiplash) caused by inertial loading is the injury mechanism observed, which, fortunately, is not a cause of major injury. The close association of head and neck injuries is well supported by these data and the role of restraint systems in reducing both types of injuries by preventing head impact is clearly brought out. The in-depth analysis of the case reports establishes the following points for further study:

1. Insights into injury mechanisms require a greater sophistication of medical data in accident investigation studies.
2. Such studies should optimally be designed as prospective research with careful attention to adequate comparability of impacts to assure that the cases used to establish the statistical profile truly reflect the claimed injury mechanisms.
3. Further clinical studies must be supplemented with experimental work to extend the knowledge of neck injury criteria from the currently accepted data which provide information on only 3 of the 9 criteria required; e.g., data on flexion and extension, bending moments and axial compression are available, but horizontal and lateral shear, torsion, lateral bending and axial-tension data are nonexistent.

The results and the conclusions of this study should not be considered definitive for neck injuries, but they do confirm the fact that neck injury characteristics in both continents are nearly identical and that similar countermeasures could produce significant injury reductions.

BIBLIOGRAPHY

1. Langwieder, K., Backaitis, S., Fan, W., Partyka, S., and Ommaya, A. K. Comparative Studies of Car Occupants in Frontal Collisions in the United States and the Federal Republic of Germany. Proc. 25th Stapp Car Crash Conference. S.A.E. 1981.
2. Smart, C. N. and Sanders, C. R., "The Costs of Motor Vehicle Related Spinal Cord Injuries." Insurance Institute for Highway Safety, Washington, D.C. 1976.
3. Langwieder, K. Dissertation. Techisches Universitatet TU Berlin 1975.
4. Langwieder, K. et al. "Kinderversicherunger in PKW." IRCOBI Proceedings. Lyon, France 1974.
5. Langwieder, K. et al. Comparisons of Passenger Injuries in Frontal Car Collisions with Dummy Loading in Equivalent Simulations. Proceedings 23rd Stapp Car Crash Conference. San Diego, Cal. 1979.
6. Mertz and Patrick. "Strength and Response of the Human Neck." 15th Stapp Car Crash Conference.
7. Monthly report for Feb. 1982. Contract No. DOT-HS-7-01792. Wayne State University (R. Morgan, NHTSA Contract Manager).

Development of Neck Injury Tolerance Criteria in Human Surrogates. I. Static Tensile Loading in the Baboon Neck: Preliminary Observations

JOHN B. LENOX, RICHARD L. STALNAKER, CURTIS D. WHITE, GARY T. MOORE, ORIN M. ANDERSON, RALPH R. SCHLEICHER, H. HERBERT PEEL, SUSAN S. MARTIN, GERALD D. DRISCOLL
Southwest Research Institute

HOWARD W. HUNTINGTON
The University of Texas Health Science Center at San Antonio

K. DEE CAREY
Southwest Foundation for Research and Education

MARK P. HAFFNER and AYUB K. OMMAYA, M.D.
National Highway Traffic Safety Administration

ABSTRACT

Currently available biomechanical data are insufficient for determining the neck loads required to produce cervical injuries in automotive accidents. The purpose of this study was to initiate a series of experiments required for identifying injury mechanisms and to develop criteria suitable for representing the spectrum of significant functional and structural neck injuries that could be sustained by car crash occupants. The first test conducted was a static neck tension test performed on an anesthetized, 12.2-kg baboon (*Papio hamadryas*). A state of muscle paralysis was maintained throughout neck loading to mimic the flaccid muscle tone present in fresh human cadavers. Tensile neck loading was increased at a rate of 20.2 N every five minutes until definitive structural failure (atlas-occipital subluxation) occurred at the 1170 N load level. Neurophysiological testing in the anesthetized animal demonstrated that cervical spinal cord function was seriously impaired at the 595 N load level, i.e., at 51 percent of the structural failure load. The potential implications of this finding are discussed, relative to the understanding of injury mechanisms. In addition, a strategy is presented for deriving functional neural tissue impairment thresholds, from fresh human cadaver data, that may apply in real accident victims.

INTRODUCTION

The primary objective of this study was the initiation of an experimental series for identification of a set of neck injury criteria suitable for representing serious neck injuries sustained by car crash occupants. Pursuing this objective meant considering the full spectrum of medically significant structural (skeletal-ligamentous) and functional neural tissue (spinal cord) injuries that could be sustained due to indirect neck loadings occurring during automotive crash events. (1-17)

Cervical spinal injuries have been studied (18-23) and some injury threshold data for static and dynamic neck loads already exist. (6,24-26) However, injury thresholds have not been experimentally established for static or dynamic head loaading that induces combined atlas-occipital tensile and shear loads and torques.

The first test of an initial static neck loading test series has been conducted in this program; specifically, a neck tension test of an anesthetized, 12.2-kg, eight-year-old female baboon (*Papio hamadryas*) is reported. A state of muscle paralysis was maintained throughout neck loading, for several reasons. First, the experiment provided a living-equivalent muscle tone state that mimicked the state of flaccid muscle tone present in fresh cadaver test subjects, in contrast to the varying muscle "tone" present either in embalmed cadavers or in cadavers that are not fresh. Second, injury thresholds derived represented worst-case, static, tensile neck loading, since the flaccid muscles could provide only minimal protection. Third, the plan was to achieve test conditions that were more reproducible than could be achieved by attempting to maintain muscle tone at levels that can only be poorly defined. Fourth, the state of flaccid muscle paralysis enhanced the physical significance of having elected to equivalently characterize neck loading by a resultant force, acting at that skull-fixed point defined by the intersection of the animal's mid-sagittal plane with the flexion-extension axis of the atlas-occipital joint, and a torque (that was essentially zero for the first test).

METHODOLOGY

Medical

Animal Care. The *Papio hamadryas* used as the experimental study model for this program was purchased from

a United States Department of Agriculture (USDA)-approved commercial animal dealer. The baboon was brought to Southwest Research Institute (SwRI) and quarantined according to established procedures for baboons. The quarantine included five weeks of strict isolation from other nonhuman primates and a specific tuberculin testing and disease monitoring regime during this period. Upon release from quarantine the baboon was maintained in an individual cage in a controlled atmosphere until used for testing. The SwRI Laboratory Animal Medicine Program and Facilities are approved by the American Association for Accreditation of Laboratory Animal Care and the USDA. Approval by these organizations is based on guidelines from the Animal Welfare Act of 1970 and the Guide for Care and Use of Laboratory Animals. In addition to these approvals all protocols involving animal care and testing are subjected to a review by the SwRI Animal Care Committee. This program was reviewed and approved by the SwRI Animal Care Committee.

Test Day Regime. On the morning of the test day, the animal was anesthetized, shaved and prepped, and a set of shape and size body measurements was recorded. Surgery was then performed to: (1) insert an endotracheal tube; (2) introduce a Millar combination blood pressure transducer and arterial blood sampling catheter into a femoral artery, placing it in the abdominal aorta at the level of the xyphoid; (3) implant right and left occipital average evoked response (AER) skull electrodes; (4) perform the minimum cutdown required to apply a Michel clip adjacent to the spinous process of the first thoracic (T1) spinal vertebra, for X ray verification reference (just prior to initiating neck loading, the T1 extender hemostat was clamped between the T1 and seventh cervical (C7) spinous processes); and (5) place an indwelling urethral catheter into the bladder.

A deep state of anesthesia was maintained throughout the test day by the veterinary anesthesiologist until death occurred. Chloralose anesthesia was utilized during loading to accentuate the far field AERs. A state of complete flaccid muscle paralysis was maintained by administering curare in divided doses prior to and throughout the loading phase. Ventilation was maintained by an abdominal respirator that was monitored and adjusted in accordance with pneumotachometer readings and arterial blood gas values.

Medical Data. Instrumentation was provided for monitoring and recording:

(1) Blood pressure (B.P.) (systolic, diastolic and mean; recorded continuously)
(2) Heart rate (H.R.) (recorded continuously)
(3) Electrocardiogram (ECG) (Lead II recorded continuously)
(4) Rectal temperature (recorded continuously)
(5) Right- or left-sided far field somatosensory and auditory AERs (implanted skull and C1 electrodes; recorded once per five-minute loading cycle midway between load increases)
(6) Ventilation rate and depth (pneumotachometer coupled to the endotracheal tube; recorded continuously)
(7) Arterial blood gases (pO_2, pCO_2 and pH measured periodically)

B.P. and H.R. were both recorded on a multichannel strip chart recorder and digitized for digital display and storage. The data stored in digital form were processed post-test to provide compact trend analysis graphs. AERs were stored on computer disks, for post-test retrieval and analysis of AER data.

Radiology. Whole body and cervical X rays were taken of the animal on test day prior to surgery and at the end of the loading phase, immediately after removal of the animal from the potted torso and head containers. In addition to repeating the standard set of pretest X rays, lateral and ventrodorsal X rays were taken of the cervical spine during reapplication of a tensile neck load estimated to be in the range of 300 N.

Post-Test Regime. Post-test, the custom-potted torso and head containers, when coupled together rigidly with linkages, provided a secure litter for transporting the neck-injured animal (without further injuring the neck) to the X ray laboratory and later to the necropsy laboratory. Following the post-test X rays, and up until one hour prior to necropsy, the test animal was kept refrigerated at 4°C. A complete necropsy was performed 36 hours post-test. The necropsy findings were thoroughly documented in writing and via medical photographs. The brain and spinal cord were then preserved in 10 percent buffered formalin for microscopic neuropathological examination.

Bioengineering

Torso and Head Constraint. Stereotaxic alignment and restraint of the head within the head container was achieved by clamping to a custom-fitted dental appliance, and butting the caudal surface of the animal's occiput and mandible up against the firm rubber grommet covering the custom-sized and shaped exit neck opening (see Figure 1). With the dental appliance in place and the mouth taped firmly shut, the occiput was pushed snuggly up against the neck hole. A four-degree-of-freedom linkage grasping the dental appliance extension pipe was then adjusted and locked to achieve maximum flexion of the head within the head container and mandibular contact with the head container, and to align the skull squarely within the head container.

Stereotaxic alignment and restraint of the torso within the torso container was achieved by using a detachable torso alignment and restraint frame. This frame had adjustable shoulder clamps for positioning and restraining the upper thorax symmetrically about the animal's mid-

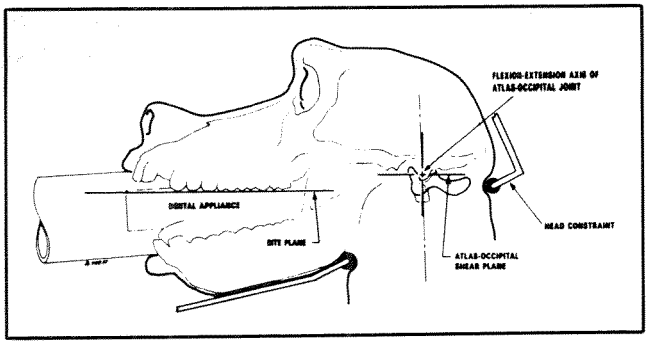


Figure 1. Head constraint, dental appliance, flexion-extension atlas-occipital axis of rotation, and definition of atlas-occipital shear plane

sagittal plane in an erect, shoulders-back, posture. In addition, this alignment-restraint frame had right and left thoracic supports, right and left pelvic/leg supports, and provisions for holding the animal in place with cephalic and caudal thoracic straps and a mid-abdominal strap. The caudal thoracic strap and the mid-abdominal strap were fastened over the abdominal respirator bell. Once the animal was secured to the alignment-restraint frame, this frame was then bolted in place in the torso container. The neck exited the torso container through a custom-sized, circular opening. The neck hole edge was covered with a firm rubber grommet for protection.

Both the head and torso containers were comprised of separate right (lower) and left (upper) halves, with provision for fastening them together in the mid-sagittal plane of the animal. The four-degree-of-freedom linkage to which the dental appliance extension pipe was secured, and the torso alignment and restraint frame, were designed to facilitate release of the head and torso after they had been potted in place with structural polyurethane foam.

Head and torso container dams were custom-shaped, using an adjustable, two-dimensional template, to conform to the mid-sagittal planar contours of the animal. These dams were inserted in duplicate between the right and left halves of the head and torso containers. In addition, custom-shaped right and left dams were also used to seal the torso container at the thoraco-abdominal junction.

Twenty-four hours prior to testing, all interior surfaces of the head and torso containers were coated with latex liquid rubber. Just prior to placing the animal in these containers, the head was covered with a latex hood and the torso and upper arms were covered with a latex jacket. The latex rubber covering on the animal, the inside of the containers, and internal stereotaxic container parts facilitated post-test release of the animal from the structural foam and the foam from the container itself.

The structural polyurethane foam was then injected and poured into the head and torso containers. Exit holes in the containers were provided for excess foam, to prevent either shifting of the head and torso within the containers or injury to the test animal as a result of overcompression of vital tissues.

Abdominal Respirator. A plaster casting had been made of the test animal's abdomen prior to test day. A fiberglass abdominal respirator bell had been fabricated with the bell opening custom-shaped to contact the animal's abdomen from just cephalad of the symphysis pubis to just cephalad of the xyphoid and along the ventro-lateral margins of the thoracic cage and walls of the abdomen. The opening of the bell was covered and sealed with a Neoprene® diaphragm that had its resting shape "domed" to match the domed shape of the abdomen. The maximum positive (expiratory) and negative (inspiratory) pressure of the ventilator could be adjusted, along with the respiratory rate.

T1 Extender. The T1 vertebral body extender consisted of a 12.7-cm straight hemostat modified by adding (1) two pins for piercing the interspinous ligaments, to minimize artifactual rotation of the hemostat; and (2) two crossbars to the handle, to serve as X-ray targets and supports for photographic targets.

Biomechanical

Head Attitude for Tensile Neck Testing. The skull-fixed shear plane of the test animal's atlas-occipital joint was defined as being normal (perpendicular) to the long axis of the thoraco-cervical spinal column when the animal's bite plane was also perpendicular to the long axis of the thoraco-cervical spinal column (see Figure 1). This definition of atlas-occipital shear plane was selected, based upon: (1) assessment of the natural, neutral position of this baboon's head, relative to the torso; (2) assessment of a contrived, human-equivalent, "eyes front" neutral position of the head, relative to an erect thorax held in a shoulders-back posture of attention; (3) X-ray flexion-extension range-of-motion studies of the head; and (4) actual study of *Papio hamadryas* cadaver atlas-occipital joint articular surfaces.

The biomechanical goal for this first tensile neck loading experiment was to position the head, relative to a shoulders-back, erect, torso posture, such that the animal's bite plane (atlas-occipital shear plane) was perpendicular to the long axis of the cervical spine. For the first test, this goal was nearly achieved with the head versus torso orientation having been set at 3.5° of head extension. Thus, a pure tensile load applied to the head by means of a load pin effectively colinear with the flexion-extension atlas-occipital axis would induce an atlas-occipital ventral shear load equal to 6 percent of the induced atlas-occipital tensile load (sine 3.5° × 100). The 3.5° of head extension could not be eliminated for this test, because the already short chin-chest clearance of baboons was further reduced by the requirement to hold the mouth open with the dental

appliance that provided clearance for the endotracheal airway.

Skull Location of Shaft (Load Pin) Transmitting Load from Head Container Translation Platform to Head Container (Skull). Prior to performing neck loading, the head container was radiographically positioned to ensure that the animal's flexion-extension axis of rotation was coincident with the vertical load pin axis. This positioning maneuver was accomplished in two iterations and confirmed by the third X ray, at which time the optical axis of the X ray beam, the flexion-extension atlas-occipital axis and the load pin axis were all essentially coincident (see Figure 2). Theoretically, when the load pin and the flexion-extension atlas-occipital axis are coincident, tensile loading of the neck by the skull can be equivalently characterized, by analyst's choice, as: (1) one resultant atlas-occipital force that can be resolved into tensile and shear components, and (2) zero applied external torque. Induced torque applied to the head by the neck, by ligamentous imbalance occurring during loading, was recorded and resisted with essentially zero rotary displacement by a rotary torque transducer that coupled the head container and head translation platform.

T1 Extender. By utilizing two visual/X-ray targets on the T1 extender and by tracking (via the overhead television video and 35 mm cameras) the "X-Z" torso container coordinates of these targets as a function of load, a full three-degree-of-freedom analysis of T1 vertebral body displacement could be performed. This provided the means for tracking translation of the T1 vertebral body centroid, even as significant T1 vertebral body rotation was occurring.

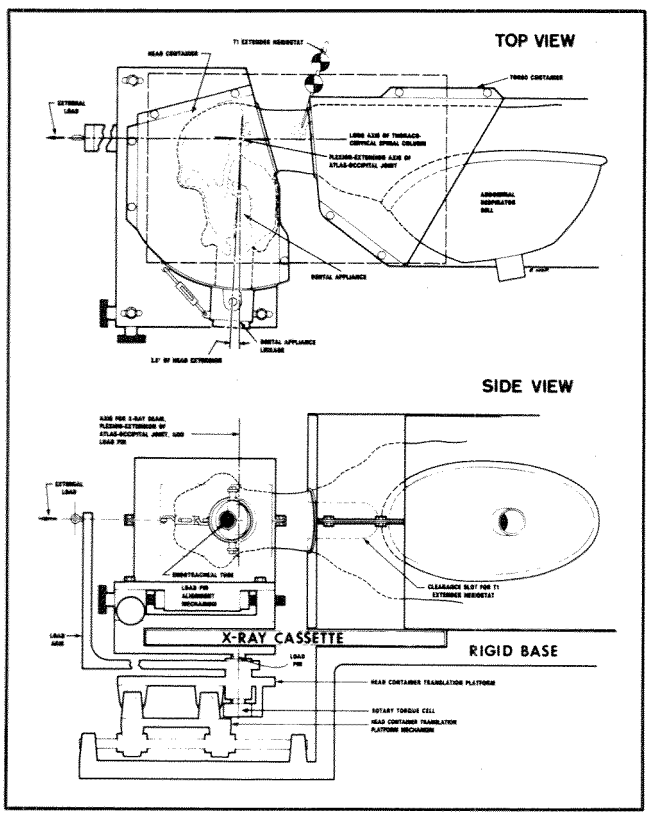


Figure 2. Static neck loading fixture setup.

X-Rays. Radiographs taken for biomechanical purposes included:

(1) Cervical spine during loading (at every fifth load level and at the last load level of 1170 N when structural failure occurred)
(2) Location of load pin versus atlas-occipital axis
(3) Location of T1 extender hemostat versus T1 vertebral body
(4) Cephalic (superior) thoracic spine (torso aligned and restrained in torso container)
(5) Caudal (inferior) thoracic spine (torso aligned and restrained in torso container)
(6) Maximum head extension (erect torso posture)
(7) Maximum head flexion (erect torso posture)

Test Configuration. Neck tension testing was conducted with the anesthetized test animal lying on its right side on a static neck testing fixture. The torso container remained fixed, while the head container was free to translate within the horizontal plane (the animal's sagittal plane) as loading was applied (see Figure 2).

Load Application Rate. Loading was applied to the head platform in 20.2 N increments at five-minute intervals. A load transducer measured the tensile load applied to the head platform (i.e., to the neck). The line-of-force of the load applied to the head platform was aligned parallel with the long (head-to-tail) axis of the thoraco-cervical vertebral spinal column of the test animal.

Engineering Data. The following engineering data were recorded continuously throughout the loading phase of the test:

(1) Tensile neck load versus time
(2) Neck torque applied to the head
(3) "Z" (cephalic) head translation (analog and manual)
(4) "X" (ventral) head translation (analog and manual)
(5) Real-time load versus head displacement plot (for monitoring during loading)
(6) Black and white photographs (one exposure per load increment midway between load increases; optical axis of camera set perpendicular to animal's sagittal plane and intersecting ventral T1 vertebral body extension target)
(7) Color television video coverage (15 seconds prior to, during and following each load increase; optical axis of camera set nearly perpendicular to animal's sagittal plane and intersecting C5 vertebral body when the neck was unloaded).

General

The described methods provided the means for applying large tensile loads to the neck without introducing

artifactual injuries more serious than minor, integument contusions or abrasions to the occiput, mandible and shoulders. Atlas-occipital loading involving predominately pure ventro-dorsal shear loading could have been induced, instead of tensile atlas-occipital loading, by adjusting the line-of-force of the applied load to be perpendicular to the long axis of the thoraco-cervical vertebral spine. However, it should be emphasized that the method currently used for computing the atlas-occipital forces and torque will not apply if the head container makes contact with the torso container.

RESULTS

Engineering

External Load Versus Time. Induced tensile neck load was increased every five minutes until the 51st load level. Death had occurred at the 50th load level. The load increments were continued every two minutes until definitive, ligamentous structural failure (definitive increase in skull displacement) occurred at the 56th load level (see Figure 3).

Neck Torque Versus Load. The neck torque magnitude varied throughout loading but never exceeded 0.45 N·m of torque.

Head Displacement, Relative to Torso Body Block, Versus Load. The total displacement of the head container, relative to the torso container, at 1150 N tensile neck loading (just prior to definitive structural failure) was 106 mm. This represented an average displacement-load ratio of 0.091 mm/N. The final total displacement at 1170 N was 115 mm. This final displacement of 9 mm exhibited a displacement-load ratio of 0.45 mm/N, a value that was 4.9 times higher than the average displacement-load ratio.

T1 Vertebral Body Displacement, Relative to the Torso Container, Versus Load. Translation of the T1 vertebral body centroid, relative to the torso container, was confined to positive Z (cephalic) displacement along the long axis of the cervical spinal column, since essentially zero X (ventro-dorsal) displacement occurred. The Z displacement of the T1 vertebral body centroid plateaued at a maximum of 6.55 cm at a tensile load of 1050 N (see Figure 3).

T1 vertebral body displacement involved left-handed rotations about a leftward-directed (Y) axis, in progressively diminishing increments, until the 20th load level of 433 N. A maximum total rotation of 16° was reached at the 20th load level. T1 vertebral body orientation did not change further at higher load levels.

Neck Length and Neck Elongation Versus Load.* The neck elongation at the tensile load level of 1150 N (just prior to the neck undergoing structural failure) was 64 percent of the initial neck length (see Figure 3).

Medical

Physiological. The mean blood pressure declined and heart rate increased until the 655 N level was reached, at which point the mean blood pressure and heart rate both fell steadily. Death occurred at the 1040 N level (see Figure 3).

Neurophysiological. The somatosensory (wrist-to-brain) far field AER test results, that provided an electrophysiological measure of cervical spinal cord and brain integrity, remained essentially normal and unchanged for the first 115 minutes of tensile neck loading, until the 24th load level of 514 N. At this 514 N level the somatosensory AER primary peak amplitude fell 50 percent and the somatosensory AER transmission time latency period had begun to increase significantly (see Figure 3). By the 27th load level of 575 N, the somatosensory AER latency time

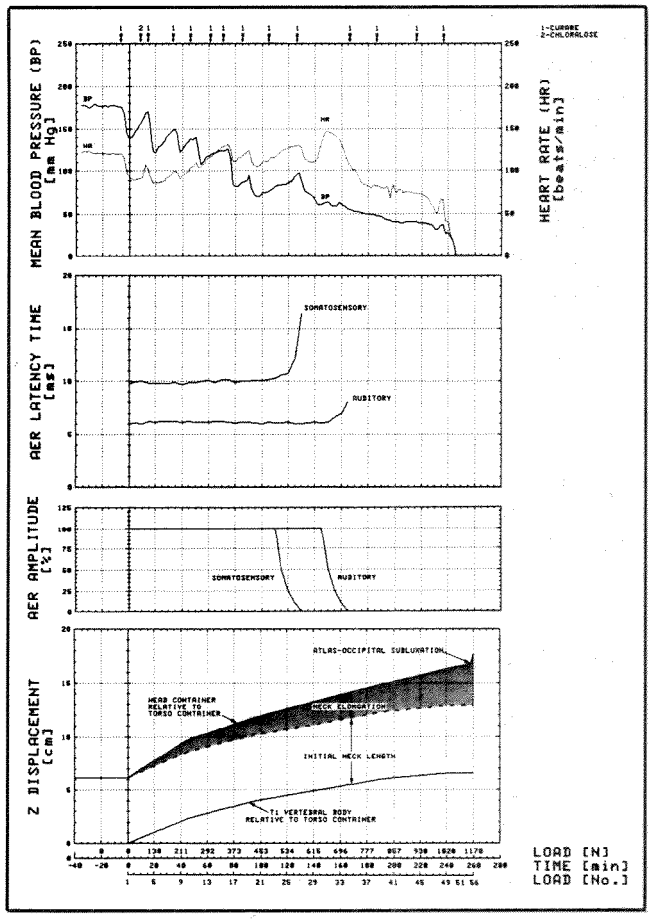


Figure 3. Mean blood pressure, heart rate, somatosensory and auditory far field average evoked response (AER) latency time and principal peak amplitude, and neck elongation versus tensile neck load.

*Neck length was defined as the perpendicular, mid-sagittal planar distance from the centroid of the T1 vertical body to the flexion-extension axis of the atlas-occipital joint.

had increased by 60 percent from 10 to 16 ms. By the 28th load level of 595 N no somatosensory AER could be detected.

The auditory (ear-to-brain) AER test results, that provided an electrophysiological measure of brain integrity, remained essentially normal and unchanged for the first 150 minutes of tensile neck loading, until the 31st load level of 655 N. At this 655 N level the auditory AER primary peak amplitude fell by 50 percent while the auditory AER transmission time latency period remained unchanged (see Figure 3). By the 34th load level of 716 N, the auditory AER latency time had increased by 33 percent from 6 to 8 ms. By the 35th load level of 736 N no auditory AER could be detected.

Radiological. Post-test, tensile, stress x-rays of the cervical spine revealed marked caudal displacement of the atlas (C1 vertebral body) relative to the occiput.

Gross Pathological. There was severe subluxation of the atlas-occipital joint, with laceration of the dura on the dorsal aspect of the spinal cord. The ventral dura was not torn. There was complete separation of the spinal cord at the junction of the medulla, although there was little evidence of hemorrhaging along the separated margins of the spinal cord and medulla. There was massive basilar subarachnoid hemorrhage, covering all surfaces of the basal meninges and extending as far ventrally as the optic chiasm.

The ventral cervical strap muscles had torn away from the occiput. The ventral atlas-occipital (C1 vertebral body-skull) ligaments were completely severed. The dorsal atlas-occipital ligaments were intact but appeared to be stretched. The atlas-occipital joint capsule was torn with severe hemorrhage into the joint space. The atlas-axis (C1 vertebral body-C2 vertebral body) joint capsule was hemorrhagic, with severe hemorrhage into the joint space.

Neuropathological. Microscopically, the edges of the separated cervical spinal cord and the medulla showed definite, acute parenchymal hemorrhage, extending several millimeters into the adjacent tissue, although no actual hematomas could be found at these margins.

DISCUSSION

Injury Thresholds for Static Neck Tension Test

Neural Function Threshold. Extinction of the somatosensory AERs, in the presence of normal auditory AERs, provided evidence for a putative site of interference with electrical signal transmission and processing between the wrist and the cerebral cortex. It appears reasonable to hypothesize that this site of traumatic blockage of transmission was at the level where complete separation of the spinal cord and medulla eventually occurred, i.e., at the spino-medullary junction. It is known that signal transmission at this level of the spinal cord comprises a critical threat to life. In fact, if respiration had not been sustained mechanically by the abdominal respirator, it appears certain that death would have resulted. Because of the large difference between the neck loads for AER blockage and for structural failure, it is reasonable to hypothesize that normal cervical spinal cord function might have been completely, or partially, restored had the static tensile neck loading been immediately removed following extinction of somatosensory AERs (i.e., at 51 percent of the structural failure load). Alternatively, once a given load level, above the threshold load level for extinction of somatosensory AERs, had been reached, injuries sustained by the cervical spinal cord might well be irreversible. Only further experiments can resolve this question.

Functional Versus Structural Thresholds. At the 595 N tensile load level there was neurophysiological evidence that transmission of electrical signals through the cervical spinal cord had been interrupted. Thus, a functional neural injury impairment of critical clinical significance had been sustained at 51 percent of the neck tensile load level required to induce structural failure in the neck tissues. It should be noted that progressive, static tensile neck loading in the anesthetized animal resulted in death at the 1040 N level. Loading was continued on this fresh cadaver until structural failure occurred at the 1170 N load level. For comparison, Sances (24) found that the cervical spinal column of an anesthetized, 12.0-kg monkey (*Macaca mulatta*) failed at a static axial tensile load of approximately 1100 N. In addition, Sances found that the afferent and efferent average evoked responses significantly decreased well before the cervical spinal column failed.

Injury Mechanisms

Cervical Spinal Cord. Although there was evidence of some fresh parenchymal bleeding, there was a remarkable paucity of blood along the separated margins of the spinal cord and medulla. This would suggest that: (1) the animal was essentially without blood pressure at the time that structural failure (subluxation of the atlas-occipital junction) occurred; and (2) the actual separation of the spinal cord occurred as a late event. Regardless, the parenchymal hemorrhage that was present would suggest that there had been severe pressure on this region of the spinal cord, perhaps from compromise of the spinal canal that had occurred with marked stretching of the atlas-occipital ligaments.

The massive basilar subarachnoid hemorrhage could only have occurred at a time when the animal had blood pressure higher than intracranial cerebrospinal fluid pressure. It is possible that the basilar or intracranial vertebral arteries high in the neck tore early in the sequence of

events as a result of tensile strains transmitted intracranially. Direct evidence of cervical vertebral artery tearing was not detected during the gross necropsy for this first tensile neck loading test. Methods suitable for detecting the source of hemorrhage associated with neck loading will be utilized in future studies.

Structural. The high cervical ligamentous, joint capsular, spinal cord dural and muscular injuries occurred, no doubt, as a result of predominately tensile loading to each of these structures. These lesions were all high in the neck, implying that the atlas-occipital and atlas-axis joints and surrounding structures must be weaker and more vulnerable to injury than the lower cervical joints. Whether disruption or tearing occurred ventrally or dorsally would have been dependent upon the relative degree of head flexion or extension present during tensile loading, along the long axis of the thoraco-cervical spinal column.

SCALING FRESH HUMAN CADAVER DATA TO PROVIDE SOFT TISSUE INJURY THRESHOLDS FOR LIVING HUMANS

No data currently exist for directly scaling *Papio hamadryas* data to predict either structural or functional neural tissue injury thresholds for neck loading in fresh human cadavers or in living humans. Although the *P. hamadryas* is one of the more human-like nonhuman surrogates available, relative to many important shape and size considerations, existing differences in structural and material properties make it nearly impossible to directly derive most human injury threshold relationships from baboon data. However, a reasonable assumption might be that the ratios of injury threshold load values for inducing neural functional failure versus structural failure, in the necks of living *P. hamadryas* and humans, are approximately the same.

Continued experimentation with *P. hamadryas* under other types of static and dynamic loading should demonstrate (for each given type of neck loading) that the threshold loading value for inducing an impairment of cervical spinal cord function can be approximated by some experimentally determined percentage of the threshold loading value for inducing structural failure of the neck. This same experimentally determined percentage value could be used in interpreting the data obtained in matched experiments with fresh human cadavers that have sound structures. Then, threshold loading values for inducing functional failure of neural, cervical spinal cord tissues in living humans may also be deduced. Such additional experimentation with *P. hamadryas* must provide for more realistic values of muscle tone in order to further refine the scaling ratios derived for predicting the values for neural tissue functional failure in living humans from the threshold loading values for structural failure in fresh human cadavers. Such functional versus structural injury scaling relationships for the necks of living humans could, perhaps, be further validated from data analysis on selected crashes and suitably paired accident reconstructions.

CONCLUSIONS

A static tensile loading experiment performed on an anesthetized *Papio hamadryas* produced neurophysiological evidence that cervical spinal cord function had been seriously impaired at 51 percent of the load subsequently required for the occurrence of structural failure (subluxation of the atlas-occipital joint). It appears likely that dynamic neck loading experiments will confirm that serious functional impairment of the neck can be produced at load levels well below those that cause structural failure of the neck.

Existing anthropomorphic automotive test dummies have generally been developed based upon biomechanical data generated from testing performed on human cadavers. This biomechanics data base should be expanded, so that future, advanced test devices can provide realistic measures of the functional impairments sustained by automotive crash victims.

ACKNOWLEDGEMENTS

The technical contributions made by the following project participants are gratefully acknowledged: biomedical engineering—Billy L. Carpenter, Victor C. Graham, Menan C. Hanz, Samuel R. McFarland, Guy N. Phillips, Houston D. Smith, Walter G. Switzer; computer science—Arthur F. Muller; dental science—Thomas B. Aufdemorte; editorial—Barbara J. Alexander, Sylvia V. Alvarado, Judy L. Brandle, Wilma B. Sloan, Lorna L. Wilson, SwRI Editorial staff; instrumentation—William H. McGinnis, M. Eugene Locke, John P. Prudhomme, Maurice C. York; mechanical design—A. Robert Nye, J. Wray Fogwell; SwRI Machine Shop staff; SwRI Photography staff; veterinary anesthesiology—Samuel J. Tomlinson, Sr.; veterinary care—J. Juan Cano, Plutarco Zertuche; veterinary medicine—Edward E. Dean; and veterinary pathology—Ned R. Zamora. In addition, the consultative support provided by the following individuals is gratefully acknowledged: biomechanics—Rolf H. Eppinger, Roger P. Daniel, Harold J. Mertz, Priyaranjan Prasad; manuscript critique—C. William Hall; and neurophysiology—Edwardo Eidelberg.

This research was sponsored by the National Highway Traffic Safety Administration, U.S. Department of Transportation, under contract DTNH-22-80-C-07165.

REFERENCES

1. Huelke, D. F., O'Day, J., Lawson, T. E., Barhydt, W. H. and Mendelson, R. E. Cervical Injuries in Automotive Crashes. Report No. UM-HSRI-80-40, HSRI, University of Michigan, Ann Arbor, 1980.
2. Portnoy, H. D., McElhaney, J. D., Melvin, J. W. and Croissant, P. D. Mechanism of Cervical Spine Injury in Auto Accidents. *Proceedings of 15th Conference of American Association for Automotive Medicine*, 1971.

   The Human Neck-Anatomy, Injury Mechanisms and Biomechanics. Publication No. SP-438. Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096. March, 1979. Includes articles (3–6) by:
3. Huelke, D. F. Moffat, E. A., Mendelson, R. A. and Melvin, J. W. Cervical Fractures and Fracture Dislocations—An Overview. (HS-026-181).
4. Huelke, D. F., Mendelson, R. A., States, J. D. and Melvin, J. W. Cervical Fractures and Fracture Dislocations Sustained Without Head Impact (HS-026-182).
5. States, J. D. Soft Tissue Injuries of the Neck (HS-026-185).
6. Melvin, J. W. Human Neck Injury Tolerance (HS-026-186).
7. Ommaya, A. K., Bakaitis, S., Partyka, S., Langwieder, K. and Fan, W. Automotive Neck Injuries—Comparative Studies in the United States and in the Federal Republic of Germany. *Proceedings of the 9th International E.S.V. Conference*, Kyoto, Japan, November, 1982.
8. Levy, L. M. An Unusual Case of Flexion Injury of the Cervical Spine. *Surgical Neurology* 17(4): 255–259, 1982.
9. Kiesel, T. M., Frerichs, R. L. and Seljeskog, E. L. Cervical Spine Injuries. *Proceedings of 13th Conference of American Association of Automotive Medicine*, 1969.
10. Neurosurgical Aspects of Traffic Accidents: Report of a Subcommittee of the Canadian Neurosurgical Society. *Canadian Medical Association J.* 97: 1364, 1967.
11. Norton, W. L. Fractures and Dislocations of the Cervical Spine. *J. Bone Joint Surgery* 44A: 115–139, 1962.
12. Roaf, R. A. Lateral Flexion Injuries of the Cervical Spine. *J. Bone Joint Surgery* 45B: 36–38, 1963.
13. Rogers, W. A. Fractures and Dislocations of the Cervical Spine. An End Result. *J. Bone Joint Surgery* 39A: 341–376, 1957.
14. Schneider, R. C. and Kahn, E. A. Chronic Sequelae of Spine and Spinal Cord Trauma. I. The Significance of the Acute "Teardrop" Fracture. *J. Bone Joint Surgery* 38A; 985, 1956.
15. Schneider, R. C., Livingston, K. E., Cave, A. J. E. and Hamilton, G. Hangman's Fracture of the Cervical Spine. *J. Neurosurgery* 22: 141–154, 1964.
16. Taylor, A. R. and Blackwood, W. Paraplegia in Hyperextension Cervical Injuries with Normal Radiographic Appearances. *J. Bone Joint Surgery* 30B: 245–248, 1948.
17. Voight, G. E. and Wilfert, K. Mechanisms of Injuries of Unrestrained Drivers in Head-On Collisions. *Proceedings of 13th Stapp Car Crash Conference*, 1969.
18. Roaf, R. A. A Study of the Mechanics of Spinal Injuries. *J. Bone Joint Surgery* 42B: 810–823, 1960.
19. Burstein, A. H., Otis, J. C. and Torg, J. S. Mechanisms and Pathomechanics of Athletic Injuries to the Cervical Spine. *Mechanisms and Pathomechanics of Cervical Spine Injury*. (J. S. Torg, ed.) Lea and Feiberger, Philadelphia, 1982.
20. Brauze, R. J. and Ardran, G. Experimental Production of Forward Dislocation in the Human Cervical Spine. *J. Bone Joint Surgery* 60B: 239–245, 1978.
21. Beatson, T. R. Fractures and Dislocations of the Cervical Spine. *J. Bone Joint Surgery* 45B: 21–35, 1963.
22. Davis, D., Boylman, H., Walker, A. E., Fisher, R. and Robinson, R. The Pathological Findings in Fatal Craniospinal Injuries. *J. Neurosurgery* 34: 603–613, 1971.
23. Holdsworth, F. W. Fractures, Dislocations, and Fracture-Dislocations of the Spine. *J. Bone Joint Surgery* 45B: 6–20, 1963.
24. Sances, A., Jr., Myklebust, J., Cusick, J. F., Weber, R., Houterman, C., Larson, S. J., Walsh, P., Chilbert, M., Prieto, T., Zyvoloski, M., Ewing, C., Thomas, D. and Saltzberg, B. Experimental Studies of Brain and Neck Injury. Paper 811032, *Proceedings of 25th Stapp Car crash Conference*, 1981.
25. Culver, R., Bender, M. and Melvin, J. W. Mechanisms, Tolerances and Responses Obtained in Neck Injury by Superior-Inferior Head Impact. Report No. UM-HSRI-78-21, HSRI, University of Michigan, Ann Arbor, 1978.
26. Mertz, H. J. and Patrick, L. M. Strength and Response of the Human Neck. Paper 710855, *Proceedings of 15th Stapp Car Crash Conference*, 1971.

Part Two: Dummies

Description and Basis of a Three-Year-Old Child Dummy for Evaluating Passenger Inflatable Restraint Concepts

M. J. WOLANIN, H. J. MERTZ,
R. S. NYZNYK, J. H. VINCENT
General Motors Corporation

ABSTRACT

A primary concern in the development of a passenger inflatable restraint system is the possibility that a child could be in the path of the deploying cushion either due to initial position at the time of an accident or due to precrash braking accompanying an accident. Previous studies by General Motors and Volvo have indicated that serious injuries to children are possible if the cushion/child interaction forces are not controlled by system design. This paper describes an instrumented child dummy which was developed to provide measurements of the various cushion/child interaction forces. An analysis is given describing the types of injuries which could be associated with the various types of interaction forces. These results were used to develop appropriate dummy instrumentation for indicating the severity of the cushion/child interaction. A description of the modifications made to an existing three-year-old child dummy are described. The usefulness and limitations of the measurements made with the child dummy are discussed. While the measurement techniques were developed for evaluating inflatable restraint system performance, some of the response measurements are appropriate for estimating child responses when restrained by a lap/shoulder belt or unrestrained.

INTRODUCTION

When General Motors started its development of a second generation passenger inflatable restraint, the interaction of the out-of-position child with the deploying cushion was identified as a topic requiring further study. In previous inflatable restraint development programs by General Motors Corporation (1) and Volvo (2), animals have been used as child surrogates to evaluate potential injury hazards to children who may be in the path of the cushion during its deployment. The General Motors' program which was conducted at Wayne state University used baboons and chimpanzees as surrogates while the Volvo study conducted at Chalmers University in Sweden used pigs. Significant brain, heart, liver and spleen injuries were noted during the courses of these development programs. It was also apparent from these programs that significant neck injury might occur if the animal was positioned so that the interaction forces produced large head to torso motion. Unfortunately, neither program provided any objective correlations between the observed animal injuries and the inflatable restraint system design factors, nor was any attempt made in either program to develop a test device to aid in understanding the relationships between the observed injuries and the forces exerted by the deploying cushions which could be used to guide the development of future inflatable cushion systems. Consequently, when General Motors initiated the development of its second generation passenger inflatable restraint system, it concurrently undertook the development of a child dummy which would provide measures of the various deployment interaction forces thought to be associated with injuries observed or inferred from previous animal test programs.

An extensive child dummy development program was considered impractical because such a program would not result in a child dummy soon enough to be used to support the passenger inflatable restraint development program. To be useful, a child dummy had to be developed in a relatively short time frame and had to provide measures of the types of forces and acelerations which were thought to be associated with the types of animal injuries observed in the previous inflatable restraint development programs.

A two-phase child dummy development program was formulated. For the first phase, instrumentation was added to an existing child dummy to improve its measuring capabilities. Due to time constraints, modifications to improve impact response characteristics were kept to a minimum. For phase two, the child dummy was further modified to improve impact response characteristics and to eliminate any major deficiencies noted while using the first phase dummy. This paper describes the child dummies (Design 1 and Design 2) developed in Phases 1 and 2, respectively.

DESIGN 1 DUMMY

Analysis of Child/Cushion Interaction Forces

To gain an insight as to what types of measurements should be made with the child dummy, the kinematics and kinetics associated with possible child/cushion interactions were analyzed.

During the initial stage of deployment, the cushion and cover material are accelerated rearward relative to the vehicle. If the child is close enough to the system he will be impacted by this mass when it is in a relatively dense, concentrated form. The center of gravity of this mass will be decelerated by the part of the child's body being impacted. This interaction force is termed "onset impulsive force".

A second type of force is developed on the out-of-position child when a sufficient volume of gas has been generated to produce a positive gage pressure in the cushion resulting in the cushion material becoming taut. Prior to this point in the deployment cycle, the cushion is unfolding and its volume is increasing in response to the gas filling it. A large positive gage pressure cannot be developed unless the cushion material is prevented from unfolding, thus restricting its volume expansion. During the unfolding phase of the deployment cycle, the forces on the out-of-position child are relatively small. However, when sufficient gas has been generated to make the cushion material taut, the cushion gage pressure will begin to increase and the child will be accelerated rearward as the remainder of the gas is generated. The forces applied to the child during this phase of the deployment cycle are called "membrane forces" since they depend on biaxial tensile forces being developed in the cushion material. The magnitude of these membrane forces is dependent on the difference in the volumes of the undeformed and deformed air cushion, the envelopment geometry, the rate at which the remaining gas is generated, the gas leakage from the cushion and the elasticity of the air cushion material.

A third type of force is applied to the child when he impacts the seat after being accelerated rearward by the air cushion. These forces are called "rebound" forces. The magnitude of the rebound forces are dependent on the relative velocity at which the child strikes the seat, and the shape and stiffness of the seat structure involved in the impact. The relative impact velocity is dependent on the magnitude of the membrane forces and the velocity of the seat structure at the time of impact.

Since injuries can be produced by any of these different types of forces, the first priority in the Phase I program was to identify techniques to measure the effects of these types of forces.

Techniques to Measure Effects of Onset Impulsive Forces

The magnitude of the impulse associated with the onset impulsive force is proportional to the product of the impact velocity and the mass of the cushion/door which contacts the child. The peak of the onset impulsive force will be large and the time to peak will be short because the mass of the cushion/cover contacting the child will be quickly decelerated to the velocity of the surface of the child which it impacts. Of importance in terms of possible serious injuries are the onset impulsive forces applied to the head and torso of the child.

The severity of the onset impulsive forces applied to the head can be measured by accelerometers mounted at the center of mass of a dummy's head since the head structure is quite rigid and will transmit short duration loads. Measurement of torso contact force is more difficult because accelerometers mounted to the spine of the dummy are not sensitive to the onset impulsive force due to the lack of transmissibility of the chest structure to short duration impulses applied to the front surface. However, an array of accelerometers attached to the front surface of the torso would be sensitive to onset impulsive forces and would give an indication of their distribution over the torso surface. The technique required to make these measurements and corresponding torso modifications are described in detail under the section on Torso Modifications.

Techniques to Measure Effects of Membrane Forces

The child can be injured in two ways by membrane forces. If large membrane forces are developed, the child will be rapidly accelerated rearward. Since the internal organs will be accelerated as well, forces will be applied to them through their internal attachments and/or through contact with neighboring organs. If these internal forces are large enough, injury to the organs and/or attachments can occur. The magnitude of these internal forces will be dependent on the magnitude and direction of the acceleration of the body segment containing the organs of interest. Injuries to the brain and the organs of the torso such as the heart, lungs, liver, spleen and kidneys are of particular concern. Measurement of the potential for injury to these internal organs due to membrane forces can be obtained from whole body accelerations. Techniques to measure whole body accelerations are discussed under the sections on Head and Torso Modifications.

A second way the child can be injured by membrane forces is by one body segment being accelerated at a different rate than an adjacent segment, resulting in high interaction forces in the connecting tissues. Of specific concern is injury to the neck area if the head is accelerated at a different rate than the torso. A load transducer inserted between the dummy's head and neck can be used to measure internal neck loads. Analysis of such loads can be used to predict the potential for neck injury. A technique to measure internal neck loads is discussed in detail under the section on Head Modifications.

Techniques to Measure the Effects of Rebound Forces

Injury to the internal organs can occur if the rebound forces are too large, as well as injury to connecting tissues if the relative motion between adjacent body segments is too great. Since these are the same injury concerns noted for the membrane forces, no additional dummy instrumentation was considered necessary to assess the severity of the rebound forces.

Mainframe Selection

In order to have a child dummy available for use in GM's Inflatable Restraint System Development Program,

an existing dummy mainframe was chosen for Design 1. At the time of this work, child dummies were being manufactured by both American and European companies. General Motors had test experience with American-made three-year-old and six-year-old child dummies manufactured by Sierra Engineering Co. and Alderson Research Laboratories, Inc. (ARL). Since Sierra was phasing out of the dummy manufacturing business, only the ARL three-year-old and six-year-old dummies were selected as possible candidates for the mainframe for the Design 1 dummy.

After weighing many considerations, the ARL VIP-3C was selected as the mainframe for the Design 1 dummy for the following reasons:

i) Due to precrash braking, more younger children would be expected to be near the instrument panel and thus involved with a deploying cushion. The three-year-old child dummy would be more representative of these size children.
ii) A greater range of possible child positions and postures could be evaluated with a smaller, three-year-old child dummy.

The ARL VIP-3C dummy is shown in Figure 1. The head is a urethane casting covered with a removable vinyl skin and is joined to the upper torso by means of a monolithic natural rubber neck. A foam-filled, molded urethane rib cage and steel weldment form the upper torso segment. The lumbar spine is a monolithic natural rubber cylinder connecting the upper torso and pelvis assemblies. A bronze casting and aluminum weldment form the pelvis which incorporates spherical sockets at the femur joints. The limbs are constructed of steel tubing covered with foam and a vinyl skin. Primary joints for the shoulder, elbow, wrist, knee and ankle are of a clevis design with adjustable joint friction.

Twist joints which are incorporated in the arms and legs utilize a rod and sleeve design with clamping friction adjustment. Spherical joints with adjustable friction characteristics are employed in the shoulder to clavicle and the femur to hip joints.

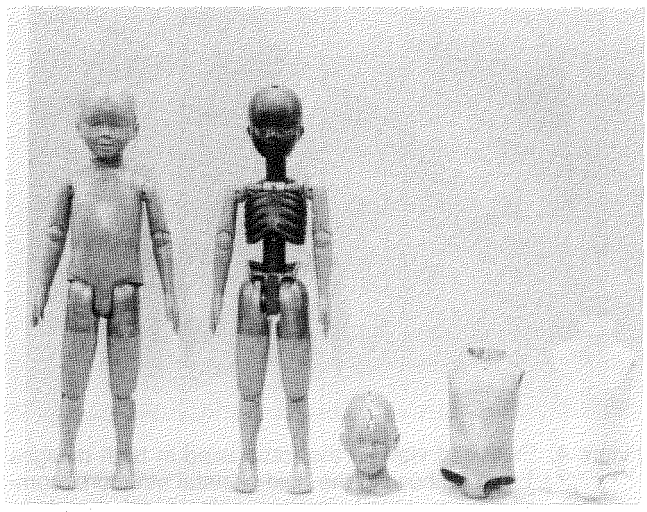


Figure 1. ARL VIP-3C three-year-old child dummy.

Head Modifications

Previous test experience with the ARL VIP-3C dummy indicated that the thin vinyl head covering frequently failed at the zipper. This vinyl skin also interacted with the head and neck in a somewhat variable manner during both neck flexion and extension bending. To improve both durability and repeatability, the vinyl skin was discarded in Design 1, resulting in a slight reduction in overall head size.

The head cavity was modified to mount five linear accelerometers; three accelerometers to measure the three components of linear acceleration of the head's mass center and two accelerometers to measure head angular acceleration in the sagittal plane (Figure 2). The acceleration of the head's mass center is measured by three Endevco linear accelerometers orthogonally mounted on an alu-

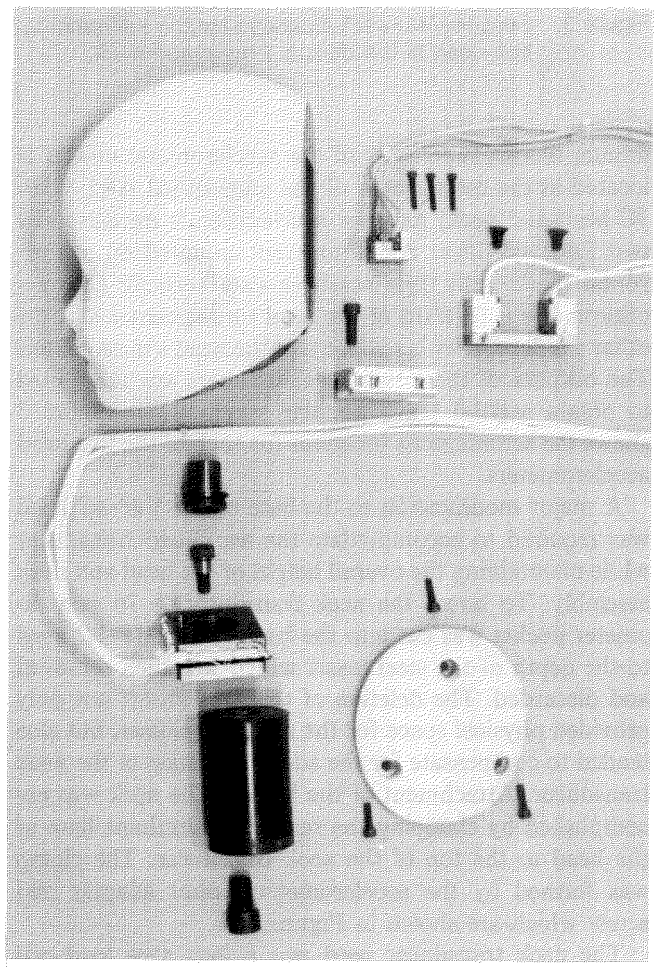
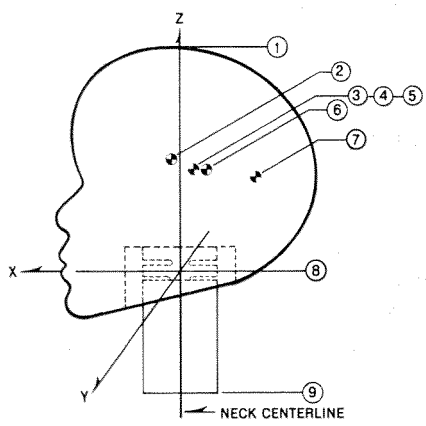


Figure 2. Exploded view of the design 1 head and neck assembly showing the various head accelerometers and neck load transducer which were added to the VIP-3C head and neck.



REF. PT.	DESCRIPTION	X	Y	Z
1	TOP OF HEAD	0.0	0.0	146.5
2	ANTERIOR HEAD ANGULAR ACCELEROMETER	4.5	15.9	76.6
3	LATERAL HEAD ACCELEROMETER	-10.2	-10.0	67.5
4	VERTICAL HEAD ACCELEROMETER	-10.2	-1.0	66.7
5	HEAD CENTER OF GRAVITY	-10.2	0.0	67.0
6	LONGITUDINAL HEAD ACCELEROMETER	-18.6	0.0	67.5
7	POSTERIOR HEAD ANGULAR ACCELEROMETER	-52.5	15.9	63.0
8	NECK TRANSDUCER GAGE PLANE	0.0	0.0	0.0
9	BASE OF NECK	0.0	0.0	-84.0

ALL DIMENSIONS GIVEN IN mm

Figure 3. Sensitive element locations for the instrumentation used in the design 1 head and neck.

minum block. The center of the accelerometer cluster is located at the mass center of the unmodified ARL VIP-3C head and neck. Angular acceleration is measured by two Endevco linear accelerometers mounted on a horizontal plane with their sensitive axes vertical. One accelerometer is forward of the head's mass center and the other accelerometer is rearward of the head's mass center. The outputs of these two accelerometers are subtracted to obtain sagittal plane angular acceleration. Figure 3 shows the seismic mass locations for each of the five head accelerometers.

A major modification to the base of the VIP-3C head was required to accommodate the neck load transducer while maintaining the overall height of the head and neck assembly. To house the neck transducer, a 76 mm diameter pocket was cut into the base of the VIP-3C head to the depth of the steel insert which was then removed and discarded. The deletion of this steel insert not only provided physical space for the neck transducer, but also tended to compensate for the additional mass of the neck transducer. Attachment of the head to the neck was accomplished by clamping the remaining urethane base of the head to the top of the neck transducer. The clamp was formed by the accelerometer mount adapter and screw which are shown in Figure 2.

The neck transducer used was a four axes load cell capable of measuring axial forces, anterior-posterior shear forces, and lateral shear forces up to 9000 Newtons and sagittal plane bending moments up to 70 Newton-metres. The neck load cell was mounted to the top of the neck since high cervical neck injuries have more severe consequences than injuries to the lower cervical area. No modification was made to the ARL VIP-3C neck structure and the overall dimension from the base of the neck to the top of the head was maintained at the ARL VIP-3C value.

Torso Modifications

The technique chosen to measure the effects of onset impulsive forces on the torso was to suspend a series of small masses near the surface of the torso and measure the accelerations of these masses as they responded to the onset impulsive forces. A uniaxial accelerometer was mounted to each mass and its sensitive axis was oriented perpendicular to the torso surface.

To mount these instrumented torso surface masses, extensive torso modifications were required. The existing ARL VIP-3C thoracic and lumbar spine structures and the foam torso were discarded. A rigid, two-piece backbone was fabricated. It was attached at its lower end to the pelvic structure and at its upper end to the neck and shoulder pivots (Figures 1 and 4). The length of the

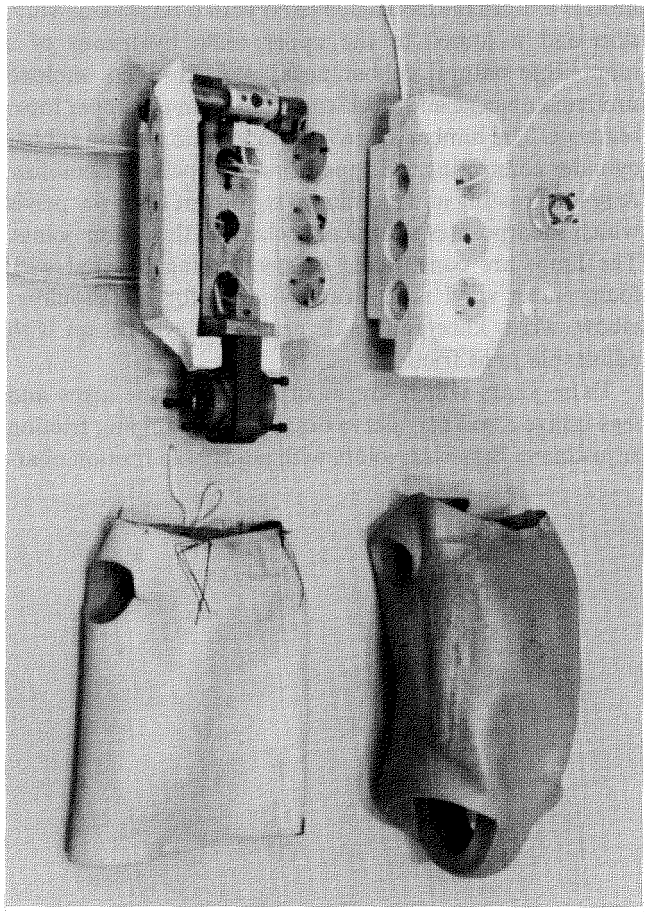


Figure 4. Exploded view of the torso used in both designs 1 and 2 showing the rigid skeletal structure, compliant foam chest structure, spine accelerometers, instrumented surface masses, and skin coverings.

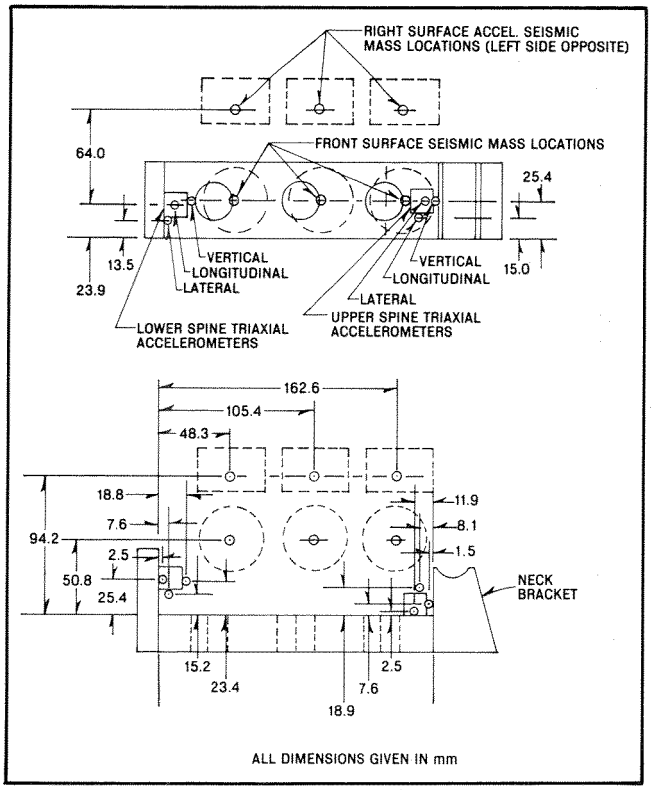


Figure 5. Seismic mass locations of the various torso accelerometers used in designs 1 and 2.

backbone was selected to maintain the torso length of the ARL VIP-3C. Closed cell foam pads were used to fabricate the torso shape. Holes were cut in the foam to accommodate the instrumented surface masses (Figure 4). Provisions were made to mount nine such masses; three in mid-sagittal plane of the front surface (upper, mid and lower torso), and three in each side. The instrumented surface masses were made of aluminum and weighed 92 grams each including the accelerometer.

The primary purpose of the torso foam was to suspend the instrumented surface masses. No attempt was made to develop a human like force-deflection characteristic for the torso because biomechanics data on child torso response characteristics were not available, and the time constraints did not allow for such a development program. Foam stiffness was not considered critical for the assessment of the effect of short duration onset impulsive forces because the instrumented surface masses will undergo only small displacements during the time required for the onset impulsive forces to reach their peak values resulting in only small amounts of foam compression during this time period. This implies that the foam resisting force will be quite small compared to the peak onset impulsive force. Thus, the peak acceleration of the instrumented surface mass should give a good indication of the peak onset impulsive force applied to the mass.

To measure the effects of membrane and rebound forces applied to the torso, triaxial clusters of uniaxial accelerometers were mounted to each end of the backbone (Figure 4). Seismic mass locations for all the accelerometers mounted in the torso are shown in Figure 5.

The torso was encased in a 1/16 inch thick, oaktanned leather jacket shown in Figure 4. Darts were sewn in the upper chest area for contouring. Brass grommets were inserted in the rear to facilitate lacing the jacket with a nylon cord. The existing ARL VIP-3C vinyl torso skin with added gussets was used to cover the torso. A 50 mm wide hook and loop tape fastener was sewn on the back to replace the zipper.

The modifications that were made to the torso resulted in a 35 mm increase in chest circumference; however, torso mass remained the same. No changes were made to the arms and legs. The complete Design 1 dummy is shown in Figure 6.

Component Response Documentation

The following response data only document the responses of the various components of the Design 1 dummy. They should *not* be construed as being representative of a child's responses.

Head Drop Test—The impact response characteristics of the head of the Design 1 dummy were documented by dropping it onto a rigid steel plate. The impact point was the forehead and the drop distance was 376 mm. A typical acceleration response is shown in Figure 7. Note the low frequency resonance which reflects the low stiffness and damping of the urethane used to mold the head.

Neck Bending Test—Dynamic neck bending tests were conducted to document the response characteristics of the Design 1 neck structure in forward flexion and rearward extension. The pendulum test fixture specified for measuring neck response characteristics in Part 572 (3) was

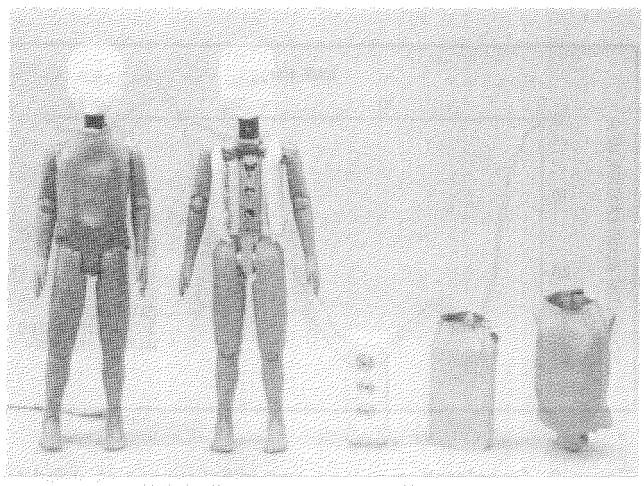


Figure 6. GM design 1 three-year-old child dummy.

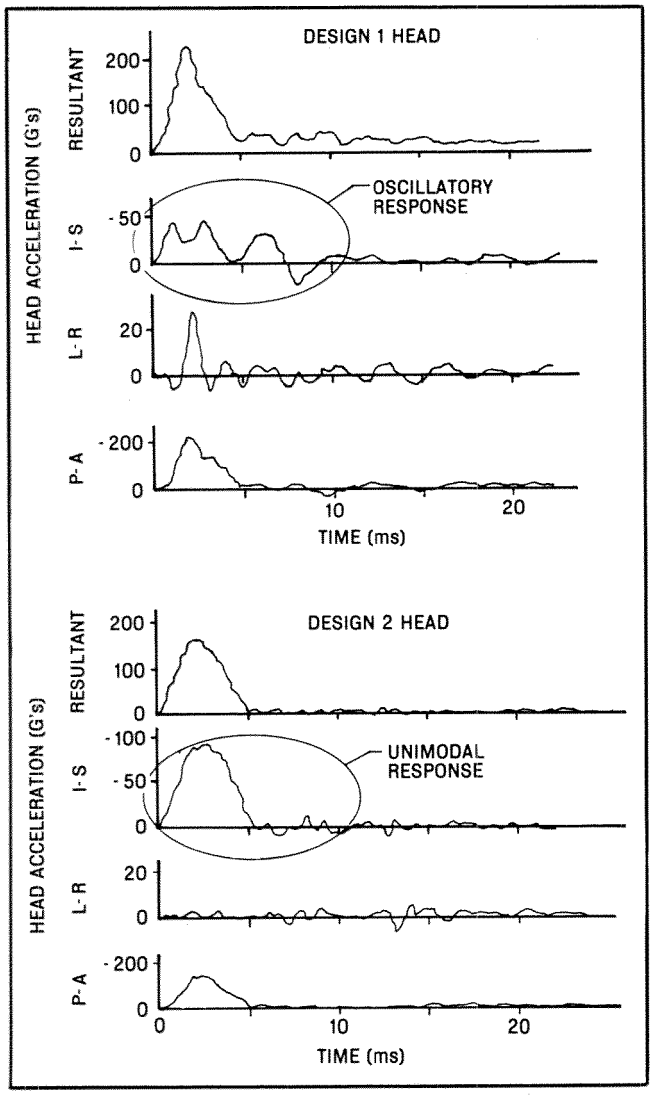


Figure 7. Typical head acceleration response curves for designs 1 and 2 from forehead impacts onto a rigid steel plate from a drop height of 376 mm.

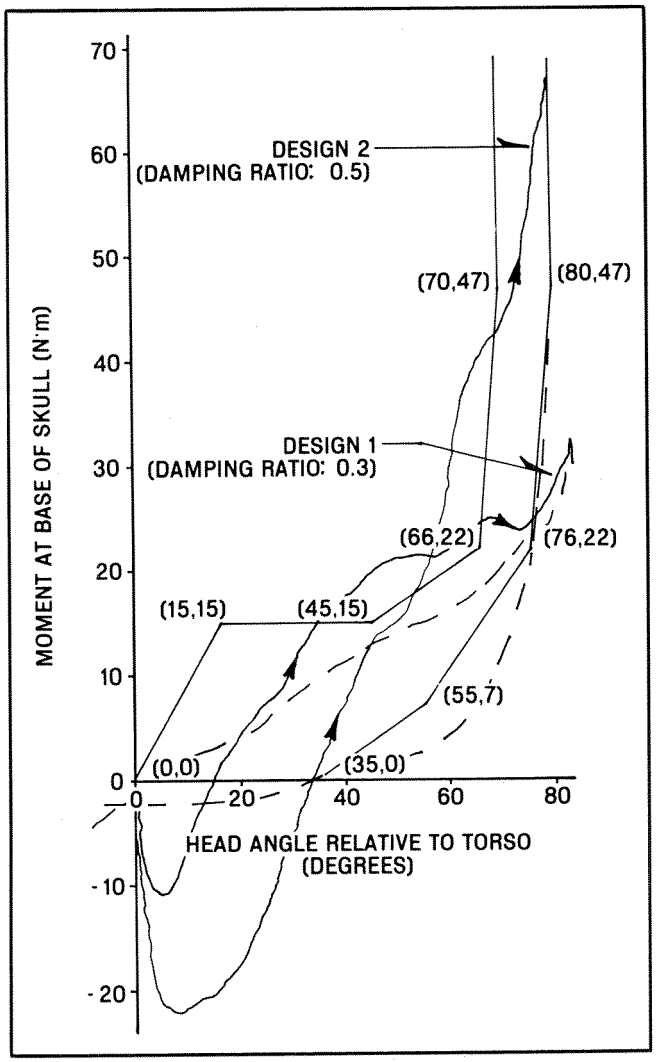


Figure 9. Forward bending responses of designs 1 and 2 head-neck assemblies compared to response envelope for a three-year-old child.

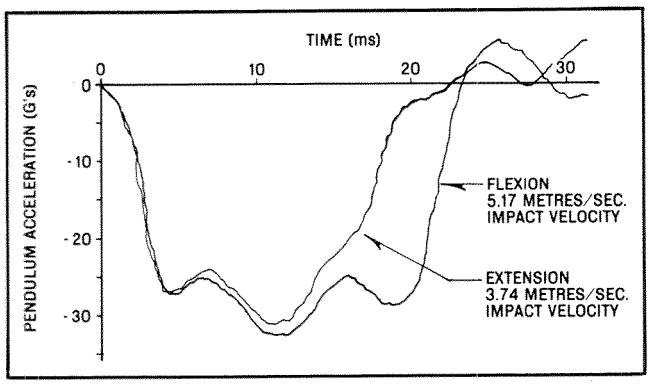


Figure 8. Deceleration pulses and initial velocities used to measure forward and rearward bending responses to designs 1 and 2 head-neck assemblies.

used to perform these tests. Typical deceleration pulses and velocities are shown in Figure 8. Response characteristics in forward flexion and rearward extension are shown in Figures 9 and 10, respectively. The ordinate of these curves is the moment measured with the neck transducer and the abscissa is the corresponding angular displacement of the head with respect to the pendulum arm.

The damping characteristic of the neck structure was determined from the head angular rotation-time curves. During a bending test, the head-neck system undergoes multiple flexion-extension cycles of progressively decreasing amplitude. A damping ratio was determined by dividing the difference in peak angles between the first and second cycles by the peak angle of the first cycle. These damping ratios are shown with their corresponding moment-angle response curves on Figures 9 and 10.

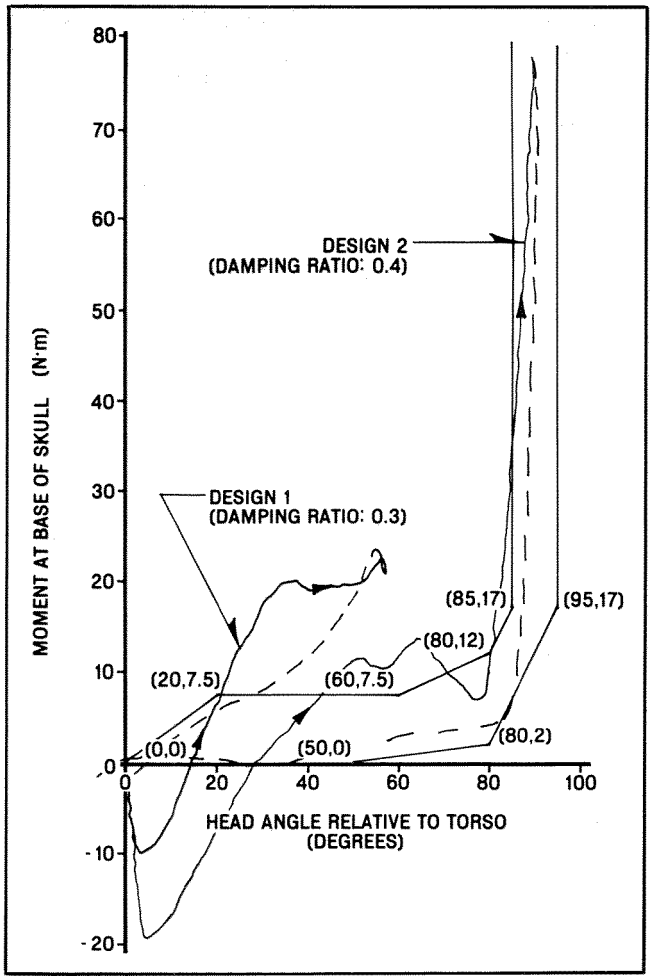


Figure 10. Rearward bending responses of designs 1 and 2 head-neck assemblies compared to response envelope for a three-year-old child.

Static Load—Deflection Test—The torso of the Design 1 dummy was subjected to a series of static load deflection tests over the course of the Inflatable Restraint (IR) development program. A 100 mm wide loading plate was centered over the middle instrumented front surface mass and a static load was applied sufficient to deflect the torso 25 mm. The resulting load-deflection curves for the various tests are shown in Figure 11. The curves demonstrate a wide range of static stiffnesses that is characteristic of closed foam materials. The results of these tests indicated that the static stiffness tended to increase with repeated stiffness testing; however, if the material was allowed to "relax" before retesting, the stiffness was close to its original value.

Use of Design 1 Dummy

The Design 1 dummy has been used in hundreds of inflatable restraint system development tests by General Motors and has proven to be a valuable test tool for assessing changes made to our various passenger inflatable restraint system concepts. These assessments were made in two ways. The first was a straightforward A to B comparison where the object was simply to reduce the magnitudes of the various dummy responses with a given IR design change. The second way was to predict the effect that an IR design change would have on an anesthetized animal's (a child surrogate) response. In order to do this latter type of an assessment, a correlation between the dummy's responses and observed animal injuries for similar exposure environments had to be established. Such a correlation study is the subject of a paper by Mertz and Weber (4) and is beyond the scope of this paper.

DESIGN 2 DUMMY

Design Considerations

As noted previously, the objective of the Design 2 dummy development program was to develop a dummy to eliminate any major deficiencies noted while using the Design 1 dummy.

Of major concern in using the Design 1 dummy was the lack of childlike bending response of the dummy's neck. Anesthetized animal tests (5) have shown that serious neck injuries could be produced by an inflating cushion, and child dummy tests (4) conducted under similar conditions resulted in high neck loads. However, both child surrogates, the anesthetized animals and the Design 1 dummy, had neck bending stiffnesses which were thought to be greater than that of a child. Further, it was hypothesized that a child with lower neck bending resistance would not experience high loads, and consequently, would not experience serious neck injuries in similar exposure environments. To determine the effect of neck stiffness on neck loads due to head/cushion interactions, it was proposed to develop a dummy neck structure whose bending resistance and range of motion would be more characteristic of a child's.

Two other modifications were considered for the Design 2 dummy. It was suggested that the chest should be replaced with a structure that had force-deflection response characterisics that simulate a child's and that a transducer to measure chest deflection should be added. Also, it was suggested that the rigid thoracic/lumbar spine should be replaced by a flexible structure. While these proposed modifications would certainly improve the biofidelity of the child dummy's responses, it did not appear that such modifications would greatly enhance the ability to interpret the significance of the cushion/torso interaction forces.

After review of these various suggested modifications, it was decided only to make the neck bending response more childlike in the Design 2 dummy. The following is a list of items which were considered important in order to improve the biofidelity of the neck bending response.

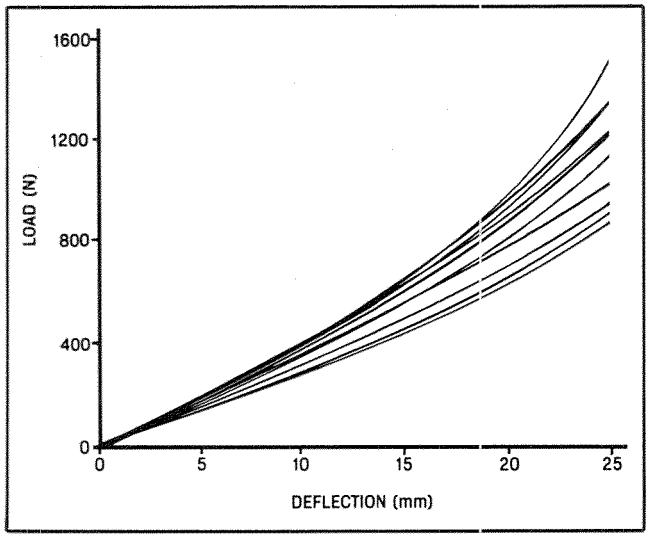


Figure 11. Static load-deflection responses for the chest structure used in designs 1 and 2.

i) The head geometric characteristics need to be childlike. The most important geometric characteristics are the locations of the center of mass and the head/neck interface relative to the exterior head surface. These dimensions control the magnitude of the moment arm of the forces applied to the head which bend the neck. Also, the head size and shape need to be childlike since these dimensions influence the magnitude of the cushion/head interaction forces.
ii) The inertial properties of the head need to be childlike with the head mass being most important because it controls the magnitude of the inertial force which bends the neck.
iii) The neck length needs to be childlike since it influences the trajectory that the head undergoes relative to the torso.
iv) The dummy's neck structure needs to simulate the fore/aft bending response of a child's neck.

It is apparent from this list that modifications to both the head and neck structures would be required in order to achieve a childlike neck bending response.

Head and Neck Geometric and Inertial Data

Table 1 and Figure 12 summarize the head and neck geometric and inertial data which were considered in the designs of the head and neck structures. The work of Snyder et al. (9) provided most of the child anthropometry data. Snyder gives data for various mean dimensions of children in the 2 to 3½ year old age bracket and 3½ to 4½ year old age bracket. A linear interpolation was done to calculate dimensions that would be representative of a 2½ to 3½ age range. The means of this age range were taken to represent a 3-year-old child and are the values given in Table 1.

For a number of the desired child dimensions, no anthropometry data were available. To obtain values for these dimensions, the adult anthropometry data listed in Table 1 were scaled using the following relationship:

$$\text{D child} = \frac{\text{C child}}{\text{C adult}} \times \text{D adult}$$

where

D child — Desired Child Dimension
D adult — Corresponding Adult Dimension
C child — Characteristic Length of Child
C adult — Corresponding Characteristic Length of Adult

The chin to front of neck dimension listed in the table was scaled from a measurement made on a 3-year-old child. The child head weight was calculated by multiplying the adult head weight by the cube of the ratio of characteristic lengths. This scaling relationship assumes that the densities of the adult and child head are equal.

The various characteristic lengths used for each calculation are given in Table 2.

Neck Bending Response Requirements

The adult fore/aft neck bending response envelopes described by Mertz et al. (11) were scaled to give the

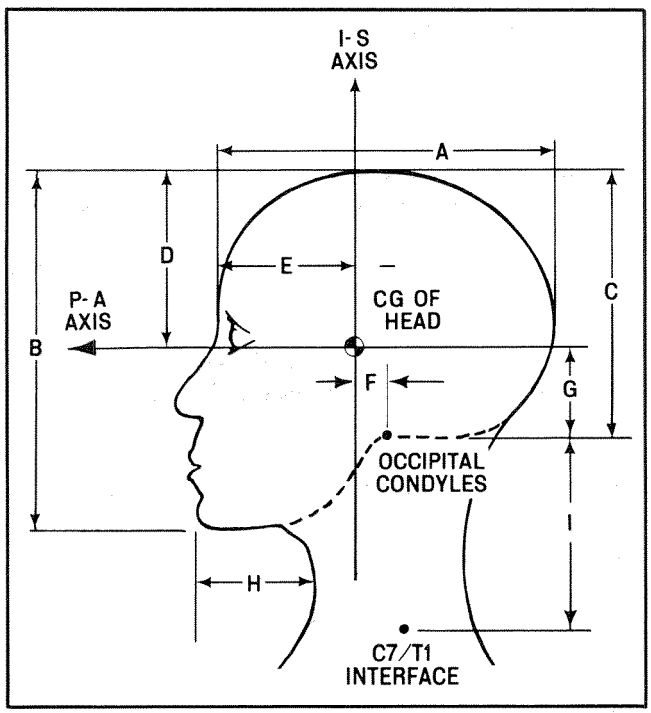


Figure 12. Definition of key head and neck dimensions.

Table 1. Head and neck anthropometric and inertial characteristics.

DESCRIPTION	SEE FIG. 12	50TH %ILE ADULT MALE VALUE	NO.	3 - YEAR OLD CHILD VALUE	NO.	DESIGN 1 DUMMY VALUE	% DIFF.	DESIGN 2 DUMMY VALUE	% DIFF.
HEAD CIRCUMFERENCE	-	572	6	496	9	479	-3	499	1
HEAD BREADTH	-	155	6	135	9	133	-1	139	3
HEAD LENGTH	A	196	6	176	9	163	-7	166	-6
HEAD HEIGHT	B	221	6	174	9	179	3	165	-5
HEAD VERTEX TO OCCIPITAL CONDYLES	C	152	6	120	SCALED	148	23	121	1
HEAD VERTEX TO HEAD C.G.	D	104	6	82	SCALED	81	-1	83	1
NASION TO HEAD C.G. (A-P)	E	84	6	75	SCALED	71.2	-5	66.1	-12
HEAD C.G. TO OCCIPITAL CONDYLES (A-P)	F	18	6	16	SCALED	-10	-163	16	0
HEAD C.G. TO OCCIPITAL CONDYLES (S-I)	G	48	6	38	SCALED	67	76	38	0
CHIN TO NECK	H	-	-	48	MEASURED	52	8	53	10
HEAD WEIGHT	-	4.5	6	2.9	SCALED	2.50	-14	2.95	2
NECK CIRCUMFERENCE	-	384	10	239	9	157	-34	220	-8
NECK BREADTH	-	-	-	72	9	51	-29	70	-3
NECK LENGTH	I	142	7	88	SCALED	82	-7	84	-5
NECK WEIGHT	-	1.4	7	0.34	SCALED	0.48	41	0.56	65
STANDING HEIGHT	-	1748	8	950	9	980	3	982	3
TOTAL WEIGHT	-	74.5	7	14.5	9	14.9	3	15.4	6

NOTES: 1 - DIMENSIONS ARE IN mm AND WEIGHTS ARE IN kg
2 - NO. REFERS TO PAPER NUMBER GIVEN IN LIST OF REFERENCES

neck bending response requirements for the 3-year old child dummy. The adult neck bending response is characterized by the neck resisting moment taken with respect to the head/neck interface (occipital condyles) as a function of the relative angle between the head and torso (Figures 13 and 14). In order to develop a neck bending response for the child, scale factors for the moment and angle needed to be determined.

Moment Scaling—The constant moment plateaus of the adult response envelopes were based on the static bending strength of the neck in resisting flexion and extension. These moments represent the levels at which the neck muscles are no longer capable of preventing the head from moving forwards or backwards in response to a static load applied to the head. Note that the magnitude of the static strength moment in resisting forward flexion is two times greater than the extension moment. This difference in magnitude is consistent with the anatomical observation that the majority of the neck muscle masses are located in the back of the neck and resist forward neck

Table 2. Characteristic lengths used in scaling dimensions.

SCALED DIMENSION	CHARACTERISTIC LENGTH
HEAD VERTEX TO OCCIPITAL CONDYLES (C)	HEAD HEIGHT (B)
HEAD VERTEX TO HEAD C.G. (D)	HEAD HEIGHT (B)
NASION TO HEAD C.G. (E)	HEAD LENGTH (A)
HEAD C.G. TO OCCIPITAL CONDYLES, A-P (F)	HEAD LENGTH (A)
HEAD C.G. TO OCCIPITAL CONDYLES, S-I (G)	HEAD HEIGHT (B)
NECK LENGTH (I)	NECK CIRCUMFERENCE
HEAD WEIGHT	HEAD CIRCUMFERENCE
NECK WEIGHT	NECK CIRCUMFERENCE

NOTE: LETTERS IN BRACKETS CORRESPOND TO DIMENSIONS GIVEN ON FIGURE 12.

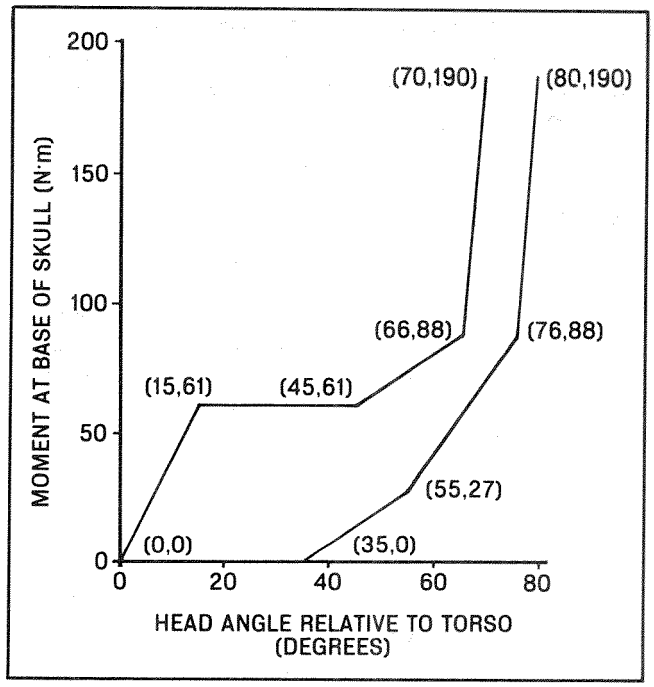


Figure 13. Forward neck bending response envelope for the 50th percentile adult male.

flexion. Similar distributions of muscle masses exist in children, but the total cross-sectional areas of their neck muscles are smaller than those of adults resulting in lower static neck strength moments. A relationship between the static neck strength moments for children and adults can be obtained by the following analysis.

From static equilibrium considerations, the magnitude of the static strength moment, M, is equal to the resultant of the neck muscle forces, F, multiplied by the effective moment arm, D, of this force.

$$M = F \times D \qquad (1)$$

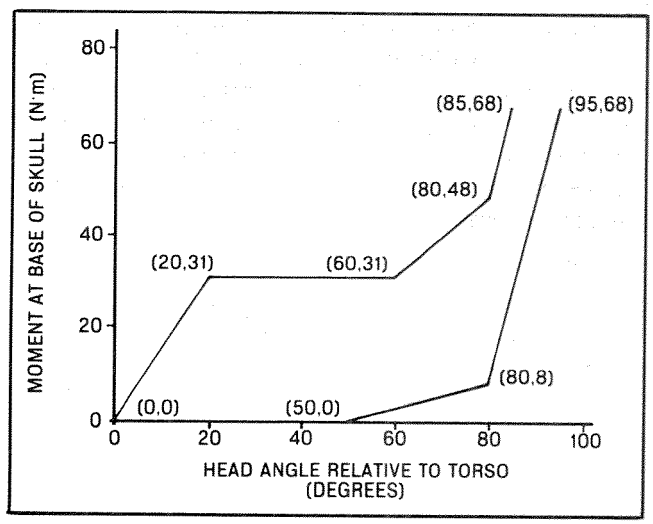


Figure 14. Rearward neck bending response envelope for the 50th percentile adult male.

The resultant neck muscle force is equal to the average stress level, S, in the muscles when the head begins to move multiplied by the cross-sectional area, A, of the muscles resisting the motion.

$$F = S \times A \tag{2}$$

Combining this equation with Equation (1) gives,

$$M = S \times A \times D \tag{3}$$

If we assume that the average stress level at which the head begins to move in response to a statically applied head load is the same for the adult as it is for the child, then the magnitudes of a child's static strength moments for flexion and extension can be calculated from the formula,

$$M \text{ child} = \frac{(A \times D) \text{ child}}{(A \times D) \text{ adult}} \times M \text{ adult} \tag{4}$$

The characteristic dimensions used to calculate the static strength moments for flexion and extension for a 3-year-old child are given in Table 2. The ordinate of the adult neck bending response envelope was scaled by the ratio,

$$\frac{M \text{ child}}{M \text{ adult}} \tag{5}$$

Angle Scaling—Table 3 summarizes the range of motion data which was considered for scaling the abscissa of the adult neck bending envelope to the child. Shown in the table are measurements taken on a 27-month-old female and a 7-year-old male, as well as data for adults (12, 13, 14). The range of motion for the 27-month-old female was slightly less than that of the 7-year-old male whose range was quite comparable to the various adult ranges. Based on these data, it was decided that no scaling of the adult head to torso angulation was required.

Child Neck Bending Response Corridors—The resulting 3-year-old neck bending response envelopes for flexion and extension are shown in Figures 9 and 10, respectively. The moment coordinates of the envelopes were obtained by applying Equation (5) to the corresponding adult moment coordinates. The angle coordinates were taken as their corresponding adult angle coordinates.

Note that this technique can be used to obtain neck bending response envelopes for any size person.

Table 3. Range of motion data for the head due to forward and rearward neck bending.

	MEASURED CHILD RANGES OF MOTION - DEG.		REFERENCED ADULT MALE RANGES OF MOTION - DEG.		
	27 MONTH FEMALE	7 YR-OLD MALE	REF. 12	REF. 13	REF. 14
FORWARD BENDING	45	60	50	60	67
REARWARD BENDING	50	60	50	61	77

Head Modifications

The Design 1 head characteristics are compared to those chosen to represent a 3-year-old child in Table 1. Generally, the comparisons indicate that the Design 1 head is smaller than the 3-year-old child. Major differences occur between the weights of the heads and between the locations of the head/neck interfaces relative to the head mass centers.

Since making a new head mold to the exact dimensions of the 3-year-old child given in Table 1 was not practical, the possibility of fabricating a new head mold to the size and shape of the ARL VIP-3C skin mold was investigated. When ARL indicated that such a mold could be easily and quickly fabricated, the decision was made to fabricate the Design 2 head to the ARL VIP-3C exterior head dimensions.

Figure 15 shows an exploded view of the Design 2 head and neck. With this design, an aluminum structure embedded in a compliant urethane head casting is used to attach the head to the neck structure and locate the head so that the head/neck interface is positioned consistent with child anthropometry. This structure also served as the mounting platform for the various head accelerometers. The desired head mass and its location

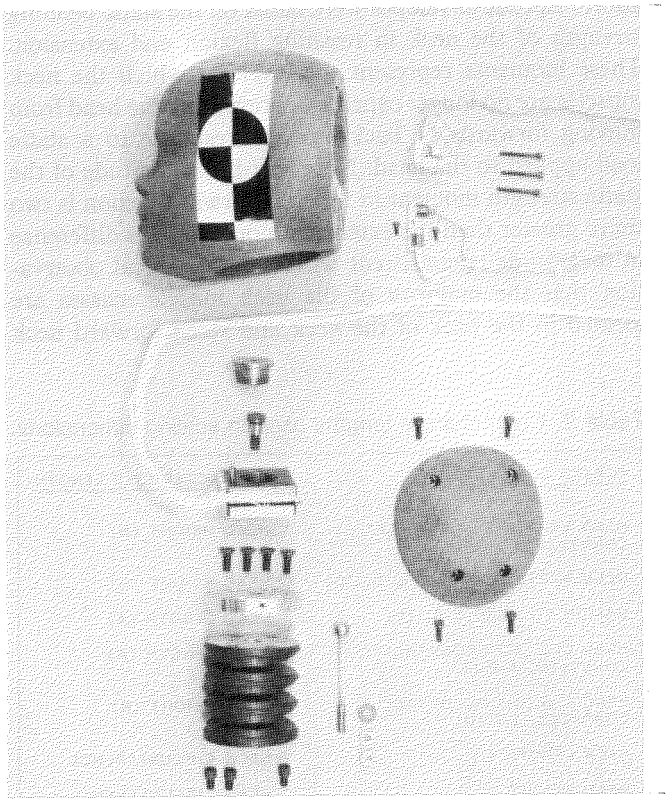


Figure 15. Exploded view of the instrumented design 2 head and neck which features modifications to improve geometry, mass and neck bending response.

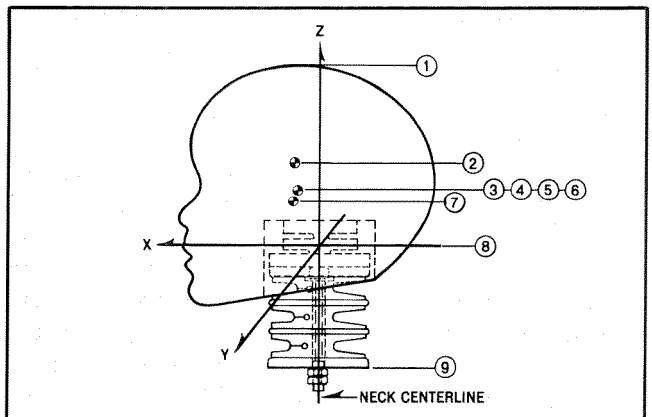
were obtained by using ballast. A 2 mm diameter hole was drilled in each side of the head to identify the mass center location.

Head instrumentation was the same as Design 1, and consisted of an orthogonal cluster of three uniaxial accelerometers located at the head's center of gravity and two uniaxial accelerometers mounted with their sensitive axes parallel to measure sagittal plane angular acceleration. Figure 16 shows the locations of these accelerometers.

The various geometric and inertial characteristics of the Design 2 head are compared to those of the 3-year-old child in Table 1. Note the excellent agreement that was obtained for the head weight and the location of the head/neck interface (occipital condyles) relative to the head's center of mass.

Neck Modifications

Inspection of both the flexion and extension moment-angle response envelopes (Figures 9 and 10) indicates that the desired neck stiffness should be low up to a threshold angle at which stiffness becomes relatively high. This desired response can be thought of as a low resistance neck which suddenly bottoms out after a specified range of motion. Further inspection reveals that neck extension stiffness, prior to bottoming out, should be lower than the corresponding flexion stiffness. Thus a nonlinear rate neck with different flexion and extension responses is required.



REF. PT.	DESCRIPTION	X	Y	Z
1	TOP OF HEAD	0.0	0.0	121.1
2	SUPERIOR HEAD ANGULAR ACCELEROMETER	23.1	21.3	60.4
3	HEAD CENTER OF GRAVITY	16.0	0.0	38.0
4	LATERAL HEAD ACCELEROMETER	16.0	-7.4	38.0
5	VERTICAL HEAD ACCELEROMETER	16.0	0.0	38.0
6	LONGITUDINAL HEAD ACCELEROMETER	20.1	0.0	38.1
7	INFERIOR HEAD ANGULAR ACCELEROMETER	23.1	19.4	30.9
8	NECK TRANSDUCER GAGE PLANE	0.0	0.0	0.0
9	BASE OF NECK	0.0	0.0	-84.0

ALL DIMENSIONS GIVEN IN mm

Figure 16. Sensitive element locations for the instrumentation used in the design 2 head and neck.

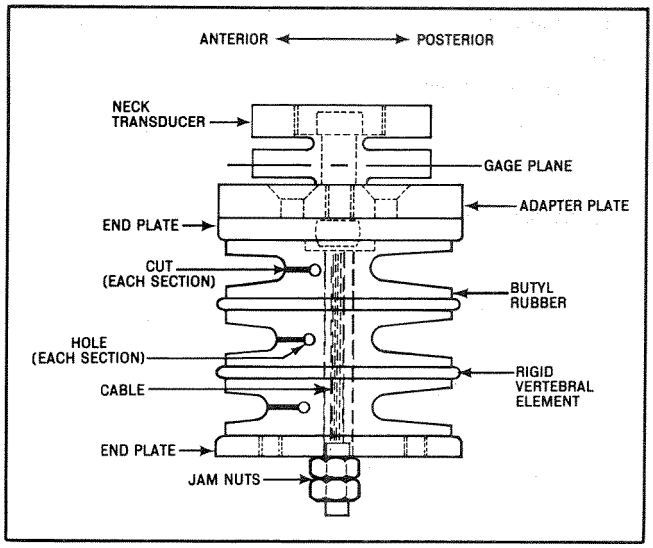


Figure 17. Schematic of the design 2 neck structure.

To achieve these desired characteristics, the concept shown schematically in Figure 17 was used in Design 2. This concept is based on the technique used in the development of the Hybrid III neck structure (15). Key components of the design are the bonded butyl rubber elements, vertebral discs, steel cable, and aluminum end plates.

Neck stiffness, prior to bottoming, is controlled by the design of the rubber sections. Each rubber element is cut from the front surface to the hole shown in Figure 17. Thus, only compression forces can be transmitted by the front portions of the rubber elements. When the neck is flexed forward, the total cross section of the rubber elements resists the bending action. However, when the neck is flexed rearward, only part of the cross section of the rubber elements resists the bending since the front portion cannot transmit tensile forces.

For both flexion and extension modes, the neck tends to bottom out at deflection angles which are designed into the physical geometry. This bottoming characteristic occurs when the rubber covered vertebral elements contact each other and significantly increase the neck's resistance to further deflection. A steel cable is contained within the neck at its axial centerline to help carry the additional tension loads which result when the neck bottoms out.

Neck length and diameter were chosen to better approximate human geometry. In the dummy, neck length is defined as the dimension from the gage plane of the neck transducer (representing the occipital condyles) to the base of the neck.

Threaded aluminum endplates provide convenient attachment of the neck to the head and torso. A neck mounting bracket was designed to interface the neck with

the torso and provide the desired standing height for the dummy.

Neck load measurements are made with the same instrumentation used in Design 1. However, the transducer's location relative to the mass center of the head and base of the neck is significantly different. Figures 3 and 16 provide a comparison of the geometric differences between the head/neck structures of Design 1 and 2. An inspection of Table 1 clearly demonstrates that the geometric and inertial characteristics of the head and neck structure of Design 2 are closer to those of the 3-year-old child than were those of Design 1.

Component Response Documentation

Head Drop Test—The head drop test conducted to document the forehead impact response of Design 1 head was repeated using the Design 2 head. A typical acceleration response curve is shown in Figure 7. Note the unimodal response curve and the absence of the undesirable resonance noted for the response of Design 1. By mounting the accelerometers to the rigid, aluminum structure in the head, the undesirable resonance was eliminated. While a desirable unimodal response was achieved, there is no assurance that the resulting acceleration level is typical of child's response. No child acceleration response data are available to make such a comparison.

Neck Bending Test—Dynamic neck bending tests were conducted to compare the response characteristics to the child neck bending response envelopes. The pendulum test fixture used in documenting the Design 1 neck response was used to produce forward flexion and rearward extension of the head/neck structure of Design 2. The rubber neck elements were tuned to give the desired neck response. Figures 9 and 10 show the neck response characteristics of Design 2 relative to the child neck bending performance envelopes for flexion and extension, respectively. Also shown are the responses of the Design 1 head/neck structure. Clearly, Design 2 responses more closely approximate the desired response envelopes.

Use of Design 2 Dummy

No inflatable restraint system development tests were conducted with the Design 2 dummy. Prior to completing the Phase 2 development program, the development work on the GM inflatable restraint was terminated. However, the Design 2 dummy was subjected to a limited test series using inflatable restraint hardware and dummy positions which had produced a range of neck injuries in anesthetized animals. In addition, Design 1 neck response data were available for each test condition selected. The results of these tests are discussed in the paper by Mertz and Weber (4).

SUMMARY

A description of the 3-year-old child dummy (Design 1) that was used extensively by General Motors Corporation in its second generation, passenger system inflatable restraint development program is given. The dummy used was a modified version of the ARL VIP-3C dummy and was instrumented to measure loads and accelerations that were thought to be associated with injuries observed or inferred from previous animal test programs of passenger inflatable restraint systems. These measurements were triaxial accelerations of the center of gravity of the head and the upper and lower ends of the one piece, rigid backbone; the angular acceleration of the head about a lateral axis; fore and aft linear accelerations at three mid-sagittal points located on the upper, mid and lower front surface of the torso; and mid-sagittal plane neck loads consisting of the fore-aft shear force, axial force and bending moment measured at the head-neck interface. No attempt was made to improve the biofidelity of the child dummy's response characteristics since such a development program would not have been compatible with the time constraint of the passenger inflatable restraint development program.

While the Design 1 dummy provided good insights into the significance of the cushion/dummy interaction forces, concern was expressed that the lack of biofidelity of the neck's bending response might lead to misinterpretation of the test results. Anesthetized animal tests that were being conducted to assess the significance of the child dummy measurements had shown that serious neck injuries could be produced for some combinations of hardware and test conditions. Child dummy tests conducted under similar exposure conditions had resulted in high neck loads. However, both child surrogates had neck bending stiffnesses which were thought to be greater than that of a child. It was hypothesized that a child with lower neck bending resistance would not experience high neck loads in a similar exposure environment and consequently would not experience severe neck injury.

To determine the effect of neck stiffness on neck loads due to head/cushion inteaction, a program was initiated to develop a dummy neck structure with childlike bending resistance and range of motion. Neck bending response guidelines were developed to characterize the fore and aft bending responses of a child's neck. These characteristics were inferred from those specified for an adult's neck by using geometric scaling factors. A description of the modified neck structure that was developed to meet these response guidelines is given. Since the geometric and inertial properties of the head influence how the neck is loaded, a new head structure was developed and is described. The new head-neck structures were mounted to the torso of the Design 1 dummy and the resulting child dummy configuration was called Design 2. Prior to using the Design 2 dummy to evaluate the performance of pas-

senger system inflatable restraint concepts, the GM Inflatable Restraint Development Program was terminated.

The improvements made to the head-neck structures of the Design 2 dummy should be useful for evaluating belt restraint performance. However, additional modifications of the thorax, backbone, abdomen and shoulder areas would be desirable if the dummy is to be used for that type of testing.

LIST OF REFERENCES

1. Patrick, L. M. and Nyquist, G. W., "Airbag Effects on the Out-of-Position Child", SAE 720442, May 1972.
2. Aldman, B., Anderson, A., and Saxmark, O., "Possible Effects of Air Bag Inflation on a Standing Child", Proceedings of the International Meeting on Biomechanics of Trauma in Children, Lyon, France, September 17–19, 1974.
3. U.S. Department of Transportation, Part 572, "Anthropomorphic Test Dummy", 38FR20449, August, 1973.
4. Mertz, H. J. and Weber, D. A., "Interpretations of the Impact Responses of a 3-year-old Child Dummy Relative to Child Injury Potential", 9th International Conference on Experimental Safety Vehicles, Kyoto, Japan, Nov. 1–4, 1982.
5. Mertz, H. J., Driscoll, G. D., Lenox, J. B., Nyquist, G. W., and Weber, D. A., "Responses of Animals Exposed to Deployment of Various Passenger Inflatable Restraint System Concepts for a Variety of Collision Severities and Animal Positions", 9th International Conference on Experimental Safety Vehicles, Kyoto, Japan, Nov. 1–4, 1982.
6. Hubbard, R. P. and McLeod, D. G., "Definition and Development of a Crash Dummy Head", Eighteenth Stapp Car Crash Conference, SAE 741193, 1974.
7. "Anthropomorphic Test Dummy", Final Report No. DOT-HS-299-3-569, December, 1973.
8. Diffrient, N., Tilley, A. R., Bardagjy, J. C., *Human Scale 1/2/3*, The MIT Press, 1974.
9. Snyder, R. G., Schneider, L. W., Owings, C. L., Reynolds, H. M., Golomb, D. H., and Schork, M. A., *Anthropometry of Infants, Children, and Youths to Age 18 for Product Safety Design*, SP-450, Society of Automotive Engineers, 1977.
10. *Anthropomorphic Source Book*, NASA Ref. Pub. No. 1024, Vol. 1, "Anthropometry for Design", 1978.
11. Mertz, H. J., Neathery, R. F., and Culver, C. C., "Performance Requirements and Characteristics of Mechanical Necks", *Human Impact Response—Measurement and Simulation*, Plenum Press, N.Y., 1973.
12. Dreyfuss, H., "The Measurement of Man—Human Factors in Design", 1967.
13. Granville, A. D. and Kreezer, G., "The Maximum Amplitude and Velocity of Joint Movements in Normal Male Human Adults", Human Biology, Vol. 9, 1937.
14. Buck, C. A., Dameron, F. B., Dow, M. J., and Skowlund, H. V., "Study of Normal Range of Motion in the Neck Utilizing a Bubble Goniometer", Archives of Physical Medicine and Rehabilitation, Vol. 40, 1959.
15. Foster, J. K., Kortge, J. O., and Wolanin, M. J., "Hybrid III—A Biomechanically-Based Crash Test Dummy", Proceedings of the 21st Stapp Car Crash Conference, SAE 770938, 1977.

Lateral Dummy Comparison Testing

K.-P. GLAESER
Federal Highway Research Institute
Federal Republic of Germany

ABSTRACT

The Federal Highway Research Institute (BASt) was engaged in comparison tests of the side impact dummies designed by:

—Highway Safety Research Institute/Department of Transportation (HSRI(DOT))
—Motor Industry Research Association (MIRA)
—Organisme National de Sécurité Routière (ONSER)
—Association Peugeot/Renault (APR).

In full scale side impact tests under the same test conditions the overall dummy behavior, repeatability, handling and durability of the different dummies were studied and compared.

In the research project "Lateral Dummy Comparison Testing" the following tests were carried out:

12 impact tests by means of a rigid moving barrier (1100 kg) against a VW Golf at an impact angle of 90° with a collision speed of 45km/h.
Variations:—4 dummy types (APR, HSRI (DOT), ONSER, MIRA)
—3 repetitions per test.

The loads and kinematics of the different dummies were compared.

INTRODUCTION

The side impact of passenger cars is the second most frequent collision type besides the frontal impact. Because of the low stiffness of the car side structure there is a high risk of a car occupant being severely injured. Side impact dummies, developed by different institutions in recent years represent a basic means of evaluating the side impact protection performance of cars. Within the frame of the "EEC Research Program on Biomechanics of Impacts with Relation to Future Vehicle Safety Regulations" in Phase 4 the following institutes took part in comparing 4 different dummy prototypes described in detail later:

—Motor Industry Research Association (MIRA)
—Instituut voor Wegtransportmiddelen (TNO) (Coordination and final summary report)
—Organisme National de Sécurité Routière (ONSER)
—Association Peugeot/Renault (APR)
—Federal Highway Research Institute (BASt)

TEST METHOD

The side impact tests carried out with the moving rigid barrier against a stationary car at an impact angle of 90° largely insure realistic and reproducible conditions of a standard side impact test.

The parameters used for the impact test within this projects were partly different from the EEVC WG6-proposal [1]:

—The chosen test velocity of 45 km/h lies ~ 10% under the 50 km/h proposed by the EEVC.
—The moving barrier was equipped with a rigid face according to SAE J 972 a, the EEVC proposed deformable elements.
—The mass of the moving barrier was fixed at 1100 kg, the EEVC proposes a mass of 950 kg.
—The impact angle of 90° into stationary test car is also proposed by the EEVC.

The test dummies thus had to sustain a largely realistic side impact test procedure and had to show their behaviour. Three tests with each of the four dummies were carried out to compare the repeatability of the dummies. Because of measuring problems, which are described later, one test with the HSRI (DOT)-dummy and one test with the APR-dummy were carried out additionally.

Test Configuration

The car type was a Volkswagen Golf with two doors. The test cars weighed 840 ± 10 kg. The impact velocity of the barrier was settled to 45 (± 1) km/h, the corresponding ΔV values for the test car were calculated from about 23 to 28 km/h.

The case car was hit on the left side in the middle between the front and rear axles. To evaluate the intrusion, the positions of 12 target points on the left side of the impacted car were measured relative to a reference plane before and after test. The dummy was belted with an automatic 3-point belt, the arms were positioned forward in driving position, the hands were on the steering wheel in 1/4 to 3 o'clock position (exception: HSRI-tests, the HSRI-dummy has no arms). The distances between the dummies (shoulder and pelvis) and interior parts were held constant. The integrated head rests were adjusted at their maximum height and their most frontward inclination.

The impact tests were filmed by 4 high-speed cameras. Two cameras were attached to the test car to film the motion of the dummy, two further stationary cameras were used.

The car was equipped with two switches to flash a spotlight. One at the moment of impact and one at the moment of shoulder/door contact.

Instrumentation and Measuring Data in General

The test car acceleration was measured 3-axial on the top of the transmission tunnel and the acceleration of the rigid barrier was measured in longitudinal direction. The seat belt forces were measured at four places, two on the lap belt, two on the shoulder belt. The analog measuring data were digitized according to the principle of pulse code modulation (PCM) and recorded by a PCM-tape recorder. In general the filtering of the analog measuring data was carried out by active analog lowpass filters, which correspond to SAE Recommended Practice J 211b.

DUMMY DESIGN,—INSTRUMENTATION AND DATA PROCESSING OF THE DIFFERENT DUMMIES

The HSRI-dummy and its design was presented several times [2,3]. The thorax consists of 5 ribs with ballast plates (to compensate the arm weight), which can rotate together around the thoracic spine and which were supported from the impacted rib side to the spine by a shock absorber. The tested dummy was equipped with a Taylor-shock absorber, filled with silicon oil. (In later tests of the other mentioned institutes a new version of shock absorber was used.) Between the ribs and the armless jacket there were foam pieces.

Figure 1 shows the HSRI-dummy.

Head, chest and pelvis of the dummy were equipped with 3-axial accelerometers. A linear potentiometer was mounted parallel to the shock absorber to measure the chest deflection. Two rib accelerometers were mounted, one on the right and one on the left upper rib in lateral direction.

According to the computer programs from NHTSA,

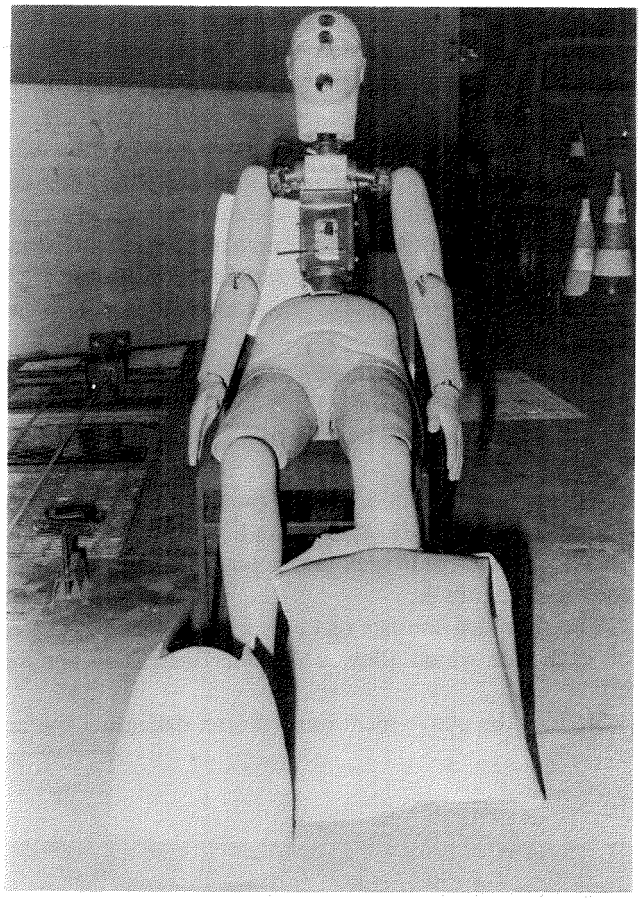


Figure 3. ONSER-dummy.

celeration of head, chest and pelvis was measured 3-axial at the provided locations.

The pelvis and lower extremities of the *APR-dummy* were taken from a Hybrid II-dummy, the head originates from the Hybrid III-dummy, the neck was an on top and on bottom with a ball joint modified Hybrid III neck version [8]. Thorax and upper extremities were designed by Peugeot/Renault and the used abdomen was developed by TNO [9]. The upper 3 and the lower 3 of the 6 ribs were connected on the impacted and nonimpacted side by a rubber spring loaded piston with the thoracic spine. The pistons on the impacted side are equipped with an optoelectronical deflection transducer. Figure 4 shows the APR-thorax and the inside of the TNO-abdomen.

The dummy was equipped with 3-axial accelerometers at the provided locations of the center of gravity of head, chest and pelvis. On the left and right upper rib an uniaxial accelerometer was mounted in lateral direction. The data processing was the same as for the HSRI-dummy, described above.

The TNO-abdomen was installed as described in [10] and the contact switch unit was adjusted to 4500 N, which means the critical penetration respectively force limit.

Table 1 shows the summarized measuring data of the different dummies in tabular form.

COMPARISON OF LOADS AND KINEMATICS

The impact speed of 45 km/h was achieved with deviations of ± 1 km/h. The maximum intrusion of the test car occurred on the car's waist line. At the dummy thorax level an intrusion of 300 ± 30 mm was measured. The ΔV-value for the B-post was calculated between 9 m/s and 11 m/s. This means a severe impact for the test car and for the tested dummies.

The comparison of the dummy test results was made under the aspect of dummy loads, kinematics, repeatability aspects particularly, durability and handling of the dummies. Table 2 shows the dummy loads in comparable form. The most interesting data of the dummy loads are also shown in Figure 5. The following data analysis was made using the mean values of each test series.

The head acceleration traces of the different dummies showed a different shape. The resultant accelerations ranged from 48 g for the MIRA-dummy to 98 g for the APR-dummy. The ONSER- and APR-dummy had besides the lateral component also a high acceleration component in vertical direction (> 60 g). The HIC was calculated between 115 (MIRA) and 835 (APR). The

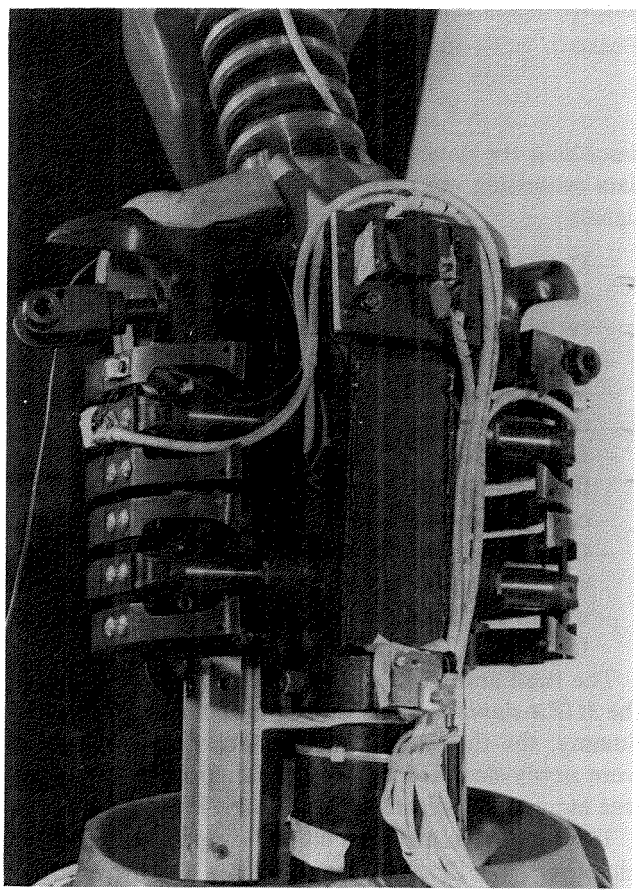


Figure 4. APR-thorax and TNO-abdomen.

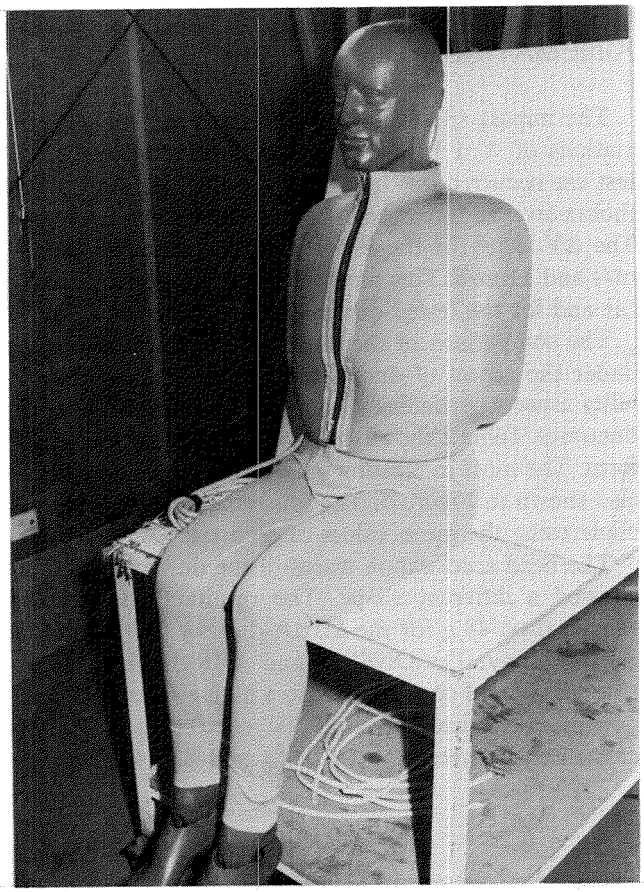


Figure 1. HSRI-dummy.

describing the data reduction procedures, the following data processing was carried out for the rib accelerometer signals:

—Data recording with a sampling rate of 8000 Hz
—Analog to digital conversion following the specification of channel class 1000 (SAE J 211b)
—Digital filtering of the data to class 180
—Subsampling data to a 1600 Hz sampling rate (reduction with factor 5)
—Digital filtering with Finit Impulse Response (FIR)-filter, passband frequency = 100 Hz for the rib accelerometer signals
—Calculation of injury predictor equations (B-factor of the left upper rib signal (BLUR)) and calculation of AIS and number of rib fractures (NRF) [4, 5] (see footnote in Table 1).

The head and neck, arms and lower leg assemblies of the *MIRA-dummy* are used from the standard Hybrid II-dummy, the thorax and shoulder, abdomen and pelvis were newly designed by MIRA. The dummy assembly was mounted as described in [6], (see Figure 2).

The thorax has six pairs of ribs, connected to the thoracic spine via 12 strain gauged plates which record the tensile and bending loads at the spine on each individual rib, (see Figure 2). These signals were recorded on both impacted and nonimpacted sides during tests. The resultant rib force on each rib was calculated by adding the mean values from the impacted and nonimpacted side. A deflection potentiometer was mounted on the 4th rib.

The pelvis was instrumented with a 3-axial load cell between the ilium and the spine, an uniaxial strain gauged force transduce at the acetabulum and one uniaxial strain gauged plate mounted across the pubic symphysis.

The accelerations of head, chest and pelvis were measured 3-axial.

The construction of the *ONSER-dummy* was different from the Hybrid II-dummy [7]. The thorax was developed for side impact testing by selecting a foam plastic for the thorax moulding to give a realistic load-deflection characteristic. The deflection of the thorax foam plastic was measured between the jacket and the thorax spine by means of a soft gear rack and a potentiometer, which is shown in Figure 3.

The shoulder consists of two spring supported pistons on each side which allow a shoulder instrusion and rotation.

Besides the above mentioned thorax deflection the ac-

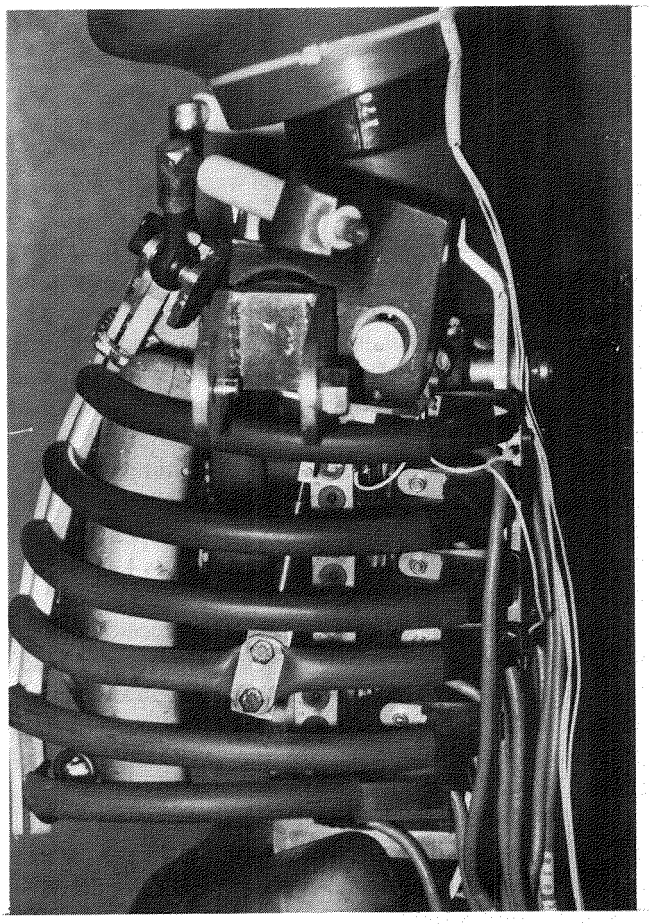


Figure 2. Thorax of the MIRA-dummy.

Table 1. Measuring data on different dummies.

		HSRI (DOT)	MIRA	ONSER	APR*
Head	accel. x	x	x	x	x
	accel. y	x	x	x	x
	accel. z	x	x	x	x
	accel. res.	x	x	x	x
	HIC	x	x	x	x
Chest	accel. x	x	x	x	x
	accel. y	x	x	x	x
	accel. z	x	x	x	x
	accel. res.	x	x	x	x
	deflect.	x	x	x	x[1)]
	accel. LUR, RUR[2)]	x	—	—	x
	BLUR[3)]	x	—	—	x
	SI	x	x	x	x
	res. rib forces	—	x	—	—
Pelvis	accel. x	x	x	x	x
	accel. y	x	x	x	x
	accel. z	x	x	x	x
	accel. res.	x	x	x	x
	force hip y	—	x	—	—
	force pubis y	—	x	—	—
	force pelvis x	—	x	—	—
	force pelvis y	—	x	—	—
	force pelvis z	—	x	—	—

[1)] Two transducers
[2)] LUR = left upper rib, RUR = right upper rib
[3)] BLUR = B-factor of LUR-signal
* additionally abdomen force (TNO-abdomen)
AIS = 1,49 · BLUR-6,68
NRF = 10,73 · BLUR-64,1

Table 2. Main dummy data for comparison.

	Dummy Type		HSRI (DOT)		MIRA		ONSER		APR	
	Test Series		ESH 1-3		ESM 4-6		ESO 7-9		ESA 10-13	
	No. of Tests		4		3		3		4	
			Mean 3 ms	Stand. Dev. (±)	Mean 3 ms	Stand. Dev. (±)	Mean 3 ms	Stand. Dev. (±)	Mean 3 ms	Stand. Dev. (±)
Head	accel. y	[g]	78	5,5	43	4,8	40	8,1	76	13
	accel. z	[g]	12	7,6	26	5,8	62	12	67	11
	accel. res.	[g]	83	5,7	48	3,0	65	11	98	7,6
	HIC[1]	[—]	536	57	115	23	354	79	835	131
Chest	accel. y C.G.	[g]	39	5,7	94	34	120	12	136	13
	accel. res. C.G.	[g]	44	6,5	106	27	123	15	157	21
	accel. rib 1[2]	[g]	142	16	—	—	—	—	183**	33
	SI[1]	[—]	263	81	958	296	1259	388	1758	469
	BLUR[1]	[—]	7,41	0,C3	—	—	—	—	7,7**	0,42
	defl.[1]	[mm]	47,5**	3,5	58*	(—)	73	9	43,5[3]*	(—)
	res ribforce[1]	[kN]	—	—	6,82	2,3	—	—	—	—
Pelvis	accel. y	[g]	156	5,6	101	5,5	113	16	145	11,2
	accel. res	[g]	162	7,4	107	6,1	143	13	169***	12
	pelvis force	[kN]	—	—	4,4**	0,57	—	—	—	—
	pubis force	[kN]	—	—	5,6**	0,78	—	—	—	—
	hip force y	[kN]	—	—	1,2	0,15	—	—	—	—

[1]Due to max. value.
[2]Off 300 Hz filtered values.
[3]Mean of upper and lower transducer.
*Of one test.
**Of two tests.
***Of three tests.

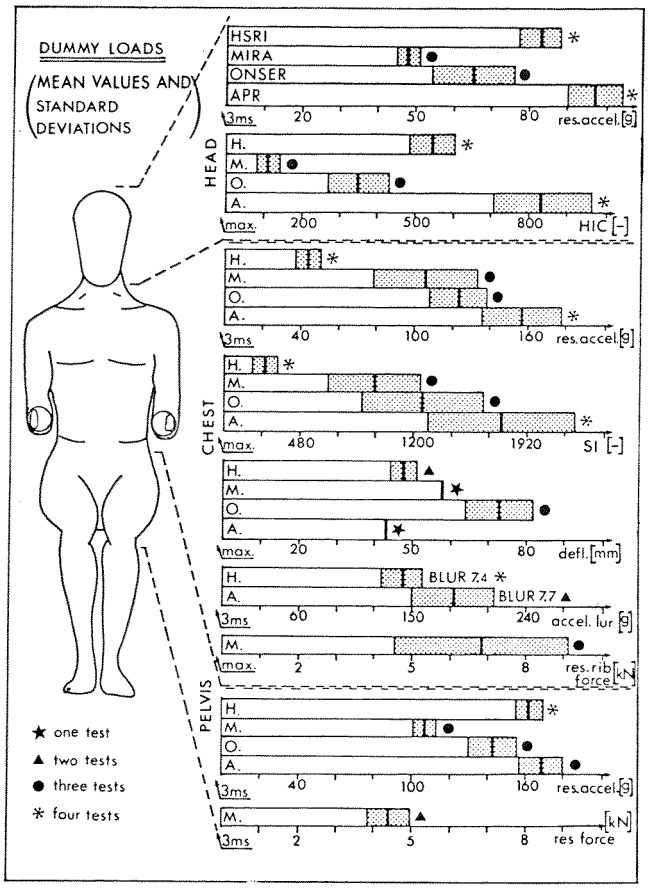


Figure 5. Dummy loads.

coefficients of variation for the resultant accelerations for all dummies were lower than 10%, except for the ONSER-dummy 17%. The variations for the HIC were much higher, for the MIRA- and ONSER-dummy about 20%, for the HSRI-dummy 11% and for the APR-dummy 16%.

The head bending of the different dummies in side window direction were similar for the ONSER- and MIRA-dummy and similar for the APR-and HSRI-dummy. No head impact against the side window occurred. Only the HSRI-dummy reached the side window level but the window was destroyed before that. The maximum head bending angles due to the vertical plane for the ONSER- and MIRA-dummy were 55–70° for the APR- and HSRI-dummy 80–105°.

The *thorax* responses of the different dummies also differed greatly. The resultant acceleration, mainly caused by the lateral component, was measured between 44 g for the HSRI- and 157 g for the APR-dummy, meaning a SI between 263 respectively 1758. For the MIRA- and ONSER-dummy a SI of about 1000 was calculated.

The coefficient of variation for the SI was, with about 30% for all dummies, very high. The acceleration of the left upper rib was measured for the HSRI-dummy to 142 g and for the APR-dummy to 183 g. Because of the low sensitivity of the BLUR and of the injury predicting parameters a BLUR of 7,4 for the HSRI- and of 7,7 for the APR-dummy was calculated, which means an AIS of 4,35 respectively 4,75 and a NRF of 15 respectively 18. The resultant rib forces of the MIRA-dummy had a mean value of 6,8 kN. The rib forces for single ribs showed very well the load distribution over the thorax, but with a partly poor repeatability.

The interpretation of the chest deflection had to be made very carefully because of the low number of successful measurements. The maximum internal chest deflections varied from ~ 43–73 mm for the different dummies. Film analyses of the external chest deflections were also not successful and are therefore not mentioned.

The thorax kinematics for the HSRI-dummy and the APR-dummy were similar. The bending angle of the thorax in door direction relative to the vertical plane varied for the HSRI-dummy 20 to 25° and for the APR-dummy between 15 and 20°. Both other dummies only reached 5–10°.

The *pelvis* accelerations of the MIRA-dummy with 107 g were the lowest, the ONSER-dummy had a resultant pelvis acceleration of 143 g and the dummies equipped with a Hybrid II pelvis (APR and HSRI) had similar values of about 165 g. The variations of the pelvis accelerations were very low (5–10%). The force measurements on the MIRA-dummy pelvis considering two transducer defects were successful and the repeatability with a coefficient of variation of less than 14% was sufficient.

COMPARISON OF DUMMY HANDLING AND DURABILITY

A comparison of the different dummy *handling* can only be made in comparison with the conventional Hybrid II-dummy. The ONSER-dummy and the APR-dummy were as easy to handle as the Hybrid II dummy, the HSRI- dummy had problems with the air-venting of the shock absorber and the MIRA-dummy with the magnitude of data channels. The magnitude of data channels must be also considered under the aspect that proposals exist to use more than one dummy in a side impact test. All the deflection transducers mounted by ourself or mounted by the dummy manufacturer were not sufficient during short impacts.

Except the HSRI-dummy all dummies had problems in respect to *durability.* The dummies with rib constructions had no damages to the ribs but the APR-dummy had problems with the easy outward motion of the rib supporting pistons and the ONSER- and MIRA-dummy with the shoulder construction. The neck of the APR-dummy at the level of the lower ball joint failed several times, because the rubber pieces left their original position. These damages must be seen also under the aspect of a possibly higher test speed in a standardized side impact test.

DISCUSSION OF TEST RESULTS AND CONCLUSIONS

The aim of this study was to compare 4 different dummies under the same test conditions in a full scale side impact test.

The test input parameters for the dummies: velocity of the rigid moving barrier, door intrusion etc., showed a good reproducibility but the dummy response of the different dummies varied much. In this project the differences in dummy response were discussed, the repeatability of dummy response of the same dummy in several identical tests was analyzed and dummy handling and durability studied.

On all dummies different techniques to measure the violence of impacts were used. For the thorax three different measuring methods are in use:

—chest deflection (internal, external)
—rib force
—rib acceleration, calculation of BLUR, AIS, NRF.

In addition, a problem that still needs to be discussed and settled is the comparison between identical measuring methods and their application on different dummies which originally had been developed for only one special measuring method.

Due to the comparable dummy loads it can be stated that the head response is completely different for the different dummies, as well accelerations and HIC. These differences can partly be explained by an additional z-component in the head acceleration normally occurring in lateral direction (ONSER, APR). The variation of head accelerations in single test series is lower than the variation of HIC. The head/neck-kinematics are influenced by the thorax behaviour.

In the thorax response the HSRI-dummy shows much lower accelerations (and SI) than all other dummies. The SI varies much for all dummies. The accelerations of the upper ribs, measured only on two dummies (HSRI and APR), are sufficiently reproducible signals and give therefore (and because of the low sensitivity) a low variation of the corresponding injury predicting parameters. The rib force measurement (MIRA-dummy) shows the force concentration onto single ribs quite well, but partly with a poor reproducibility. Because of several transducer defects not much can be said about the reproducibility of the chest deflection. Different thorax accelerations and single different chest deflection values of the different dummies lead to the assumption of different thorax stiffnesses.

The pelvis response shows the highest reproducibility and the dummies with the Hybrid II-pelvis show similar acceleration values, the others (ONSER-, MIRA-dummy) have lower values. The pelvis force measurement of the MIRA-dummy was sufficient and sufficiently reproducible.

Due to the kinematics of the dummies, they can be separated into two groups, first: dummies with a great head and thorax bending (HSRI(DOT),APR), second: dummies with a lower head and thorax bending (ONSER,MIRA). A conclusion due to the realism of the kinematic behaviour can not be drawn, because no cadaver data under the same test conditions exist.

From the described dummy handling and -durability problems the following suggestions for dummy improvement can be made. Because of several defects of the chest deflection transducers, these should be part of the dummy, should sustain impacts of short duration and record the chest deflection without vibration and interruption. This represents a suggestion applying to all dummies. For each dummy special improvements should be attempted:

—HSRI (DOT)-dummy:
  —mounting and air-venting of the "Taylor" shock absorber
  —MIRA-dummy:
  —reinforcement of the shoulder construction
  —adding and averaging the A and B rib strain guage signals on each rib side by hardwarde, meaning a reduction of rib force channels to the half of their
  —ONSER-dummy:
  —easy motion possibility of the shoulder pistons also during short (oblique) impacts
  —APR-dummy:
  —easy motion possibility of the chest deflection pistons also during short (oblique) impacts
  —construction of the neck at the lower ball joint level.

In the critical examination the main emphasis should be placed on the aspect of biofidelity of the dummies. This was not a task of this project. An overall assessment of dummy behavior, especially under the aspect of biofidelity, will be made under inclusion of the results of the other contracting institutes. This will be done by TNO till the end of this year.

REFERENCES

1. EEVC: Working Group "Structures", Improved Side Impact Protection in Europe, 9th ESV-Conference 1982.
2. Melvin, J. W., et al.: Experimental Application of Advanced Thoracic Instrumentation Techniques to Anthropomorphic Test Devices, 7th ESV-Conference 1979.
3. Robbins, D. H. et al.: Assembly Procedures for HSRI-Side Impact Dummy Thorax, NHTSA DOT-HS-4-00321, 1980.
4. Eppinger, R. H. et al.: Development of a Promising Universal Thoracic Trauma Prediction Methodology, 22nd Stapp Car Crash Conference 1978.
5. Robbins, D. H., Lehmann, R. J.: Prediction of Thoracic Injuries as a Function of Occupant Kinematics, 7th ESV Conference, 1979.

6. MIRA Side Impact Dummy—Brief Specification for EEC Biomechanic Programme, Phase IV, MIRA 1982.
7. Cotte, J. P.: The ONSER 50 Dummy—A Research Tool for Safety, 8th ESV-Conference, 1980.
8. Fayon, et al.: Development and Performance of the APR-Dummy (APROD), 8th ESV-Conference, 1980.
9. Maltha, J., Stalnaker, R. L.: Development of a Dummy Abdomen Capable of Injury Detection in Side Impacts, 25th Stapp Car Crash Conference, 1981.

Side Impact: A Comparison Between HSRI-, APROD-, and HYBRID II Dummies and Cadavers

G. KLAUS
Volkswagenwerk AG, Wolfsburg, Chairman of FAT Working Group 5, "Biomechanics"
D. KALLIERIS
Institute for Forensic Medicine, University of Heidelberg

ABSTRACT

The effectiveness of vehicle engineering measures to increase passive safety will be examined by means of experimental simulation utilizing dummies. Suitable dummies, which can be used to simulate loadings on vehicle occupants during real accidents, must be available in order to be able to transform these results into real world accident scenarios.

Within its Working Group 5 "Biomechanics", the German Research Association for Automobile Technology (Forschungsvereinigung Automobiltechnik e.V., abbreviated "FAT"), an association of German automobile manufacturers (Verband der Automobilindustrie e.V., abbreviated "VDA") has set for itself the task to determine whether the HSRI dummy or the APROD dummy, which were newly developed especially for the side impact, will best correlate with the cadavers behavior. This is a further step within the extensive field of biomechanics to evaluate the relationships between protection criteria and occupant protection during a side impact. Along with the HSRI- and APROD dummies, the Hybrid II dummy was also examined since this dummy has been employed for some time in experimental simulation of side impacts.

This report describes, and presents the initial results of, "FAT" activities in the indicated research project.

INTRODUCTION

The work by the Forschungsvereinigung Automobiltechnik e.V., FAT, in the field of biomechanics, that is described in this report, is part of the FAT Research Project "Loading Limits and Injury Mechanics of Vehicle Occupants Wearing Seatbelts During Side Impact Collisions", a successor project to that of the same name for frontal impacts.

The study will be completed by the FAT Working Group 5, "Biomechanics". It is supported by the Arbeitsgemeinschaft Industrieller Forschungsvereinigungen e.V. (Industrial Research Associations Working Group, abbreviated "AIF"). The Institute for Forensic Medicine, University of Heidelberg, Professor Georg Schmidt, is the Contractor.

The objective of the project is to measure accelerations and forces on various dummies and cadavers by means of experimental simulation of a 90° vehicle-to-vehicle side impact, and to determine kinematics. Cadaver injuries are to be analysed and correlated to mechanical loadings. The tests have been initiated with the goal of being able to develop a statement regarding the suitability of the dummies for experimental simulation through comparison of the loadings and kinematics of the dummies examined with those of cadavers.

The Committee of Common Market Automobile Constructors (CCMC) has expressed its willingness to make available the Deformation Element of the Deformable Barrier that it developed for the simulation of 90° side impacts. The deformation behavior of the front structure of the striking vehicle, which corresponds to a mid-size European vehicle, will be simulated during a side impact at 50 km/h with this element.

The report describes the status of the project. Initial results are given.

STATEMENT OF WORK

The contractor shall complete the following tests:

—Cadaver Tests	:	15
—HSRI Dummy Tests	:	5
—APROD Dummy Tests	:	5
—Hybrid II Dummy Tests:		5

Kinematics and loading of dummies and cadavers are to be cross-compared and assessed. Additionally, cadaver injuries are to be determined according to AIS. The reproducibility of the tests under the same test parameters is to be examined.

TESTS AND TEST PARAMETERS

Striking and Struck Vehicles

Experimental simulation of a 90° vehicle-to-vehicle side impact will be accomplished with pre-defined test rigs (Figures 1 and 2). Figure 3 shows the test rigs before and after the test.

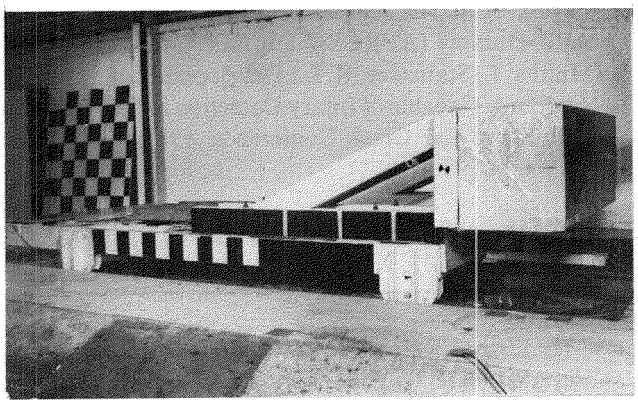


Figure 1. Side view of the sled with the CCMC deformation element used to simulate the striking vehicle.

—Striking Vehicle

The sled already available at the institute was used as the striking vehicle. This was fitted with one part of the CCMC barrier frame and the CCMC Deformation Element was mounted on the front of the frame (CCMC Report 1981). The weight of the striking vehicle, consisting of the sled, CCMC barrier frame, Deformation Element, and supplemental weights, amounted to 950 kg (Figure 1).

—Struck Vehicle

An Opel Kadett body mounted on a movable platform (dolly), was used as the struck vehicle (Figure 2). The weight of the struck vehicle, consisting of the dolly (Figure 4), car body, seat, test subject and supplemental weights, also amounted to 950 kg. The vehicle was impacted under an angle of 90° at a collision speed of 50 km/h.

Significant details of the test setup are defined as follows:

—Mass relationship of the vehicle with mounted superstructure:
$\mu = 1: m_1 = m_2 = 950$ kg
—Speed of the:
striking vehicle: 50 km/h
struck vehicle: 0 km/h
—Impact angle: 90°
—Impact point: SR
—Vehicles:
striking vehicle—sled with CCMC Deformation Element
struck vehicle—dolly with a mounted Opel Kadett two-door carbody
—Occupants: HSRI-, APROD-, Hybrid II Dummies, or Cadavers
—Seat position: on the impacted side, middle seat position
—Restraint system: 3-Point Automatic Belt
—Side windows and steering wheel removed.

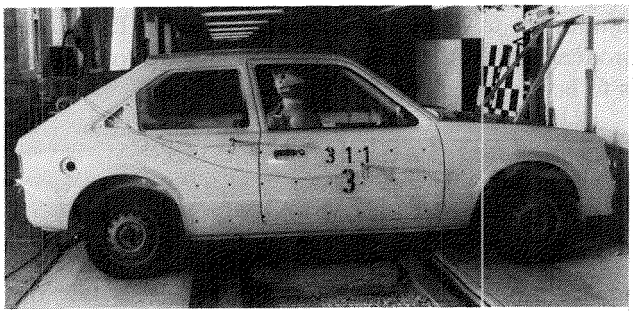
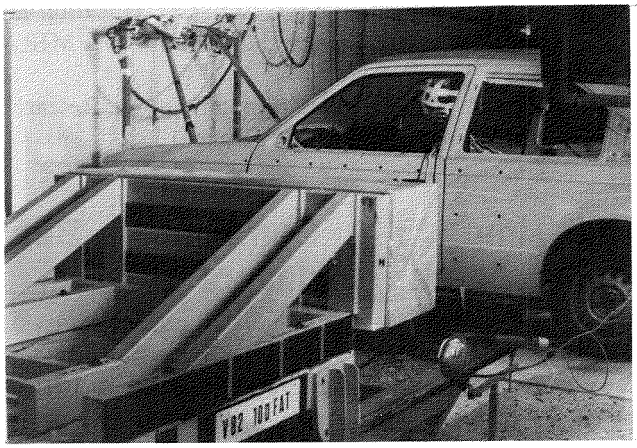


Figure 2. Side view of struck vehicle with Opel Kadett carbody.



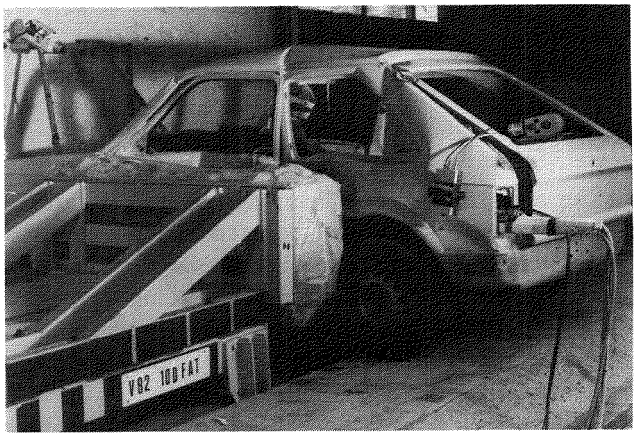


Figure 3. Deformable barrier and the Opel Kadett carbody on the dolly, before and after the crash.

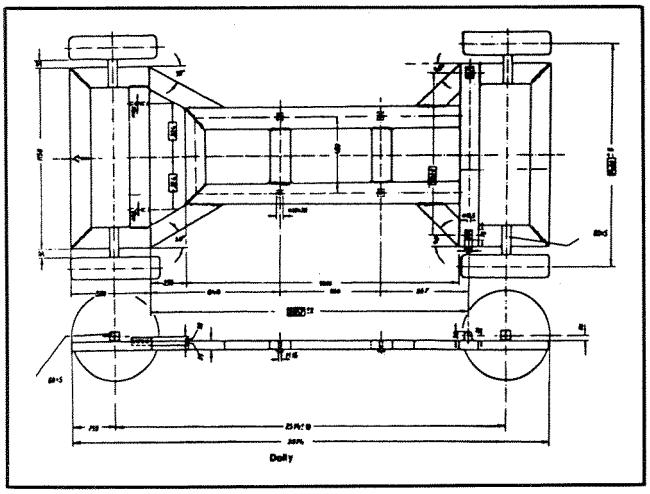


Figure 4. Design drawing of the movable platform (dolly).

Test Subjects

Dummy

Dummies under study are: the Side Impact Dummy developed by the Highway Traffic Safety Research Institute (HSRI), the omnidirectional Side Impact Dummy developed by the Association Peugeot-Renault (APROD), and the Hybrid II Dummy.

The HSRI Dummy was made available by NHTSA, the APROD Dummy by APR, and the Hybrid II Dummy by Opel AG.

Cadavers

Age, height and weight of cadavers for this project should be within the following areas:

—Age: 25–65 years
—Height: 165–180 cm
—Weight: 650–800 N

Measuring System

Two FM telemetry systems were employed for recording measurement data; four sets of 10 measurement channels to one multiplex system (direct channels) in each case. Multiplex signals were transmitted via cable and stored direct on an analog magnetic tape recorder. FM channels were used to register intrusion measurement with an inductive motion sensor.

Measurement Points

Striking Vehicle

Deceleration along the X-axis.

Struck Vehicle

Acceleration at the dolly along the Y-axis; acceleration at the inner side of the struck door along the Y-axis, and intrusion was measured at the inner side of the door and in the vicinity of the B-Pillar with an inductive motion sensor (Figure 5). As a cross-check, intrusion was optically determined with a marked telescoping rod (Figure 5).

The physical portion of deformation in the struck area was measured at the outside and the inside at 24 fixed points (Figure 6).

Test Objects

—Dummy

Head: acceleration at the head center of gravity, 3 axes, right and left in the Y and Z directions (Schmidt et al., 1978).

Figure 5. Inductive motion sensor (WA) and marked telescoping rod (TS).

Thorax: accelerometers as per the method recommended by NHTSA (Robbins et al., 1976, Figure 7).

Sternum, upper:	X-axis
Sternum, lower:	X-axis
4th Rib, left:	Y-axis
8th Rib, left:	Y-axis (X-axis)
4th Rib, right:	Y-axis
8th Rib, right:	Y-axis
Thorax vertebra 1 (T1):	3 axes

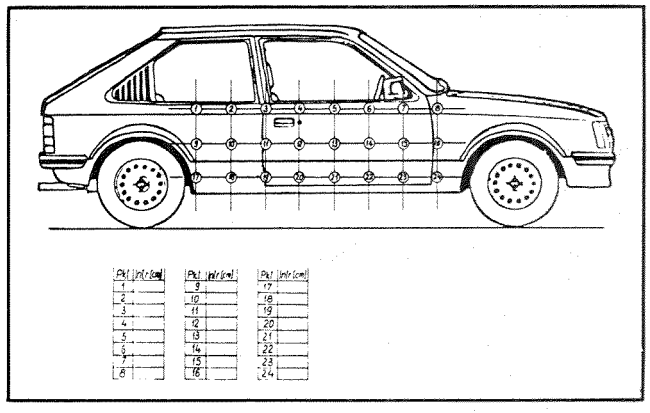


Figure 6. Deformation measurement points in the struck area at the outside and the inside ar 24 fixed points.

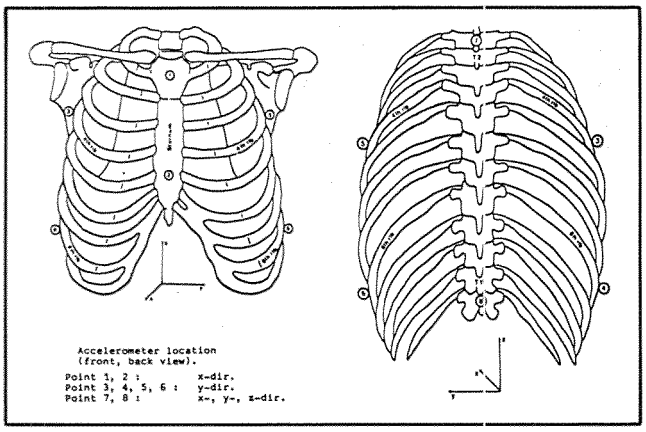


Figure 7. Locations of the thorax accelerometer of the 12 components method.

Thorax vertebra 12 (T12): 3 axes
Pelvis:
At the sacrum: 3 axes
At the center of gravity: 2 axes (X-Axis, Y-Axis)

—Cadaver
Head: acceleration right and left in the Y and Z axes
Thorax: 12 acceleration component measurement in keeping with NHTSA (as with the Dummy)
pressure on the lungs
Pelvis: At the sacrum, 3 axes

Measurement Evaluation

Measurement evaluation was accomplished at VW-AG. Head signals were filtered pursuant to SAE J 211a according to channel class 1000; chest and pelvis signals according to channel class 180, and the vehicle acceleration signals and seatbelt force signals according to channel class 60.

Photographic Documentation

The collision phase was documented with three high-speed cameras (stationary and onboard) at 500, 600 and 1000 frames per second.

FIRST TEST RESULTS

Partial results from 5 HSRI-, 4 APROD-, and 4 Hybrid II Dummy Tests and 8 Cadaver Tests are given in the following figures.

Figures 8-27 cross-compare the accelerations of the 4th rib on the impacted side, the 1st thoracic vertebra (T1), and the sacrum, as well as the head deflection angle, of the individual test subjects as a function of time.

For each test subject group the figures show the mean acceleration/time curve and the outer boundary of the

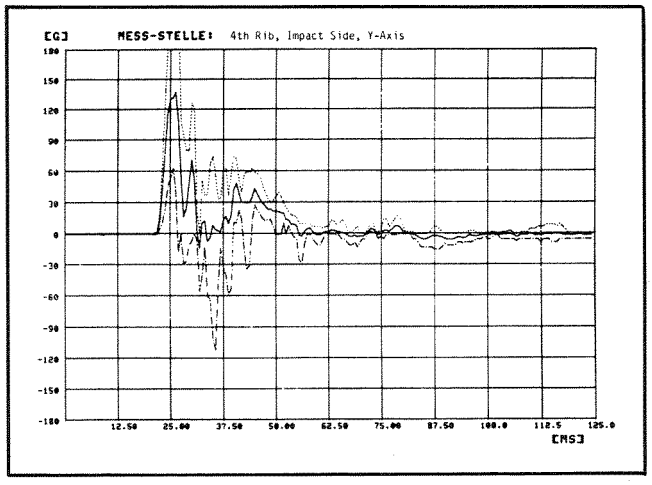


Figure 8. Lateral accelerations of the 4th APROD rib highest, mean and lowest values of 4 tests.

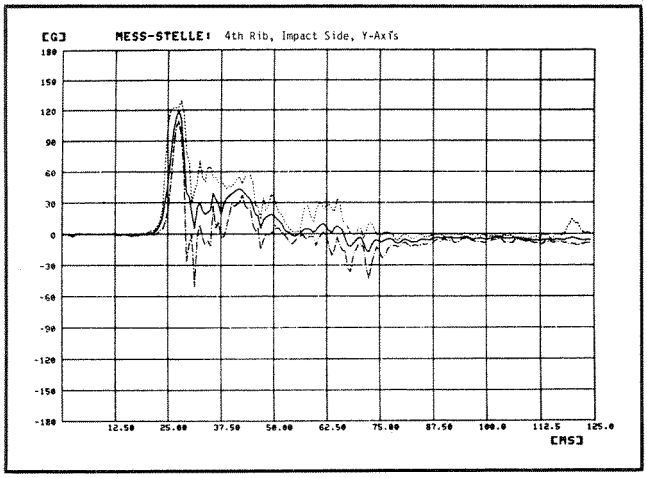


Figure 9. Lateral accelerations of the 4th HSRI rib highest, mean and lowest values of 5 tests.

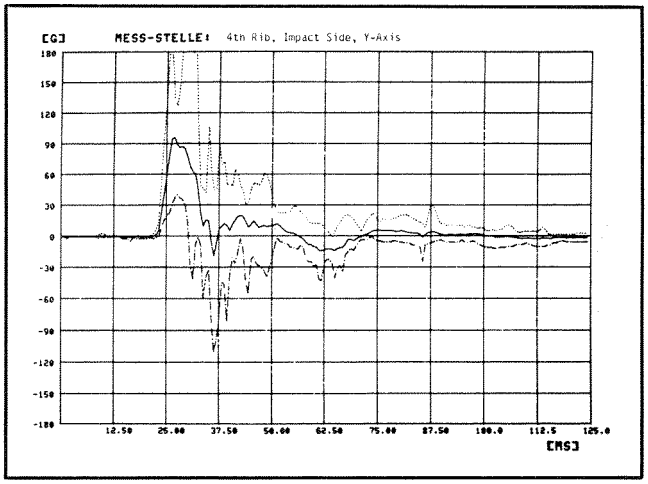


Figure 10. Lateral accelerations of the 4th cadaver rib highest, mean and lowest values of 8 tests.

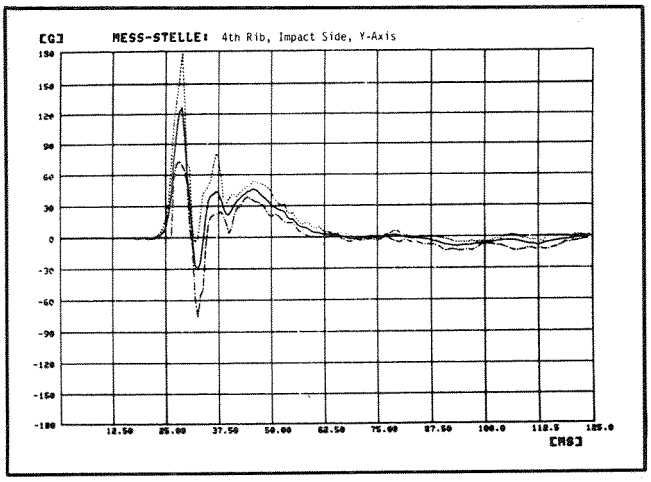


Figure 11. Lateral accelerations of the 4th Hybrid II rib highest, mean and lowest values of 4 tests.

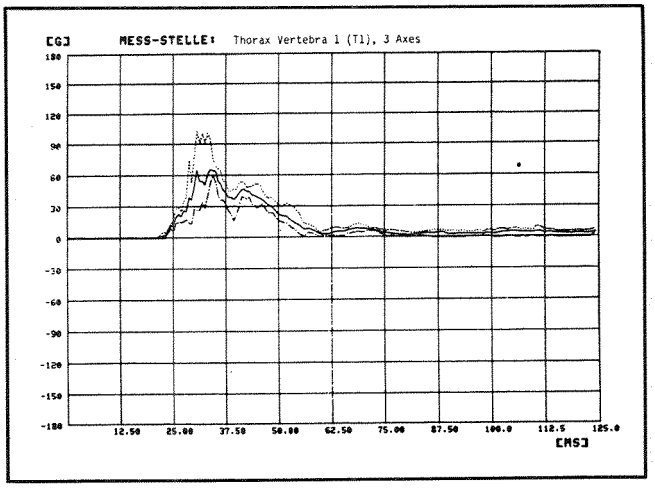


Figure 12. Resultant APROD upper thorax accelerations highest, mean and lowest values of 4 tests.

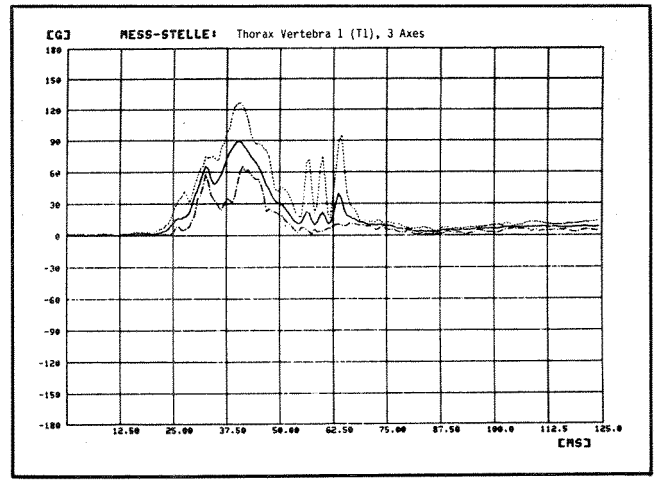


Figure 13. Resultant HSRI upper thorax accelerations highest, mean and lowest values of 5 tests.

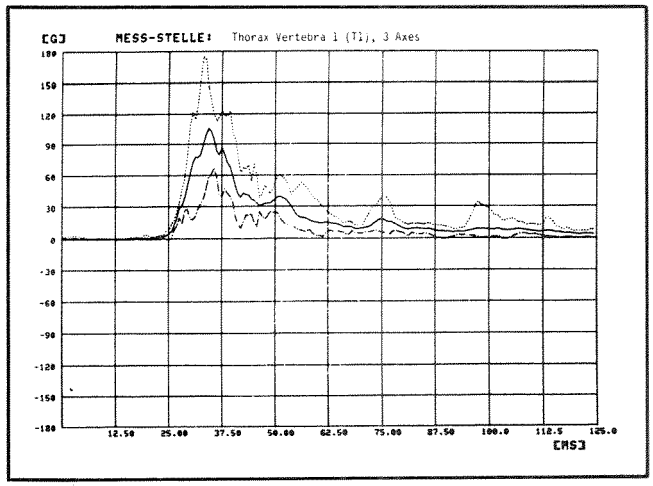


Figure 14. Resultant cadaver upper thorax accelerations highest, mean and lowest values of 8 tests.

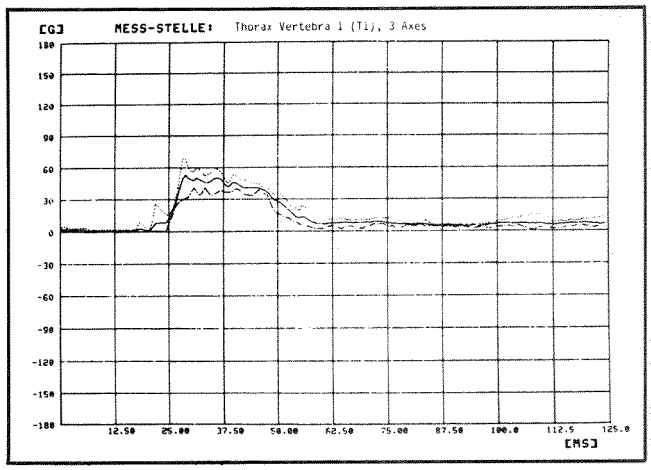


Figure 15. Resultant Hybrid II upper thorax accelerations highest, mean and lowest values of 4 tests.

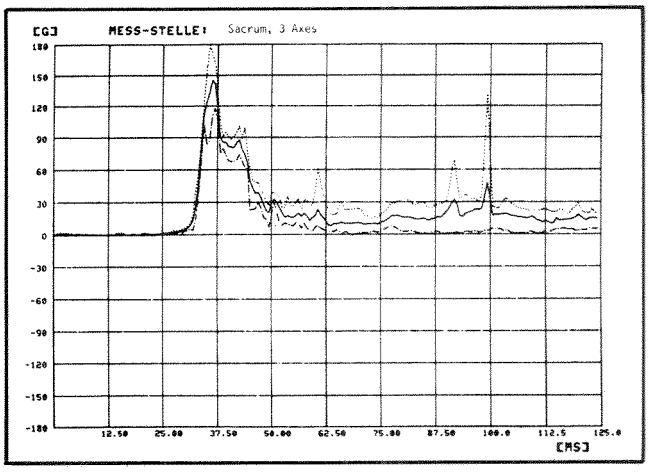


Figure 16. Resultant APROD sacrum accelerations highest, mean and lowest values of 4 tests.

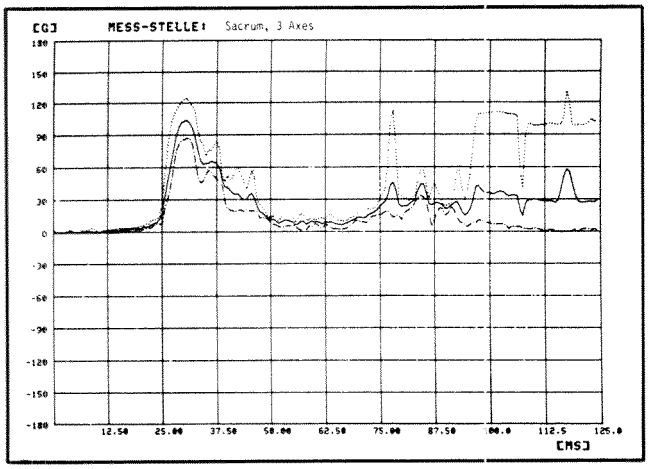


Figure 17. Resultant HSRI sacrum accelerations highest, mean and lowest values of 5 tests.

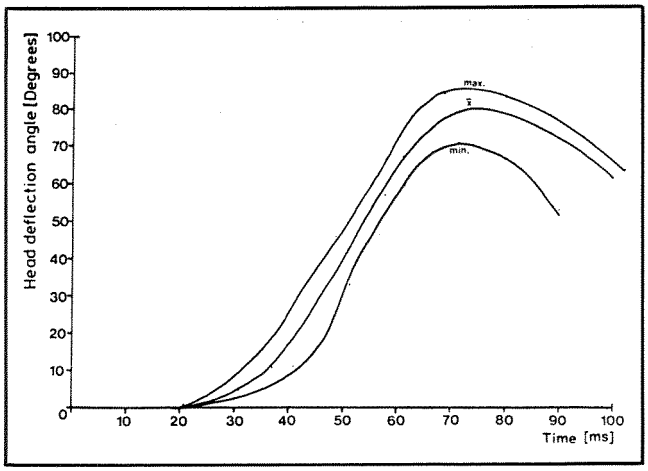


Figure 20. APROD head deflection angles highest, mean and lowest values of 4 tests.

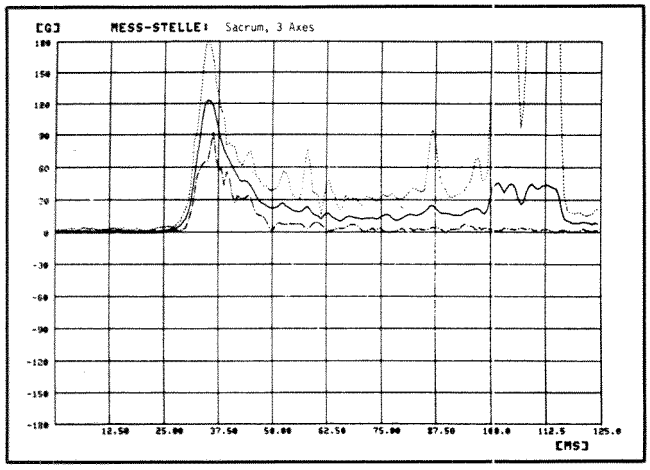


Figure 18. Resultant cadaver sacrum accelerations highest, mean and lowest values of 8 tests.

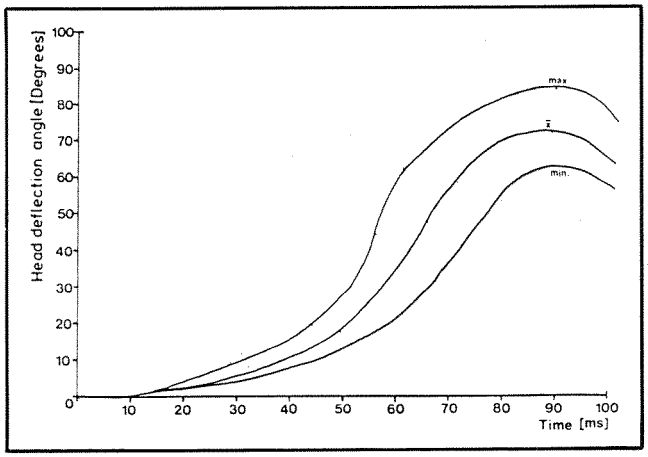


Figure 21. HSRI head deflection angles highest, mean and lowest values of 5 tests.

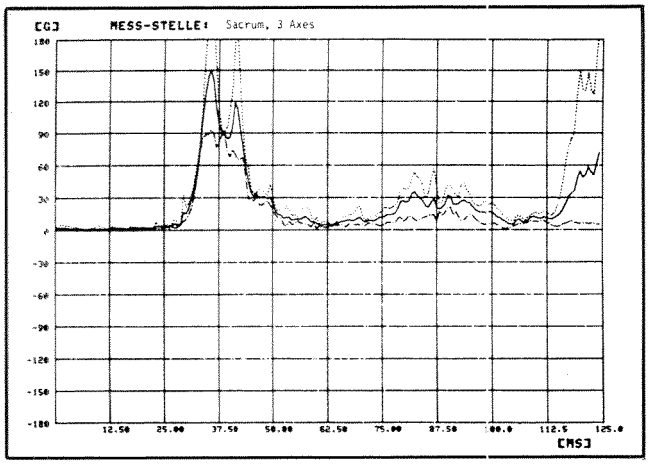


Figure 19. Resultant Hybrid II sacrum accelerations highest, mean and lowest values of 4 tests.

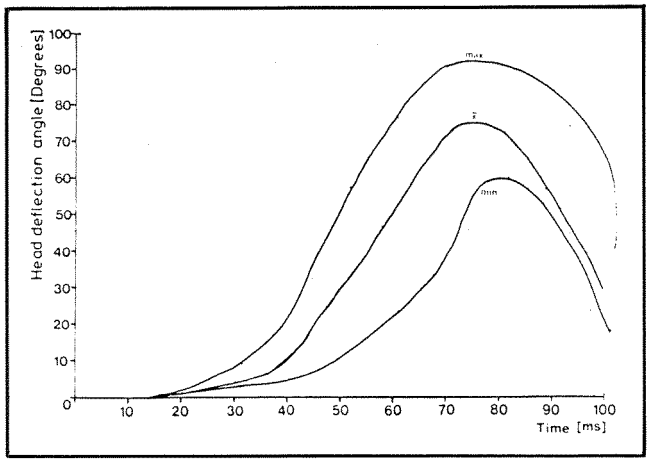


Figure 22. Cadaver head deflection angles highest, mean and lowest values of 6 tests.

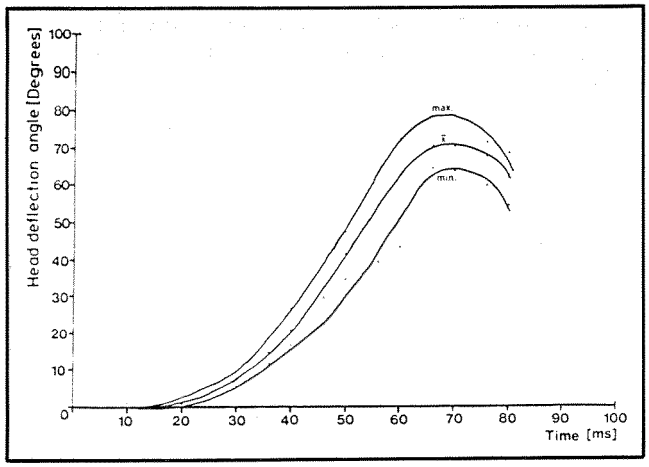


Figure 23. Hybrid II head deflection angles highest, mean and lowest values of 4 tests.

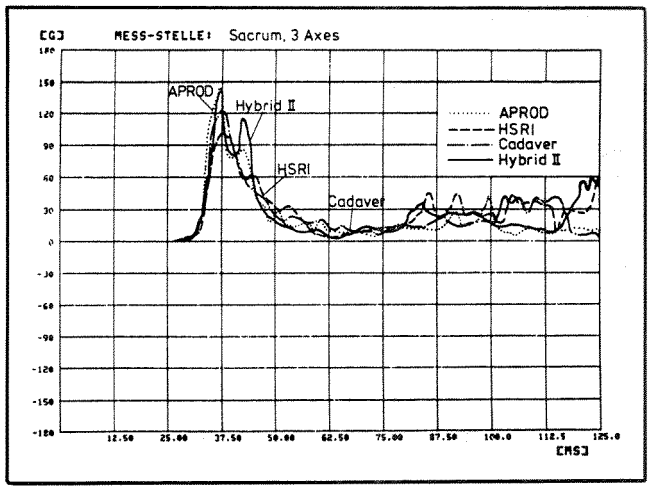


Figure 26. Mean resultant sacrum accelerations of APROD-, HSRI- and Hybrid II dummies and cadavers.

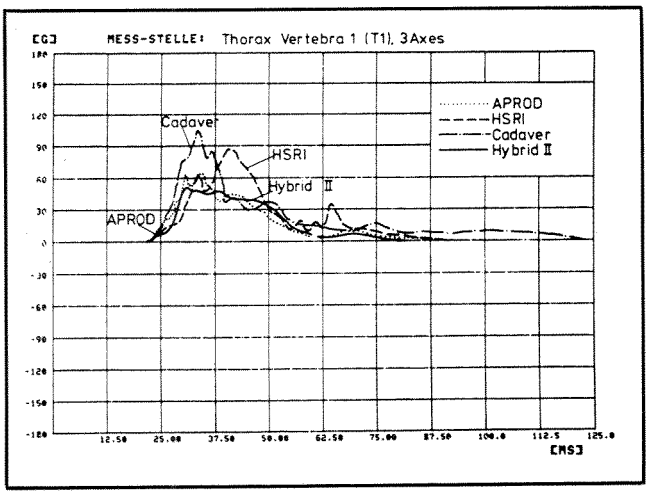


Figure 24. Mean resultant upper thorax accelerations of APROD-, HSRI- and Hybrid II dummies and cadavers.

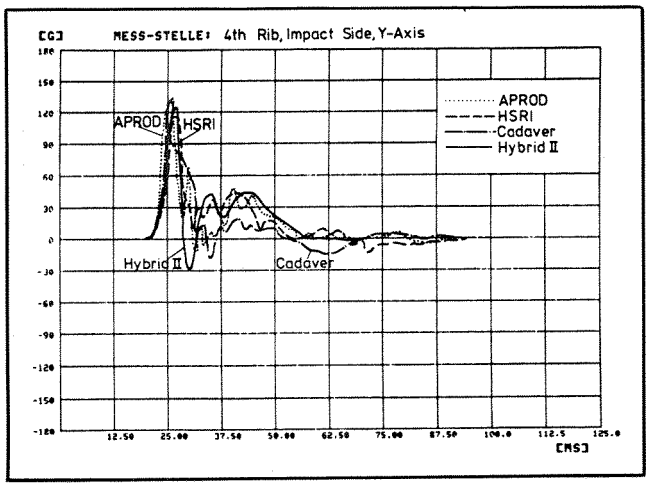


Figure 25. Mean resultant 4th rib accelerations of APROD-, HSRI- and Hybrid II dummies and cadavers.

acceleration/time field. It was necessary to adjust a few curves in time so that the start of acceleration at the applicable measurement point is the same within the text subject group. Placement in time of accelerations of individual measurement points with each other is thus not always assured. This will be documented for the individual tests in the final report.

Comparison of the mean acceleration/time curves shows the great variances between the dummies and the cadavers, particularly to Thoracic Vertebra 1 (Figure 24). The behavior here of the Hybrid II and the APROD dummies is similar. The curves in the first phase of the dummies are nearly the same in the area of the 4th rib (Figure 25). These differ in amplitude and time from those of cadavers.

The mean acceleration/time pattern for dummies and cadavers deviated less in the sacrum area (Figure 26). Figure 27 shows the mean curves of the head deflection angle as a function of time. Angular velocity is approx-

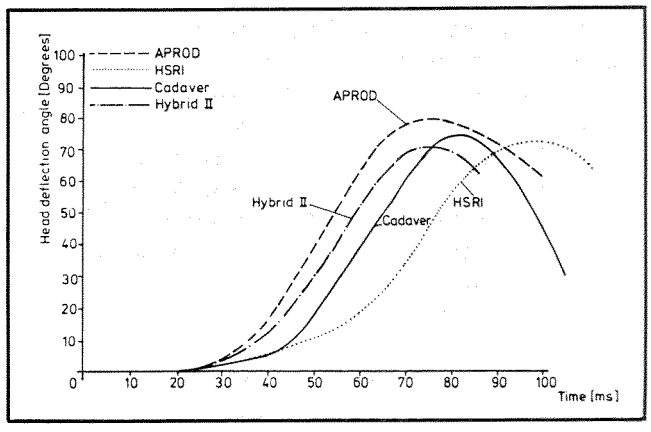


Figure 27. Mean head deflection angles of APROD-, HSRI- and Hybrid II dummies and cadavers.

imately the same at the beginning for the APROD and Hybrid II dummies and higher than that of cadavers and of the HSRI dummy. The mean maximum deflection angle is approximately the same for the cadavers and for the Hybrid II and HSRI dummies but smaller than that of the APROD dummy.

CONCLUSIONS

The initial results discussed in this status report of the ongoing project do not yet allow generally applicable statements to be made regarding the compatibility of the dummies examined but it can be said that all of the dummies examined must still be refined and are not yet ready for experimental simulation.

The test series has still not been completed and, additionally, loads were only determined at one collision speed and for one specific test configuration. The initial comparison, that has still not been accomplished with statistical procedures, of the mean acceleration/time and head deflection angle/time patterns in this report indicates that the development of the dummies examined, which were especially designed for the side impact, is still not complete. This finding is also confirmed by the fact that some of the dummies had unexpected structural failures.

Analysis of the results of this project could supply a contribution toward a more accurate simulation of side impact dummy behavior to the behavior of cadavers. It would be logical to correlate dummy loadings with cadaver injuries, and to derive protection criteria or loading limits respectively for belted occupants during a side impact, only after the loadings and the kinematics of dummies and cadavers are similar.

The final results will be made available towards the middle of the next year.

These results will show to what extent under these test conditions the behavior of the dummies is in conformity with that of the cadavers, thus enabling the necessary conclusions to be drawn with regard to the dummy modification and protection criteria.

Injury Criteria in Lateral Collisions, When an APROD Dummy is Used

B. HUE, C. TARRIÈRE, Y. C. LEUNG, and A. FAYON
Laboratory of Physiology and Biomechanics, Peugeot S.A./Renault

C. GOT, A. PATEL
I.R.O.-I.R.B.A., R. Poincaré Hospital, Garches, France

ABSTRACT

Modifications brought to APROD dummy since the 8th ESV Conference in Wolfsburg are presented and explained. They result in new features of biofidelity and of dynamic response as regards the main body segments. Simultaneously, the injury criteria to be associated to the use of APROD in lateral collisions are discussed. They include in particular the case of the abdomen. Besides, the new head and neck assembly is matched to HIC 1500 and the thorax to a relative deflection criterion which is commented upon.

SINCE THE EIGHTH ESV CONFERENCE, numerous studies concerning biomechanics and future dummies have been performed. In particular, many researches were carried out in the framework of contracts with the E.E.C. They resulted in more precise requirements to be met by dummies; besides, their dynamic response was investigated. The APROD dummy underwent consequently several modifications; the purpose of this paper is related to this development and its consequences on the possible injury criteria when using the APROD.

TECHNICAL EVOLUTION—Three main grounds triggered the changes brought to APROD; they concern biofidelity, accidentological data and mechanics, respectively.

New biomechanical data are available which define the human head response to direct lateral impact, and which define the head kinematics, due to the neck response, when the body is pushed sidewards. To a certain extent, the APROD head and neck assemblies were modified accordingly.

Accidentological data showed the weight of abdominal injuries in lateral collisions (7). The abdominal section built by TNO (12) from APR data (7) is able to detect the likelihood of injuries and was incorporated with APROD body.

Dynamic testing showed some shortcomings of the previous APROD thorax. A mechanical analysis of the thorax response was performed which resulted in structural modifications.

These sundry improvements will be detailed below for each body segment.

Neck—For reasons of mechanical resistance and consistency of accelerometric measurements at the level of the head, the Part 572 dummy neck (which equipped

previously the APROD dummy) is essentially constituted with a hard rubber, cylinder. The inferior face of this rubber block stays integral with the thorax and the superior face with the head base. It arises from that a low magnitude of the head/neck relative displacement. Furthermore, the curvature radius of the head trajectory is too short (Fig. 1).

The analysis of car-to-car reconstructions and sled tests carried out with cadavers shows a very different response of the human subject head if the thorax is struck sideways. One can discern a translation phase which delays the tilt of the head and is due to its inertia when forces and torques transmitted by the neck are too low. Then comes an important rotation phase, if no impact occurs.

If these kinematics are analyzed, two rotation centers appear, each one being situated near the interfaces head/neck or neck/thorax, respectively.

Figure 1 shows other noticeable features of the human head and neck kinematics under the Ewing's test conditions (8) with 22 kph and 7 g.

In particular, the maximum angles reached by the head and the neck, and the maximum head sidewards displacements relatively to the thorax are mentioned.

In order to achieve an improved simulation of the human head bending motion during side impact, researches were devoted to modifications to be brought to the Hybrid III neck (the middle part of which is more flexible), in the areas of the head/neck and neck/thorax interfaces. One half-sphere was arranged at each neck extremity; both half-spheres were connected by a tensioned cable. The inclination of the head depended upon the neck rigidity and also upon the frictions between the half-spheres and their sockets, according to Figure 2.

The braces of rubbers that were placed between the head or the thorax respectively and the extremity of the neck play an important role in head-neck kinematics.

As for other modified body segments, the results obtained will be presented in the next section of the paper.

Head—As the modified neck is longer than the one which equips the Part 572 dummy, a Hybrid III head was chosen. This one allows to keep the same erect sitting

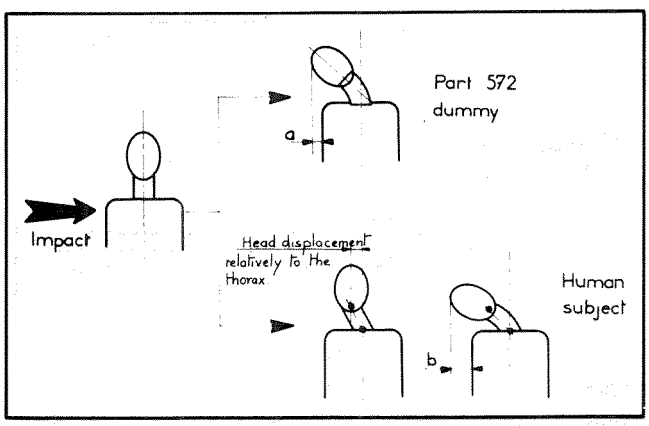


Figure 1. Neck motions in lateral impact.

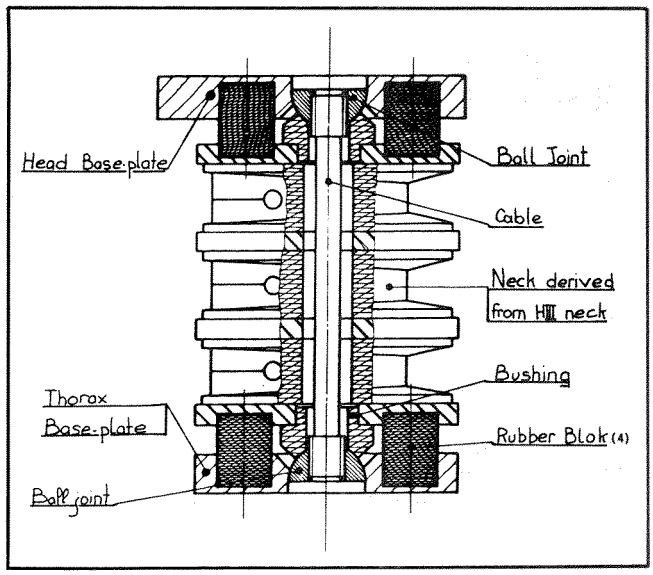


Figure 2. Sketch of APROD 82 neck.

height; besides, more humanlike impact responses are expected. These impact responses were not defined in the available literature. In the frame of an EEC research programme, cadaver drop falls were carried out onto paddings, the impact occurring on the parietal area of the head. Although the results of these tests are not yet complete (by the way, they are to be published by spring 1983), the duplication of these tests with the APROD dummy equipped with a Hybrid III head seems to indicate that the use of a Hybrid III head confers a more humanlike impact response. Particularly, the HIC levels are very close to those obtained during some cadaver tests.

Shoulder-clavical-arm—No modifications to note since the versions presented at the last ESV Conference. As a reminder, since 1980, APROD is equipped with clavicles in molded compact polyurethane with steel inserts, and such a clavicle was tested at speeds of up to 40 kph in rigid impacts.

Thorax—Three points have to be recalled concerning the requirements to be met by a lateral dummy thorax.

1) Only a proper stiffness of the thorax allows to get an accurate deformation of the side wall of the vehicle (Fig. 3), which may be equipped with paddings.

2) It is essential to duplicate the thorax deformation because the measurement of this deformation (called thoracic deflection) is a good injury predictor as previously presented (5).

3) A humanlike deformation of the thorax and the shoulder area is needed to enable a correct simulation of a possible head impact.

Lateral impacts with cadavers already published (1)(2) enabled to define the curve of force versus deflection of the impacted half-thorax (Fig. 4). Therefore, an important capacity of deformation had to be brought to the dummy thorax.

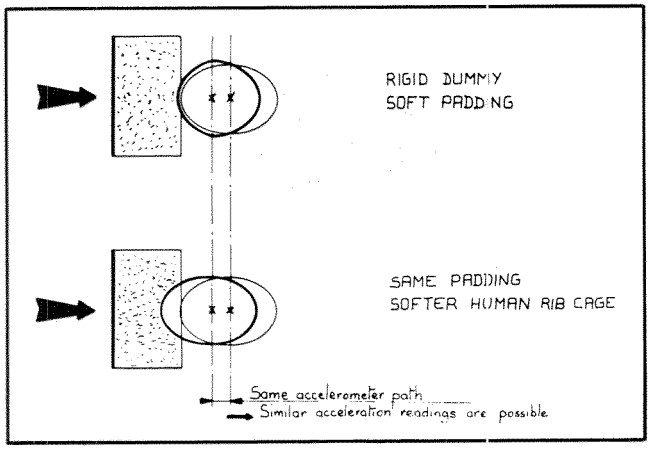


Figure 3. Stiffness of dummy rib cage must be human like and matched in padding stiffness.

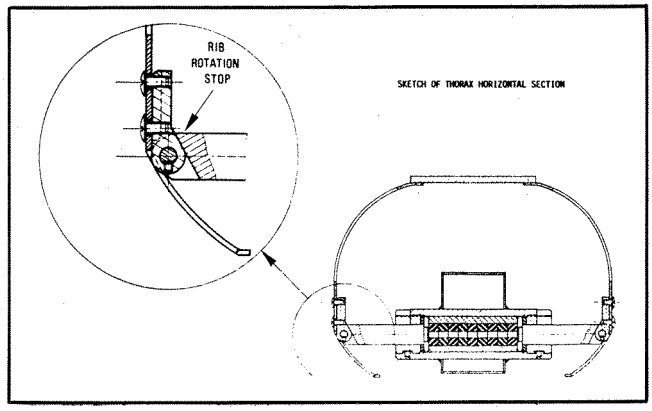


Figure 5. APROD 80.

APROD 80—In 1980, the horizontal section of the dummy's thorax was as presented on Figure 5.

A horizontal cylinder can be seen; two such cylinders are superimposed and each one of them corresponds to 3 pairs of ribs. The square crosssection of the pistons was designed to prevent the rib cage from collapsing diagonally when compressed in antero-posterior direction.

To get the previously shown force-deflection characteristics of the thorax, the main adjustment parameters were compression disks located inside the horizontal cylinders and the rib thickness.

APROD 81—Because a jamming of the pistons was noted, the APROD design was reviewed to get rid of this undesirable phenomenon.

If one looks to a simplified horizontal crosssection of the thorax, it appears that offset or oblique impact forces develop reaction forces on piston bearings, and therefore they increase friction.

It was noted that a modification of the joints between ribs and pistons could drastically diminish the reaction forces. The corresponding principle is shown on Figure 6. The limitation of the ribs outwards rotation, relatively to the pistons, is provided on the opposite side to impact, contrary to 1980 version.

Figure 7 shows the horizontal crosssection of APROD 81: the square section of the deflection tubes disappears.

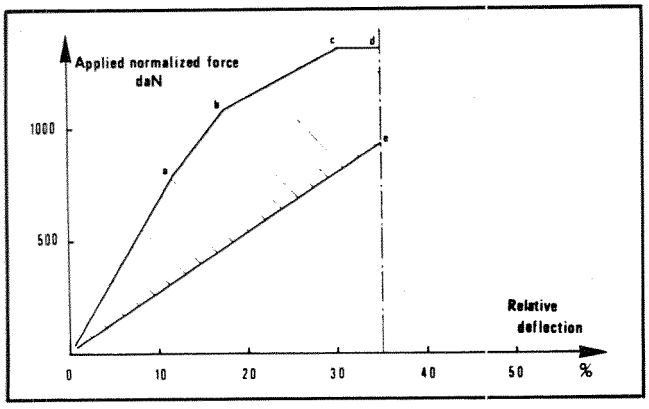
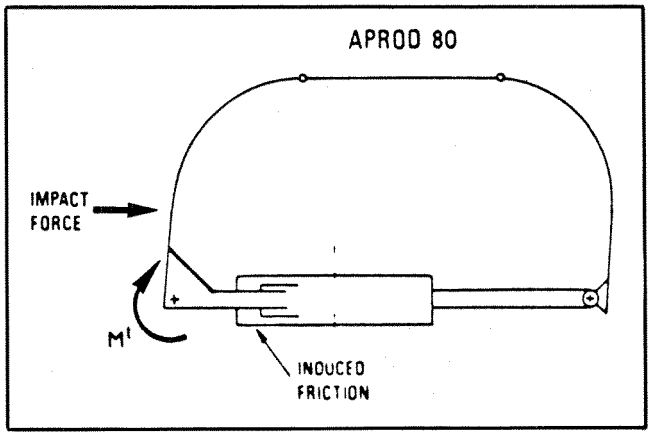


Figure 4. Corridor for force/deflection characteristic of the dummy.



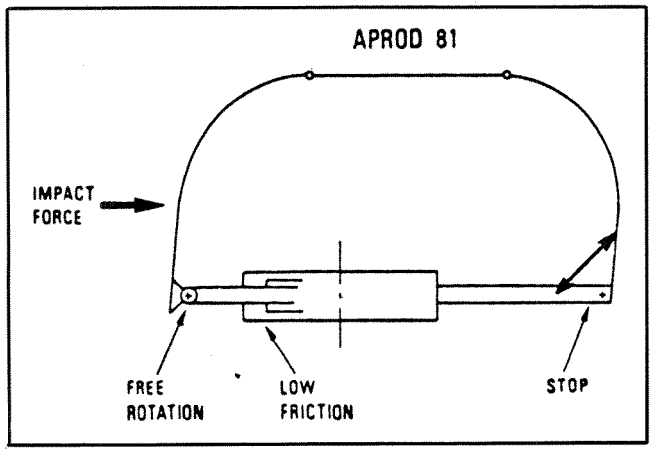
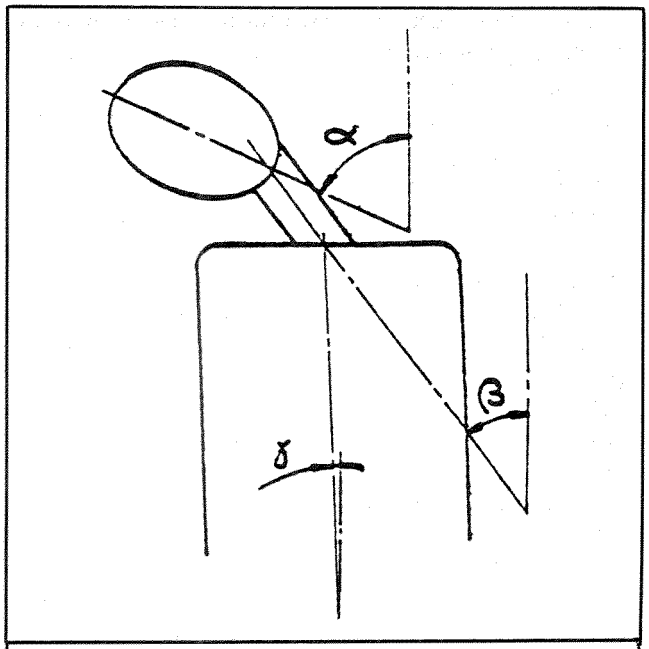


Figure 6. Principle sketch of the 80 and 81 rib cage kinematics.



	α	β	γ	α − γ
APROD 82**	61	48	9	52
Cadaver	72	108*		
Volunteer	68	103*		

*Due to the head rotation around its z-axis, that displaces the targets, these values exceed the real ones.
**When new neck and TNO abdomen are fitted simultaneously on APROD 81, is referenced as APROD 82.

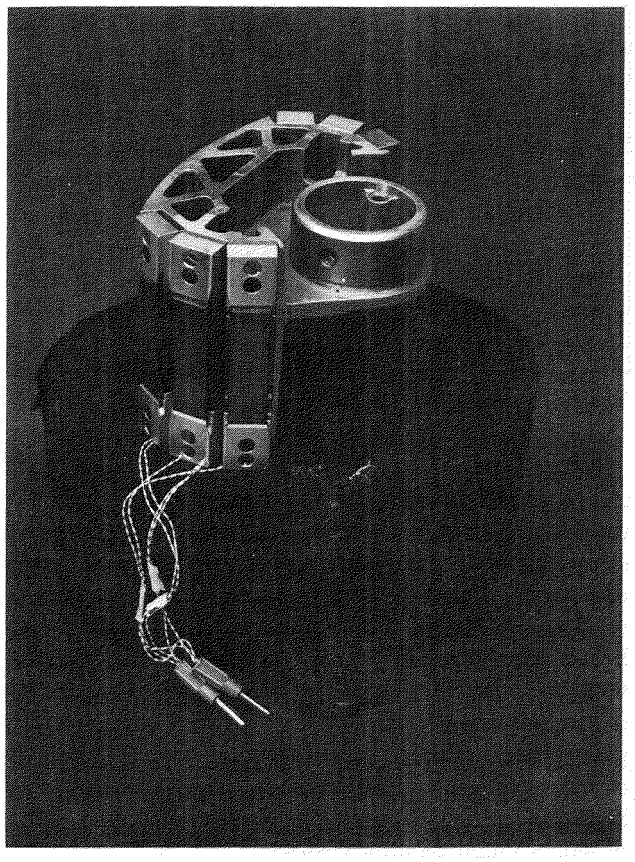


Figure 9. T.N.O. abdomen.

But, if tests under severe dynamic conditions are carried out, important technical problems will appear as regard the neck mechanical resistance. From the size and the geometry of ball-joints, excessive friction forces can be generated, inducing an insufficient rotation of the two half-spheres. It results in shearing forces which induce an important risk of neck cable rupture.

In order to increase the surface of the spherical bearings and diminish, too, the friction forces, we have been led to modify the size of the two half-spheres and the location of their centers. Although no more failure was recorded, we think that the present design is still not fully satisfactory (too much friction in the joints; neck elongation observed on volunteers and cadavers not properly duplicated). Thus, complementary studies were undertaken, which take into account the phenomena brought to light during the first evaluation.

Thorax results—drop tests: To evaluate the above presented improvements, thoracic drop falls were carried out. Test conditions are identical to those used to define the load-deflection corridor of the cadavers. The drop height was either 1 m onto rigid surfaces with the arm involved, or 2 m onto APR padding material with the arm out of the way.

The results are gathered in the here-under table and compared with the results obtained with the APROD 80 version, already presented at the 8th ESV Conference.

A difference appears between the half-thoracic deflection related to exterior dimensions and which is evaluated from film analyses and the intrusion of lower piston. But the deformation of the skin and the light amount of rib rotation and deformation (which are not measured by the transducer) are to be taken into account. Their cumulated values can be estimated at about 12,5 mm for these tests.

Drop Type	Impact Force (daN)		Translation of Lower Piston (mm)		Half-Thorax Deflection (mm)	
	80	82	80	82	80	82
1 m—rigid	900	920	1	6	~24	19.5
arm involved		1250		11	1	24
2 m—padding	630	570	23	36	48	~47
arm out of way		660		36		~47

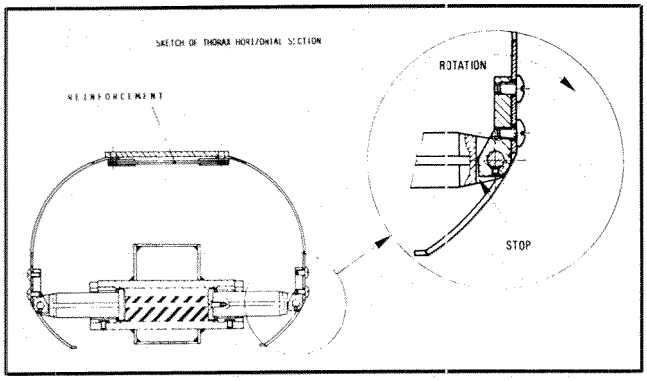


Figure 7. APROD 81.

Although this solution was satisfactory in its principle, it remained opened to criticism; in fact, the producing of such parts and of their guide-system was a delicate matter, and they were likely to produce excessive frictions, as soon as parallelism was not perfect. The pistons were hence redesigned; they got a circular cottered section, with the cotter acting as a stopping device in rotation motion during frontal impact. [In the beginning, the guide-system included self-lubricating rings. The fragility of these parts in frontal impacts led us to discard them in favour of a metal-on-metal guide-system, the gliding of which might be improved when necessary.]

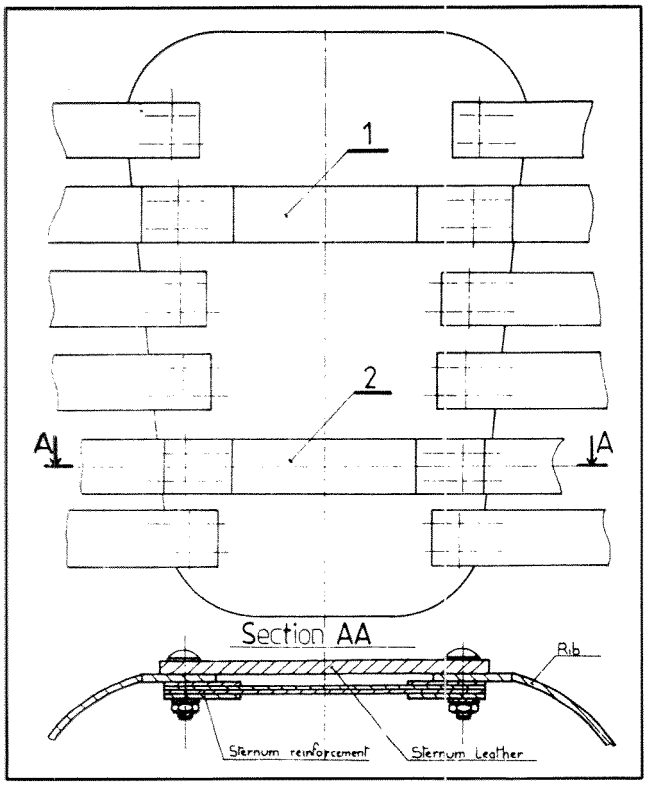


Figure 8. Sternum reinforcement locations

Inside the deflection tubes, rubber washers controlled the dummy's internal dynamic rigidity. During the occurrence of impact, the pile made by those washers underwent axial force and they often buckled. This instability had two consequences, i.e., unrepeatability of tests and the need to disassemble the dummy after every test in order to replace the washers. Thus, these washers were replaced by a triangular-shaped single piece, the hardness of which is 50-shore.

To prevent excessive rib cage deformations ensuing from oblique impact, it was decided to equip the APROD 81 with a reinforced breast plate (Fig. 8).

Abdomen—In lateral collision, the abdomen of presently existing dummies does not make it possible to evaluate the risk of occurrence of abdominal injuries. However, accidentological studies show that the statistical weight of the abdominal lesions, evaluated by means of a combination of their frequencies and their cubed AIS, is of the same magnitude as that of the head and thorax lesions, for which side impact protection criteria have already been contemplated.

In order to palliate this insufficiency, G. Walfisch et al. (7) defined, by means of tests with cadavers, the tolerance of the human abdomen area in terms of a couple force-penetration. Simultaneously, the dynamic data enabled a definition of an abdomen model to be integrated in a dummy. A first attempt for a protection criterion associated with measurement devices fitted into this abdomen is also made.

According to this work, the TNO developed a new instrumented abdomen section. A continuous force and penetration reading is not needed in order to check whether the tolerance limit is exceeded or not. Thus switches are placed inside the abdomen near the penetration limit; if those switches are designed to operate at a force limit, obtained from a pressure limit, then injury predictors at any point inside the abdomen at the required penetration level are installed according to the response of the switches. More details are already published (12). Six switches are located on the periphery of a drum shown on Fig. 9.

RESULTS OF TESTING

Neck results—Several sled tests were carried out for evaluating the improved neck. The procedure was similar to Dr. Ewing's tests with volunteers, with the greatest violence used (22 kph, 7 g). These tests confirmed that the achieved modifications confer to the neck a more satisfactory response according to the cadaver and volunteer data. However, the maximum angle reached by the head from the vertical axis remains too small, yet (Cf. here-under table).

For APROD 80, there was an almost constant deviation of 23 mm between the external deflection (recorded on film) and the internal deflection (measured by the transducer). This more important further deflection is due to the difference in kinematics of the 80 and 82 rib cages, when they are struck sideways.

Full scale tests—For evaluating the APROD 82 in such tests, two experimental collisions were carried out, in which APROD 82 was seated in the struck car on the struck side. As a matter of fact, these two tests are two supplementary reconstructions of a real accident involving two Peugeot 504, the precise description of which was presented at the 8th ESV Conference (4).

At this same conference, results of such reconstructions with an APROD 80 dummy occupying the struck car were also presented. Therefore, it enables, today, comparing the results obtained with an APROD 80, on the one hand, and with an APROD 82 on the other hand, under the same conditions.

The trajectories of the APROD head, linked to the displacement of the neck base are very close to that of the cadavers of already mentioned reconstructions (4). In particular for both human surrogates constituted by human subjects and APROD 82 dummies, the sidewards displacements of their heads were of the same order of magnitude. It is reminded that, due to the technology of the new neck of APROD 82, it is possible to duplicate more easily the translation of the head inside the passenger compartment which occurs before the head rotation phase, as previously recalled in this paper.

As regards the thorax, kinematics is satisfactory. Nevertheless, the thoracic deflection results for APROD 82 are rather low in comparison with the results for APROD 80. The differences in kinematics of 80 and 82 rib cages could be an explanation.

Regarding the abdomen, the switches have not been actuated, that cannot be correlated with the AIS = 4 abdominal lesion of the real victim. It seems that the distribution of the six switches at the periphery of the drum, where they are separated by 15° intervals, may be responsible for this failure. As a matter of fact, the direction of the forces applied to the abdomen may have exceeded the angular limits corresponding to the proper work of the switches.

PROTECTION CRITERIA TO BE MET WHEN USING THE APROD 82 DUMMY

1. Head—The results of the tests carried out with cadavers and APROD 82 dummies, since they display similarities in kinematics and in head impact response, show that it is possible to choose a protection criterion level close to the human tolerance, that is a HIC equal to 1500 according to a paper released during this ESV Conference (11) and other previous publications (8)(10).

2. Thorax—Previous studies (3,9) have shown that 35% of the half-thoracic relative deflection can be associated with 7 to 8 rib fractures for the middle class, as regards the overall resistance of the population at risk; this deflection figure can be used as a thoracic human tolerance, as far as force-deflection characteristics of APROD and human being are similar; so, a relative deflection equal to 35% could constitute for the APROD dummy a protection criterion. These 35% correspond at about 40 mm for the driving-in of the one piston, for which the deflection is the greater. This point will be precised by complementary tests under other conditions.

3. Abdomen—Even if it is necessary to redefine the force which triggers the switches, or the locations of these switches, it seems that the TNO abdomen can be kept inside of this dummy to develop a satisfactory abdominal protection criterion.

4. Pelvis—Previous studies have shown that it is possible to take the value of 100 g/3ms measured in the median sagittal plane of the dummy's pelvis as protection criterion for this body area.

DISCUSSION

At the 8th ESV Conference, it had been noted that some mechanical jammings appeared at the level of the thoracic pistons. It seems that the mechanical jammings have today disappeared as regards metallic parts, due to

		HIC	γ max. thorax	γ 3ms thorax	Half thoracic deflection	γ max. pelvis	γ 3ms pelvis	Abdomen switch
Part 572	1st test	309	75	60	—	110	100	
	2nd test	1017	72	60	—	—	—	
	3rd test	811	—	—	—	—	120	
APROD 80	1st test	737	62	60	42	190	125	
	2nd test	1130	42	38	36	188	140	
APROD 82	1st test	653	73	65	39	110	100	no
	2nd test	338	56	45	24	121	120	no
cadaver	1st test	440	121	95	43	107	90	
	2nd test	837	93	75	37	147	118	
	3rd test	110	104	70	—	128	105	

the improved paths of loadings and kinematics obtained from the modifications brought to the thorax (free rotation on side impact and stop on the opposite side—sternum reinforcements). However, for some drop fall tests onto rigid surface, it was observed an interruption of piston motion during impact. An in-depth analysis of these tests brought to light the existence of two main paths of loadings, through the piston and through the plastron respectively. The reinforcements of the plastron makes the corresponding transmitted forces no more negligible. As regards forces passing through pistons, it seems that an excessive friction of the rubbers, when compressed, can be responsible for a stopping of the piston displacement.

This point will be investigated and the rubber shape will be modified accordingly.

CONCLUSIONS

Improvements developed for the APROD dummy provided benefits as regards its biofidelity and its dynamic response. Some technical problems remain concerning the neck, for which a new study will be undertaken. It seems that the mechanical jamming, observed on the previous version have today disappeared as regards metallic parts.

Protection criteria for the main body areas have been proposed. APROD 82 can be used for improving side impact protection since it makes it possible to evaluate the degree of safety afforded.

ACKNOWLEDGEMENTS

This presentation has been made possible thanks to results obtained within the frame of the Joint Biomechanical Research Project KOB, and to results obtained from the E.E.C. research contracts which supported the development of this dummy and its testing, simultaneously with other types of dummies.

This paper reflects the author's opinion and commits the organizations quoted in no way.

REFERENCES

1. A. Fayon Y. C. Leung, R. L. Stalnaker, G. Walfisch, M. Balthazard, C. Tarrière, "Presentation of a frontal impact and side impact dummy, defined from human data and realized from a "Part 572" basis." Proceedings of the 7th International Technical Conference on E.S.V., Paris, June 1979.
2. R. L. Stalnaker, C. Tarrière, A. Fayon, G. Walfisch, M. Balthazard, J. Masset, C. Got and A. Patel, "Modification of Part 572 dummy for lateral impact according to biomechanical data". Proceedings of the 23rd Stapp Car Crash Conference, San Diego, October 1979.
3. A. Fayon, C. Tarrière, G. Walfisch, M. Duprey, M. Balthazard, "Development and performances of the APR dummy (APROD)," proceedings of the 8th International Conference on E.S.V., Wolfsburg, October 1980.
4. C. Tarrière, B. Hue, A. Fayon, G. Walfisch, "Reconstruction of side collisions", proceedings of the 8th International E.S.V. Conference, Wolfsburg, October 1980.
5. J. Sacreste, F. Brun-Cassan, A. Fayon, C. Tarrière, C. Got, A. Patel, "Proposal for a thorax tolerance level in side impacts based on tests performed with cadavers having known bone conditions", 26th Stapp Car Crash Conference, October 20-22, 1982, Ann Arbor, Michigan.
6. D. H. Robbins, J. W. Melvin, R. L. Stalnaker, "The prediction of thoracic impact injuries", proceedings of the 20th Stapp Car Crash Conference, Dearborn, October 1976.
7. G. Walfisch, A. Fayon, C. Tarrière, J. P. Rosey, F. Guillon, C. Got, A. Patel, "Designing of a dummy's abdomen for detecting injuries in side impact collisions", in proceedings of the 5th International IRCOBI Conference on the Biomechanics of Impacts, 9-10-11 September 1980, Birmingham, Great Britain, ONSER Secretariat, 109 Ave. Salvador Allende, 69500 Bron, France.
8. C. Tarrière, G. Walfisch, A. Fayon, C. Got, F. Guillon, A. Patel, "Acceleration, jerk and neck flection angle: their respective influences on the occurrence of brain injury", AGARD Conference, 1982, Köln, Germany.
9. G. Walfisch, F. Chamouard, D. Lestrelin, A. Fayon, C. Tarrière, C. Got, F. Guillon, A. Patel, J. Hureau, "Tolerance limits and mechanical characteristics of the human thorax and transposition of these characteristics into protection criteria", proceedings of the 7th International IRCOBI Conference on the Biomechanics of Impacts, September 1982, Köln, Germany.
10. C. Got et al., "Results of experimental model for closed head impact injury", proceedings of 20th Stapp Car Crash Conference, Dearborn, October 1976, SAE paper 760 825.
11. D. Lestrelin, C. Tarrière, G. Walfisch, A. Fayon, "Proper use of the HIC under different typical collision environments", proceedings of the 9th International Technical Conference on E.S.V., Kyoto, November 1982.
12. J. Maltha and R. L. Stalnaker, "Development of a Dummy Abdomen Capable of Injury Detection in Side Impacts", Proceedings of the 25th Stapp Car Crash Conference, San Francisco, Calif., Sept. 1981, SAE.

Proper Use of HIC Under Different Typical Collision Environments

D. LESTRELIN, C. TARRIÈRE,
G. WALFISCH, A. FAYON
Laboratory of Physiology and Biomechanics
Peugeot S.A./Renault

C. GOT, A. PATEL
I.R.O.-I.R.B.A., R. Poincaré Hospital,
Garches, France

J. HUREAU
Laboratory of Anatomy-Biomedical U.E.R.,
Saints-Pères, Paris V University

ABSTRACT

Authors present a synthesis of data concerning the relationship between HIC values and head injury levels, obtained from various methods and under several particular test conditions. Then, frontal collisions are discussed. Two cases are separately considered; when head impacts occur, and without head or neck impacts. Accidentological data allow one to conclude that no criterion is presently needed when no head impact is recorded. On the contrary, when head impacts are undergone, biomechanical data and analyses of kinematics are in favour of HIC 1500 as far as 3-point belt is used.

The other classical types of accidents are mostly relevant to the case of direct head impacts; HIC 1500 criterion may apply provided that a sufficient pressure distribution exists—besides, the protection of the face is a particular problem.

THE HEAD INJURY CRITERION (HIC) is an already old concept which was often criticized for both its mathematical formula and its relationships with any injury level. However, in 1982, no alternative candidate criterion appears which was sufficiently known and directly available from measurements on present dummies.

This paper aims in particular to determine if meeting the requirements of a HIC value in a dummy test can provide a better safety to real accident victims, by protecting them from rather severe injuries when they undergo similar impact conditions. Various accident circumstances will be examined.

FRONTAL COLLISIONS—RESTRAINED SUBJECTS AND DIRECT HEAD IMPACTS

First of all, some old data will be recalled because they have been used in the beginning in order to situate the tolerance levels.

Everybody knows the Wayne State University tolerance curve and the Eiband data (4) based on acceleration/time diagrams. They allowed C. W. Gadd to write (1):

> —In view of the scatter of the data, it is suggested that a straight line approximation on a log-log plot is sufficient at this time for head injury likely to result from front to rear head acceleration over a range of between approximately one and fifty ms. This brackets the pulse time duration encountered by vehicle interior head impacts.

This resulted in the 2.5 exponent.

However, on WSU curve, the data points located on the left side of the curve correspond to rigid head impacts when data points located on the right side are related to whole body exposures which do not involve a direct blow to the head (4). No obvious reason exists which gave the same tolerance level for these 2 very different types of assaults.

As regards whole body exposures, a sketch of Eiband data, from a J. Versace paper (2) is shown on Figure 1. Versace noted that "the military data summarized by Eiband are expressed in terms of the deceleration of the seat (it results in) almost certain amplification of acceleration at the subject's head".

When Versace's paper was presented, the mathematical formula which computes the HIC value according to standard 208 was not used. Today, one can observe that the line $1000 = TA^{2,5}$ drawn on Figure 1 corresponds, *at seat level,* to a higher 208-HIC value than 1000, due to the very definitions of the magnitude and duration of the acceleration which were used; only a value inferior to present 208-HIC, as this later uses the whole deceleration pulse, can be obtained. So, harnessed volunteers

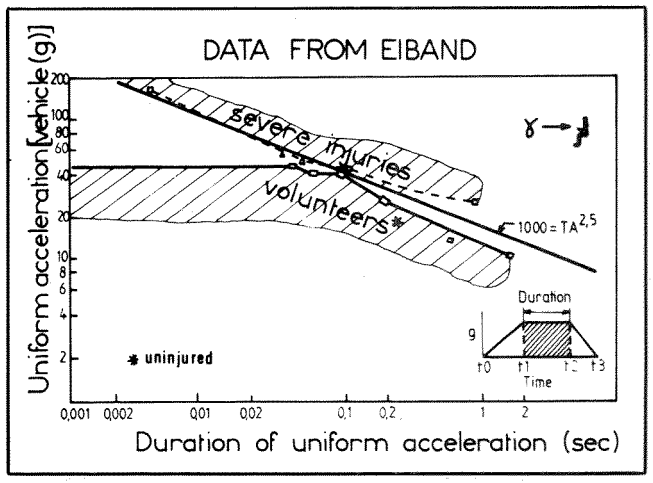


Figure 1. Data from Eiband, (J. Versace, in 15th Stapp car crash conference).

Table 1. Head injuries with and without head impacts. Belt wearers in frontal collisions—front places.

ΔV (kph) AIS	0	1	2	3	4	5	6	Totals
			Head AIS Versus ΔV—No Contact—					
≤20	271	0	0	0	0	0	0	271
21-30	221	0	0	0	0	0	0	221
31-40	142	0	0	0	0	0	0	142
41-50	56	0	0	0	0	0	0	56
51-60	14	0	0	0	0	0	0	14
61-70	4	0	0	0	0	0	0	4
>70	0	0	0	0	0	0	0	0
	708	0	0	0	0	0	0	708
			Head AIS Versus ΔV—With Contact—					
ΔV (kph)	0	1	2	3	4	5	6	Totals
≤20	1	34	3	0	0	0	0	38
21-30	2	29	8	1	0	0	0	40
31-40	1	62	19	2	0	0	0	84
41-50	1	53	33	7	0	1	0	95
51-60	0	22	15	3	1	5	0	46
61-70	0	2	11	2	0	4	0	19
>70	0	0	1	0	0	0	0	1
	5	202	90	15	1	10	0	323
			Head AIS Versus—Contact Questionable—					
ΔV (kph)	0	1	2	3	4	5	6	Totals
0-max	0	8	1	0	0	0	0	9
			Head AIS Versus Mean γ—No Contact—					
Mean γ	0	1	2	3	4	5	6	Totals
≤4	208	0	0	0	0	0	0	208
5-6	269	0	0	0	0	0	0	269
7-8	134	0	0	0	0	0	0	134
9-10	53	0	0	0	0	0	0	53
11-12	26	0	0	0	0	0	0	26
13-14	13	0	0	0	0	0	0	13
15-16	2	0	0	0	0	0	0	2
17-18	2	0	0	0	0	0	0	0
19-20	0	0	0	0	0	0	0	0
21-22	1	0	0	0	0	0	0	0
>22	0	0	0	0	0	0	0	0
	708	0	0	0	0	0	0	708
			Head AIS Versus Mean γ—With Contact—					
Mean γ	0	1	2	3	4	5	6	Totals
≤4	0	18	2	0	0	0	0	20
5-6	4	57	9	0	0	0	0	70
7-8	1	56	12	2	0	0	0	71
9-10	0	31	28	2	0	3	0	64
11-12	0	21	20	4	0	0	0	45
13-14	0	16	10	4	1	1	0	32
15-16	0	2	5	2	0	1	0	10
17-18	0	1	2	0	0	5	0	8
19-20	0	0	1	1	0	0	0	2
21-22	0	0	1	0	0	0	0	1
>22	0	0	0	0	0	0	0	0
	5	202	90	15	1	10	0	323
			Head AIS Versus Mean γ—Contact Questionable—					
Mean γ	0	1	2	3	4	5	6	Totals
0-max	0	8	1	0	0	0	0	9

probably sustained HIC values superior to 1000 without head or neck lesions.

This constitutes an earlier indication that, when no direct head impact occurs, the isolated Standard 208-HIC requirement brings no supplementary protection to the occupant. As a matter of fact, such runs with restrained volunteers exist which exhibit high S.I. or HIC value without head or neck injuries. According to Gadd (5), S.I. about 1500 were sustained by volunteers; therefore, one has to look at available accidentological data to check, if injuries are reported among restrained occupants in frontal collisions, without head impact, but under severe deceleration pulses.

Finally, the severities of head injuries, with and without head impact, were investigated by means of the data obtained from the IRO/PEUGEOT S,A/RENAULT multidisciplinary accident analysis.

The sample involves 1040 front seat occupants wearing a 3-point seat belt and who sustained a frontal collision.

For each subject sample, the following parameters are known:

—collision severity in terms of speed variation (ΔV) and car average deceleration (mean γ),
—localisation and severity, in terms of AIS of head injuries,
—injury causation; a head impact is assumed taking into account the recorded interior deformations (steering wheel, dashboard . . .) and the very nature of the observed lesions.

Table 1 makes a summary of available results.

Head injuries are distributed according to the collision severity in terms of ΔV on one hand, and mean γ on the other hand. They concern 708 occupants without head impact and 323 which sustained a head impact. In 9 cases, the occurrence or not of a contact could not be established.

In the analyzed sample, in frontal collisions without head impact, seat belt wearers never reached the head AIS value 2, i.e., a short loss of consciousness, at any collision severity.

On the contrary, among seat belt wearers which were submitted to a skull trauma, AIS $\geq$ 2 cases correspond to more than one third of the cases.

When a ΔV equal to 50 kph is exceeded, no head injury is found without head impact for 18 cases recorded; with head impact, 15 occupants out of 66 sustained an AIS $\geq$ 3.

Same results are observed when mean γ exceeds 12g.

In conclusion, head injuries are negligible without head impact in a sample which includes the most severe head-on collisions, since 1040 occupants were taken into account without selection.

As a complement, the severities of neck injuries were also examined when a head/neck impact occurs or not.

The sample and the methodology are the same as previously.

The cases for which direct neck impacts occur were added to the cases of head impacts, in order to keep separated the cases of pure posterior-anterior neck bending.

Table 2 shows a summary of the results.

In the analysis, neck injuries are distributed according to the severity of the frontal collision in ΔV on one hand, and in mean γ on the other hand.

—656 occupants without head or neck impact are involved
—339 with a head or neck impact are involved
— 45 cases could not be classified.

Beyond 50 kph, no neck AIS $\geq$ 2 is observed among 18 cases without head or neck impact. With such impacts, 4 AIS $\geq$ 2 are recorded out of 66 cases.

So, when no direct head or neck impact occurs, the risk of considerable neck injury is very little, and head injuries are negligible.

Furthermore, in some cases of the sample, the thoracic restraint is likely to have exceeded in terms of equivalent decelerations on dummies the classical limits. In addition to accidentological results, thinking of the existence of a prescribed limit for the thorax in any set of injury criterion, one concludes that no criterion is needed when no head or neck contact occurs in frontal collisions.

TOLERANCE TO DIRECT BLOWS TO THE HEAD

Only the cases where blows to the head are sustained have to be taken now into account. Blows without whole body exposure will be considered firstly.

Coming back to the WSU curve and to another already mentioned reference (4), 2 assessments can be made:

—As regards head impacts, it is very likely that American football players sustained HIC near 1500 in some cases since "football helmets were designed to attenuate head impacts to an S.I. of less than 1500 in a simulation of severe football head impacts" (30).
—Conversely, data points on the left side of the WSU curve, which corresponds to a lower S.I., are related to fractures and short duration impacts. Thus, a distinction appears necessary between padded impacts and the rigid ones which commonly produce fractures.

The head tolerance to skull fracture will be examined below.

RIGID IMPACTS AND SKULL FRACTURES

In 1971, the results of a research about human tolerance to skull fracture were published by Hodgson and Thomas

Table 2. Neck injuries with and without head and/or neck impact. Belt wearers in frontal collisions—front places.

				Neck AIS Versus ΔV—No Contact—				
ΔV (kph) AIS	0	1	2	3	4	5	6	Totals
≤20	250	9	0	0	0	0	0	259
21-30	200	4	0	0	0	0	0	204
31-40	121	4	0	0	0	0	0	125
41-50	48	2	0	0	0	0	0	50
51-60	13	1	0	0	0	0	0	14
61-70	4	0	0	0	0	0	0	4
>70	0	0	0	0	0	0	0	0
	636	20	0	0	0	0	0	656
				Neck AIS Versus ΔV—With Contact—				
ΔV (kph)	0	1	2	3	4	5	6	Totals
≤20	35	6	0	2	0	0	0	43
21-30	37	6	0	0	0	0	0	43
31-40	76	12	1	1	1	0	0	91
41-50	84	10	1	1	0	0	0	96
51-60	38	5	2	1	0	0	0	46
61-70	15	3	0	0	0	1	0	19
>70	1	0	0	0	0	0	0	1
	286	42	4	5	1	1	0	339
				Neck AIS Versus ΔV—Contact Questionable—				
ΔV (kph)	0	1	2	3	4	5	6	Totals
0-max	8	34	1	1	0	1	0	45
				Neck AIS Versus Mean γ—No Contact—				
Mean γ (g)	0	1	2	3	4	5	6	Totals
≤4	193	7	0	0	0	0	0	200
5-6	245	4	0	0	0	0	0	249
7-8	117	4	0	0	0	0	0	121
9-10	46	2	0	0	0	0	0	48
11-12	21	2	0	0	0	0	0	23
13-14	10	1	0	0	0	0	0	11
15-16	1	0	0	0	0	0	0	1
17-18	2	0	0	0	0	0	0	2
19-20	0	0	0	0	0	0	0	0
21-22	1	0	0	0	0	0	0	1
>22	0	0	0	0	0	0	0	0
	636	20	0	0	0	0	0	656
				Neck AIS Versus Mean γ—With Contact—				
Mean γ (g)	0	1	2	3	4	5	6	Totals
≤4	18	3	0	2	0	0	0	23
5-6	63	12	1	1	0	0	0	77
7-8	67	5	1	0	0	0	0	73
9-10	60	4	1	0	1	0	0	66
11-12	37	7	0	1	0	0	0	45
13-14	26	6	0	0	0	1	0	33
15-16	6	3	1	1	0	0	0	11
17-18	6	2	0	0	0	0	0	8
19-20	2	0	0	0	0	0	0	2
21-22	1	0	0	0	0	0	0	1
>22	0	0	0	0	0	0	0	0
	286	42	4	5	1	1	0	339
				Neck AIS Versus Mean γ—Contact Questionable—				
Mean γ (g)	0	1	2	3	4	5	6	Totals
0-max	8	34	1	1	0	1	0	45

Table 3. Results of head impacts at fracture level, published by: V. R. Hodgson and L. M. Thomas at the 15th Stapp Conference, SAE.

Cad No.	Drop ht., in	Vel., ft/sec	Peak Force, lb	Peak A_{CG} Result, G	Mean A_{CG}, G	Pulse Time, s	Peak A_{a-p}, G	(SI) (A_{CG})	(SI) (A_{a-p})	EDI (A_{CG}) Resp, in	EDI (A_{a-p}) Resp, in
Front—Flat Plate											
1747	10	7.3	1600	230	75	0.0076	195	794	400	0.14	0.11
1701	10	7.3	1450	370	123	0.0045	345	2020	1800	0.18	0.12
1699	10	7.3	1700	270	87	0.0076	230	1280	792	0.17	0.13
1805	10	7.3	1450	190	63	0.0076	150	565	390	0.13	0.11
1873	25	11.5	2100	240	85	0.0061	195	1020	724	0.16	0.13
1857	30	12.7	2000	220	83	0.0076	220	1250	561	0.19	0.11
Average	14	8.9	1720	250	86	0.0068	220	1150	780	0.16	0.12
Front—8 in Radius Hemisphere											
Average	21	10.3	1400	—	—	0.0068	220	—	565	—	0.12
Front—3 in Radius Hemisphere											
Average	15	9.7	1030	—	—	0.0064	190	—	550	0.13	—
Front—1 in Radius Cylinder—Sagittal Plane											
Average	16	8.5	1960	—	—	0.0048	280	—	910	—	0.12

Table 3 bis. Comparison of Alderson 50th percentile dummy to cadaver response at fracture level front-flat plate; published by: V. R. Hodgson and L. M. Thomas at the 15th Stapp Conference, SAE

	Subject	Drop ht., in	Peak Force, lb	Pulse Time (Force), s	Peak Accelerate, G		Pulse Time (accelerate), s	Severity Index		EDI (A_{a-p}) Resp, in.
					res	a-p		A_{res}*	A_{a-p}	
(Cadavers)	Average	14	1720	0.0051	250	220	0.0068	1150	780	0.12
	Dummy	10	2350	0.0034	305	270	0.0072	1680	890	0.10
		15	3070	0.0034	325	290	0.0072	2040	1150	0.12
		20	4000	0.0028	425	384	0.0061	3270	2020	0.14

*A_{res} = Resultant of A_{a-p} and $A_{transverse}$ measurements of dummy.
A_{res} = Resultant CG Acceleration (A_{CG}) for cadavers.

(6). Hereunder is a duplication of a part of the conclusions of this study. Besides, Table 3 gives numerical results. Embalmed moist human cadavers were used.

"These test results confirm that frontal bone fracture occurs in the human cadaver at the same level of acceleration as predicted by the Wayne State University Tolerance Curve.

Average values of SI and EDI (*) computed for six impacts which produced linear skull fractures due to frontal rigid flat plate impact are in close agreement with critical values predicted by authors of these two methods.

For the drop height range which produced linear fracture in the cadaver due to frontal impact against a rigid flat plate, the SI for the Alderson 50th percentile dummy head acceleration response was much higher than for the cadaver".

These conclusions can be commented as follows.

Pulse durations (Table 3) remained inferior to 8 ms: the impacted areas were rigid, unyielding surfaces.

When resultant accelerations at the center of gravity are available, HIC 1000 appears here a reasonable estimate of skull fracture tolerance (by interpretating the published S.I. values). Here, accelerations give a good estimate of the loading imposed to the head, because the whole path of loading concerns skull bones with a single impact in frontal area. However, the tolerance level suggested by these experiments has not to be kept as far as head-on car collisions are concerned, because of the very nature of impacted area, because of the differences in the paths of loadings, and because of the different dummy head responses.

As regards the impacted areas, presently no unyielding surface of infinite mass exists in a car, under the conditions of the contemplated dummy tests.

The surfaces in contact with the head yield more or less; Figure 2 shows the much longer impact durations and HIC computation intervals which commonly appear

(*) EDI: see (29)

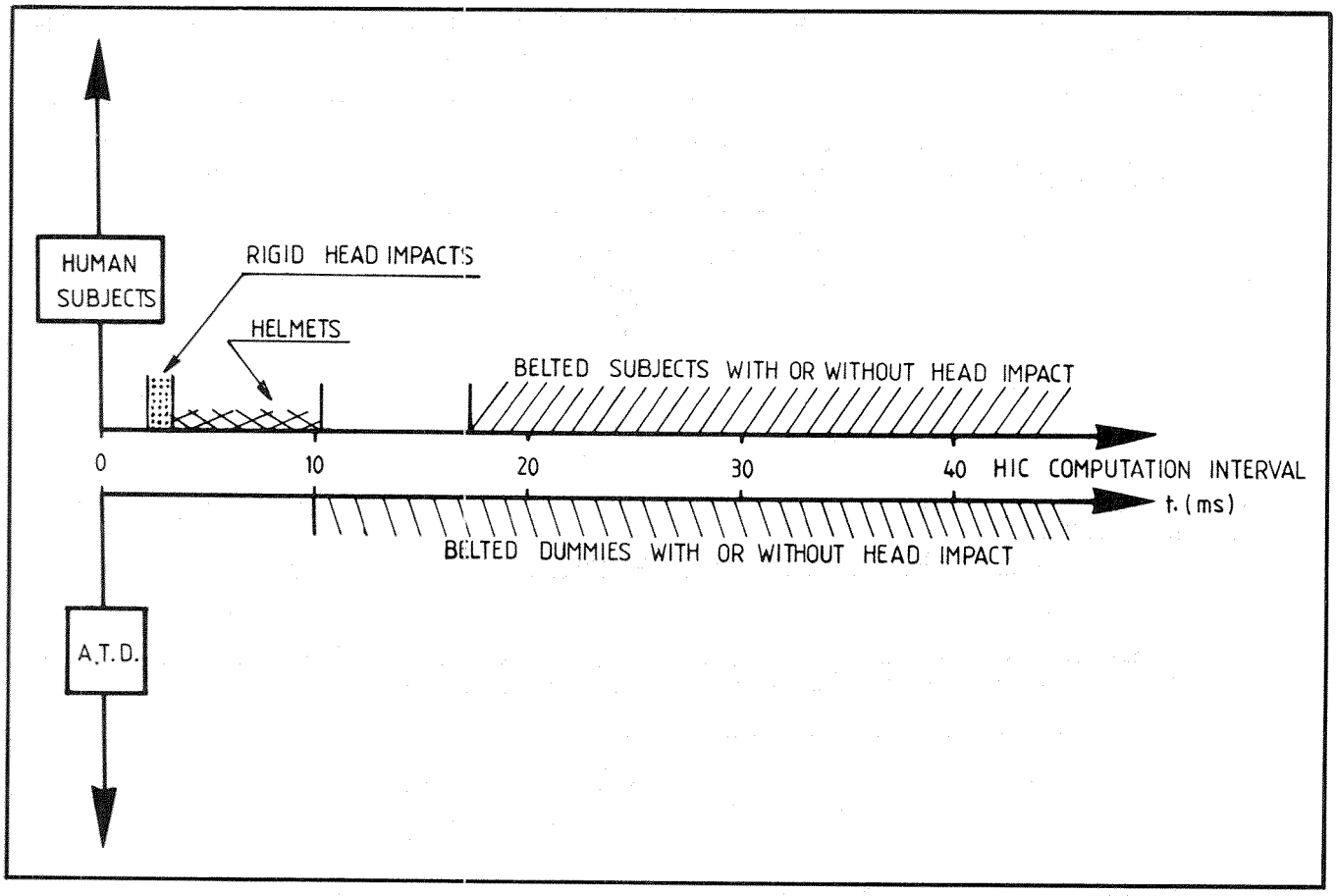


Figure 2. HIC computation intervals of various accident types.

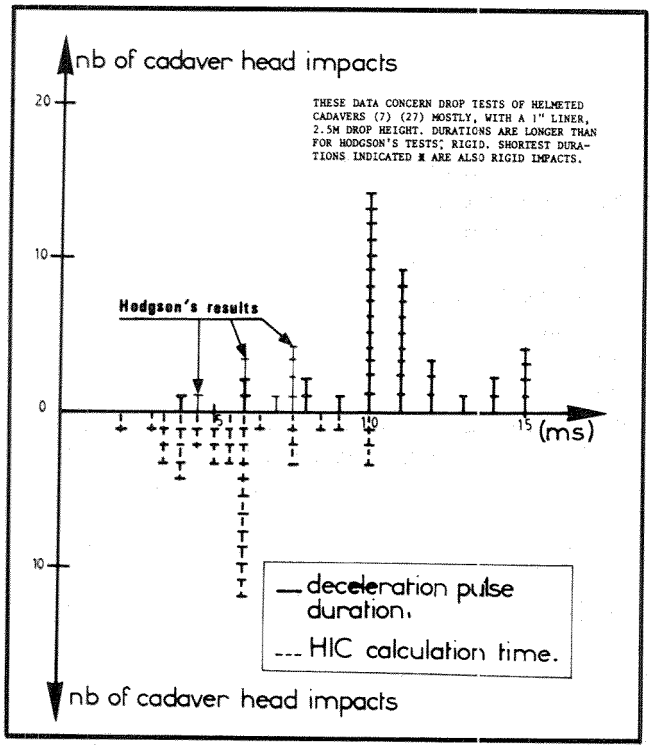


Figure 3. Head impact durations, rigid vs. padded.

in automobile collisions; Figure 3 illustrates the increase in head impact durations which occurs as soon as some padding is provided. The difference in impacted areas justifies thus the research of the tolerance level to head-impact which better fits the conditions of frontal collisions.

As regards the paths of loadings the head of a restrained occupant can be decelerated essentially by two ways: impact forces and neck forces, these latter being sufficient when no impact occurs. HIC computation cumulates these two phenomena without isolating the part of each one. This point will be also detailed later on. (Fig. 4).

As regards the dummy head response, the lowest lines of Table 3 show a much higher acceleration of VIP 50 head: S.I. on the average was 1150 for a 14 in. drop height of cavavers; VIP 50 head reaches 1680 for 10 in. drop height and 2040 for 15 in.

Finally, authors of (6) intended to use some fit between tolerance to skull fracture and tolerance to mild concussion. The previous remarks concerning the double path of loading of the head in frontal collisions and the pulse duration apply. The order of magnitude of HIC computation interval in (6) might be 3 ms.

At last, it may be concluded that HIC 1000 concerns

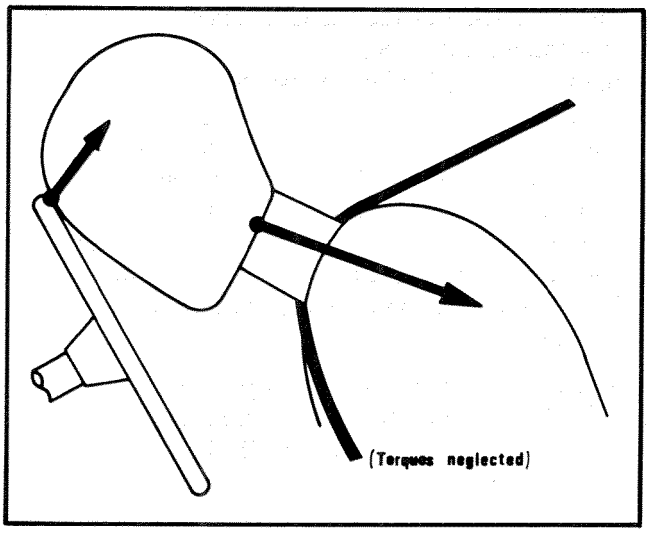


Figure 4. Impact force is only a part of forces stopping the head.

rigid impacts of short duration which relate to skull fracture but does not apply to the requirements of restrained occupants *in a car environment.*

BETTER ESTIMATE OF HEAD TOLERANCE TO DIRECT IMPACT

"Better estimate" means: with longer impact durations than the previous ones, against rigid unyielding surfaces. When fresh unembalmed cadavers are used, for investigating the closed brain injury risk, a vascular injection method was developed by Got et al. (7) which allows the detection of capillary ruptures due to impact. Series of drop tests were performed, head striking more or less padded surfaces, or wearing a helmet; Figure 3 recalls the durations.

Table 4. Brain injuries distribution among 133 scannerised patients.*

Contusion Alone:	42	(31%)
Contusion Alone or Associated:	72	(55%)
Oedema Alone:	28	(21%)
Oedema Alone or Associated with Sub-Arachnoidal Blood:	38	(28%)
Oedema Alone or Associated with All Types of Brain Injuries:	53	(40%)
Brain-Stem:	12 or 13	(10%)
Extra-Dural Hematoma Alone:	5	(4%)
Extra-Dural Hematoma Alone or Associated:	15	(11%)
Sub-Dural Hematoma Alone:	5	(4%)
Sub-Dural Hematoma Alone or Associated:	13	(10%)

*Mostly traffic victims.
This chart could be obtained in the framework of a research contract with the European Economic Community.

Simultaneously, a method for computing the linear and angular accelerations at the center of gravity of the head, by means of 9 accelerometers, was implemented. When the injection method is already described (7) and used by other teams, it was not the case as regards the computation of acceleration. Therefore, some details are presented here.

A complete set of acceleration measurements is achieved on the skull periphery in order to obtain by computerization the following data:

—Every kinematic feature of the head movement and, particularly, angular velocities and accelerations in terms of time.
—The resultant linear acceleration at the head center of gravity and the usual parameters calculated by means of this function (γ max, γ 3 ms, S.I., HIC).

A method using accelerometers is implemented with a so-called 3-3-3 configuration, as described by Alem (28). For improving its accuracy, the distance between transducers has to be as large as possible. Tests were performed in order to evaluate the robustness of the whole procedure. Some parameters appeared of secondary importance; they are:

—Using a computation process with simple or double precision,
—Filtering of analog data, as far as HIC is concerned, with 600-1000 Hz range.

On the contrary, the choice of the integration method, the precision on the locations and the orientations of the transducers, the number of channels appeared of primary importance. These findings lead us to improve the methodology; as examples:

—A RUNGE-KUTTA integration method with a constant integration step was tested and eliminated;
—A photographic method for measuring the angles of the accelerometers in the anatomic reference frame was implemented (rigid metallic rods replace the transducers just before the test, when photographs are made).
—Due to the number of channels available, the computation of the accelerations can be made according to several ways. So, one can check that results yielded are similar. Besides, a graphic display of the computed head kinematics is obtained; therefore, a comparison with the films is possible.

This method could not be systematically used in (7) but it was the case of (27), a more recent paper of the same team. This explains the slightly different values which can be found for some same subjects, when comparing (7) and (27), this latter paper displays more data points.

HIC computation interval was usually between 3 and 7 ms, i.e., closer to automotive needs.

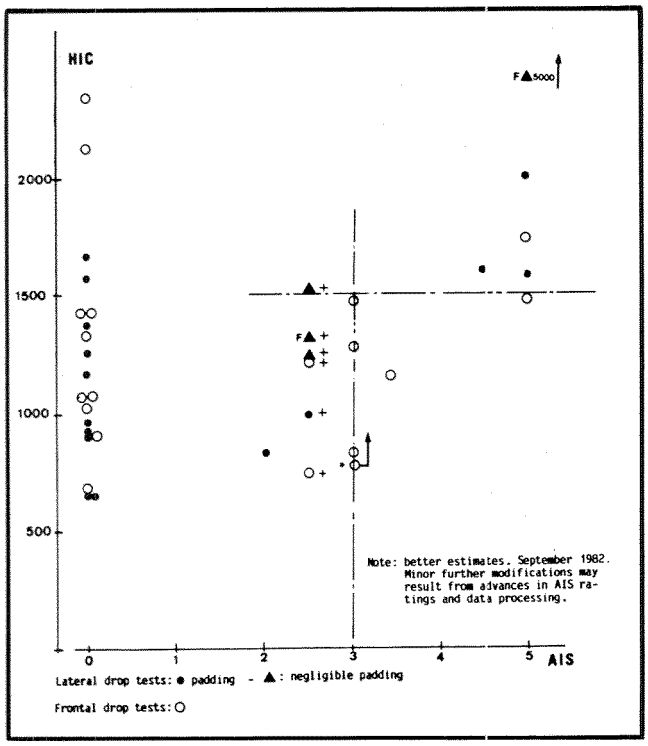


Figure 5. Relationship between HIC/AIS (the whole HIC value due to impact). Drop tests, mainly from (7) and (27), including reviews.

(⋆) HIC questionable. 8 accelerations only. Probably higher (1200 ?)
(+) AIS 2.5, mean AIS 2 or 3. Better estimate impossible.
(F) Skull fracture

So, authors in (7) were enabled to claim for a *threshold* of HIC 1500 for the appearance of AIS > 3 level brain injuries when skull is impacted and they wrote: "with regard to pure frontal impact without fractures, it would seem that an acceleration pulse linked to an HIC exceeding 1500 could be supported by the head of a living person (. . .) without severe injury in the majority of cases."

Figure 5 displays a summary of the experimental results which support this conclusion. Figure 6 is an attempt to present them in terms of probability of occurrence of injuries, the severities of which reach a given level. Figures 5 and 6 take into account the human subjects of (27).

In (7), the discussion of these results was fairly deep: some of the points commented upon were:

—the detection of injuries:
When oedema type injuries cannot be detected, one may observe that the frequency of oedema *alone* is low among brain injuries (21%—Table 4).
—the compatibility with results of the other teams using vascular injection (8) (11), which was checked,
—the comparison with dummy tests, that gives different results according to the test conditions,
—the comparison of the "cadaver tolerance" to that of a living person (28),
—the scatter of individual tolerances,
—the difference between the threshold at which injury appear and a "tolerance level", which is necessarily higher according to the authors; as a matter of fact, authors assumed like L. M. Patrick (12) that the tolerance level corresponds to 50% of the population considered undergoing an AIS $\geq$ 3, when this population is submitted to the assaults corresponding to the tolerance level.

Besides, it was noted that facial impacts occurred with lower acceleration levels under conditions of impact for which simulation by the rigid Part 572 head is unsatisfactory. This problem remains unsolved; however, the more the impact force is distributed on a larger area, the closer to the skull tolerance is the facial tolerance (1), in terms of applied force.

Discussions and Conclusions of (27) in addition mentioned that, among the considered parameters for analysing the results of the sample of cadaver drop tests, i.e., γ max, γ 3ms, the maxima of angular acceleration and velocities, HIC gave the best explanation of the results in terms of injuries.

Discussion about the most validated criterion and the most sound tolerance level are not terminated today in the cases of pure skull impacts. However, even if HIC 1500 were not yet evident, the case of the restrained occupant has to be considered now in order to examine the differences between a direct head impact and a frontal collision, when both deliver a HIC 1500 value.

CASE OF RESTRAINED OCCUPANT

Let us consider a car driver and a front passenger, submitted to the same frontal collision. Figure 7 shows the corresponding head resultant accelerations in a typical case, when two Part 572 dummies are used.

Of course, if human beings were considered, instead of dummies, the rationale would be identical. The head of the driver underwent two impacts, one against the rim and the second against the hub of the steering-wheel. From the beginning of the collision to the head impact, γ R for driver and passenger are similar. The increase of the driver head severity index with the time, by a continuous computation of $\int \gamma^{2.5} dt$, is also drawn on the Figure 7.

The first impact is accompanied with a small increase of the S.I.; the second one by a noticeable one, which lies around 1000 S.I. units (Δ_2(SI) on Fig. 7). This increase is not entirely due to the impact, as explained below. What is the corresponding severity of such an impact? During the head contact, two sets of forces are acting simultaneously, i.e., impact forces and neck restraint forces. (Fig. 4).

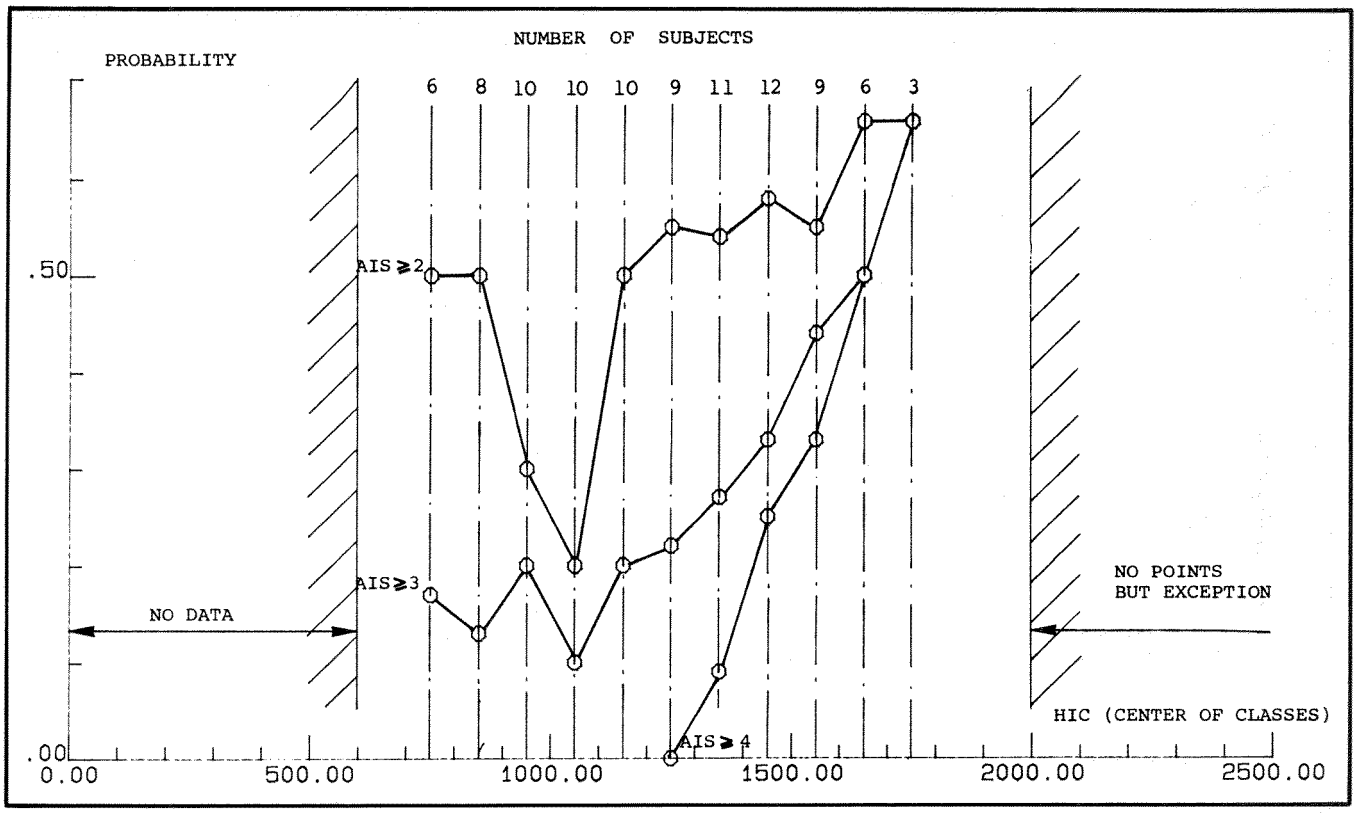


Figure 6. Direct head impacts · probability of exceeding a given A.I.S. level versus HIC value ·
Note: Each plotted point at HIC = X represents the tests with HIC included between (X−150) and (X +)

Without impact, the head would have sustained here more than 60 g's, according to the passenger resultant on the Figure 7.

With impact, a peak up to 170 g is reached, but only a part of this deceleration is due to the impact. A geometrical addition of the forces is necessary at each instant. The severity index (Gadd, 1) associated to the impact alone, is:

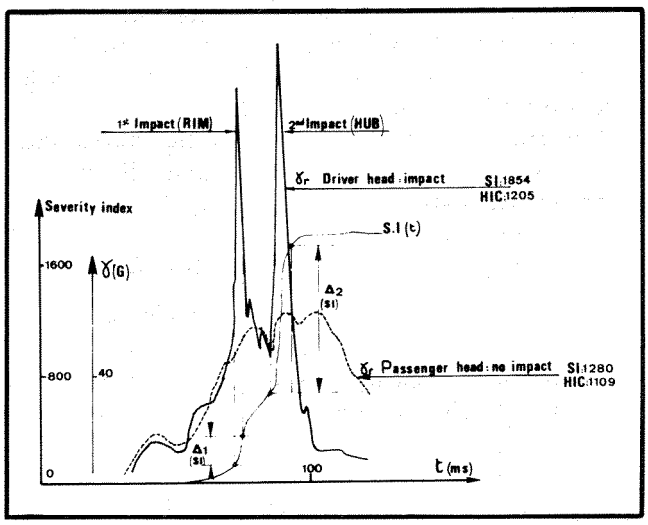


Figure 7. Typical head resultant acceleration: frontal collision—restrained dummy.

$$\int \left\| \vec{\gamma}_R - \vec{\gamma}_F \right\|^{2,5} dt$$

Returning to the example on Figure 3, during the duration of the impact, the increase of S.I. due to the neck forces only is about 220; the S.I. due to impact forces might be 650, e.g.; this latter value was estimated with the following assumptions: impact forces perpendicular to neck forces, triangular shape of impact forces pulse.

For illustrating the correctness of this argument and for confirming the order of magnitude of much evaluations, a mathematical model was used. It is a 2 D and 10 degrees of liberty model, called PRAKIMOD. It was already described at the 8th E.S.V. Conference (34).

Here head on collisions were simulated. The occupant aimed at is a P572 dummy wearing an automatic 3-point seat belt, with a gliding buckle. The characteristics for the restraint are fairly good. All the data are as realistic as possible, according to available data from real cars. However, the speed variation of the simulated vehicle reached 65 kph, in order to get high HIC values; that differs from full-scale testing. It seems that mathematical modeling generally yields lower HIC than dummies. Besides the shortages of the mathematical simulation, such as a long and constant radius for the head trajectory, this may be due to the lack of a 3rd dimension and to the absence of any technological shortcomings which give acceleration discontinuities in dummy testing.

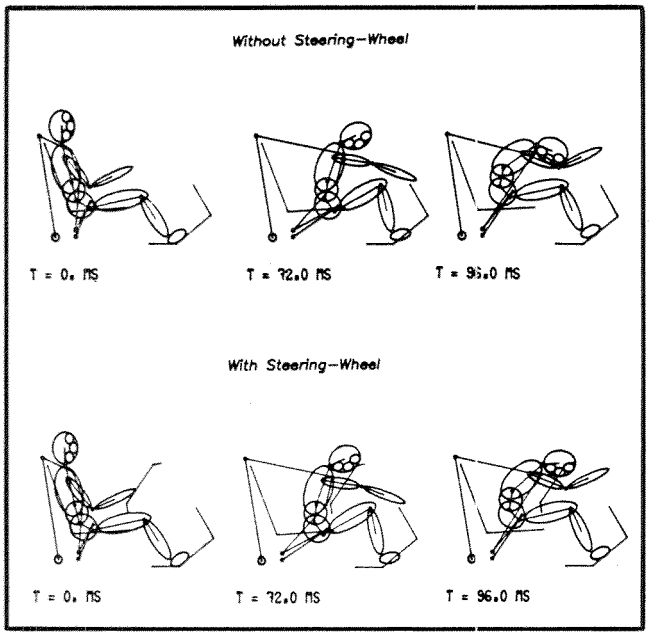


Figure 8. Compared kinematics for the two simulations.

tical, except a steering wheel which is simulated in only 1 out of these 2 cases. (Figure 8). Head accelerations,

As a reminder, mathematicals models are good tools for the study of isolated parameters, or for a dynamical analysis, i.e., forces and energies managements. However, one cannot rely upon the values yielded for any parameter without an in-depth validation. One of the greatest interests of mathematical modeling is enabling one to get values for parameters which cannot be measured in dummies; the present use enters this category.

The purpose here is not to find HIC values which were obtained with dummies, the goal is to get an order of magnitude for the phenomenon roughly evaluated above, related to the respective influences of the head impact and of the head restraint by the neck forces. Thus, 2 simulated runs were performed. Their conditions are iden-

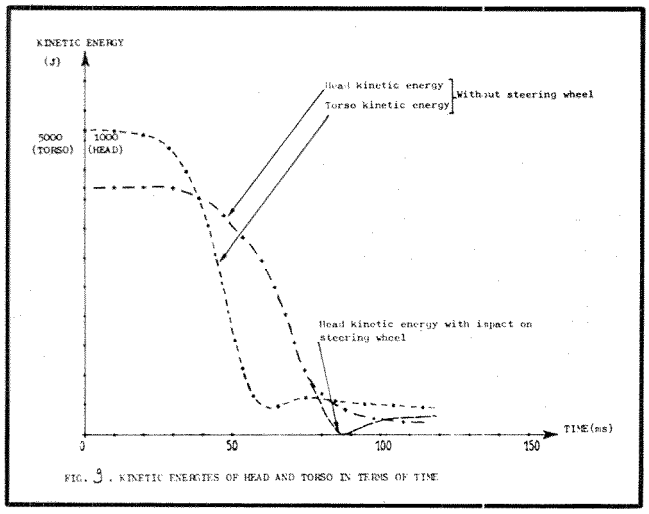


Figure 9. Kinetic engeries of head and torso in terms of time.

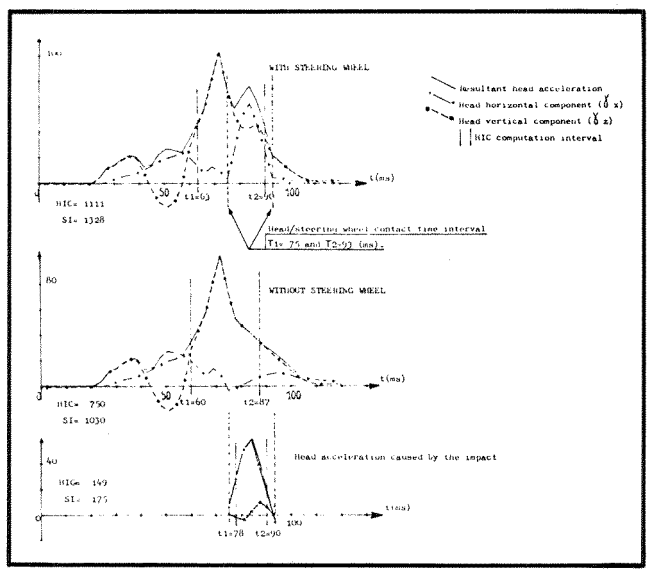


Figure 10. Mathematical Modeling: Comparison between the head accelerations of restrained occupants with and without the head impact. This figure brings in light the accelerations caused by the only head impact.

without steering wheel, are shown on Figure 10. The maximum acceleration reaches 104 g (t = 72 ms), a short time before the head impact; the acceleration level exceeded during 3 ms is 91. The components, when maximum occurs, are 9.9 g for γ x and 103.7 g for γ z, in an anatomical frame. This illustrates the role of the neck in the increase of the S.I.: the thoracic restraint induces a head restraint; corresponding forces have a direction roughly along the neck axis. Kinetic energy of the head decreases slowly (Figure 9); the centripetal acceleration, simultaneously, produces a strong increase of S.I. and HIC. According to this first mathematical run, S.I. is 1328 and HIC 1111; in the 2nd run, without steering wheel, the maximum head acceleration reaches 103 g (γ_x = 8.9 g; γ_z = 102.2 g) at the same time as previously (72 ms). The absence of hands-steering wheel contact forces explains the little differences of values. The important point is the decrease of S.I. and HIC values; S.I. falls from 1328 to 1030 and HIC from 1111 to 750.

For obtaining the effect relevant to the impact alone, the forces transmitted by the neck were eliminated in another computation. S.I. consequently falls to 175 and HIC to 149. (Fig. 10).

A summary of the previous results is as follows:

—The head/steering wheel impact, which is the only possible head injury causation according to real accidents, corresponds to a S.I. equal to 175, an HIC equal to 150 in this simulation. These very low values may be associated to the absence of hazard.

—The head restraint forces due to the neck correspond to S.I. 1030, HIC 750, from the 2nd simulation.

—Then the steering wheel is added (1st simulation), and therefore when impact forces and neck forces

are cumulated, S.I. increases to 1328 and HIC to 1111 for the whole pulse duration.

Mathematical modeling confirms that the HIC, when computed for a restrained occupant with the occurrence of a mild head impact, can reach high values without any correspondence with the severity of the blow, in terms of injuries. By the way, mathematical modeling showed also, by means of other runs, that a less efficient restraint could significantly diminish the HIC values.

Coming back to full-scale testing with dummies, the resultant head deceleration curve shown on Figure 3 is an example where 208-HIC value exceeds 1000 without exceeding 1500, and where recorded impacts are tolerable, even if the most severe head impact protection criteria are used. As far as the thorax restraints are used, high values of HIC can be recorded and can simultaneously correspond to mild impacts.

One may object that human tolerance under these particular loading conditions (i.e., impact occurring during a severe head movement) are not identical to the tolerance to isolated impacts. That is a challenge for research. However, today, experiments with cadavers, in particular, can be referred to.

EXPERIMENTS WITH RESTRAINED CADAVERS

From the 18th Stapp, many experiments were reported which deal with the *whole body restraint* (WBR) of fresh unembalmed cadavers: Schmidt (13)(18), Cromack (14), Patrick (15), Cesari (16)(22), Fayon (17), Walsh (19), Alem (21), Schimkat (24).

Tests where simultaneously a head injury detection was feasible on the cadaver by means of a vascular injection method, and where HIC computation was achieved have to be considered here. Besides, among these data, tests of belted occupants who sustained head impacts will be selected.

—Walsh (19) reports the case of the so-called subject CALMAN 2, who hits a steering-wheel. No face, brain and skull damage were found. HIC value 736 on a lateral triaxial accelerometer. He reported also in (20) other cases with head AIS 0, but low HIC values.

—Data from Alem, (21), as published in the proceedings of the 22nd Stapp Car Crash Conference, are not complete (although they exist in other reports.)

—Cesari did not publish HIC values associated to the injury data related to cadavers, except in particular cases. One HIC 2412 case associated to AIS 0 for the head for a driver is mentioned. His rationale was rather to relate measurements to the injuries of the real victims of the accidents that he reconstructed. The same author, from another series of reconstructions (23) reported one HIC 260 associated to a frontal scalp AIS 2, due to a steering-wheel radius, one HIC 634 associated to a nose fracture due to the steering-wheel spider.

This rises two head important problems:

—Let one consider 2 cases of AIS 3 of restrained occupants, due to impacts against two different surfaces; for example, a poorly padded hub and a fairly collapsible dashboard. The severity AIS 3 will be reached, e.g., at 40 kph in the first case and at 60 kph in the second one. The head accelerations induced by the restraint forces will be much higher in the second case, and eventually the HIC value will be higher too. Such phenomena may explain, up to a certain extent, some of the discrepancies between the results of different teams. Besides, using less padded cars in simulations or reconstructions may lead to lower HIC values at the same injury level. This points out the interest in the test conditions which use as much as possible the environmental conditions of actual cars, even if tolerances only are considered.

—The protection of the face is a particular and intricate problem for which neither the skull and brain protection criteria, nor the Part 572 rigid dummy faces are adapted. The use of a deformable face as described by Tarrière et al. (25) allows someone to estimate the risk of facial injury; a complementary criterion concerning the face would so be added to the HIC which is related to closed brain injuries.

The cooperation between the Institute of Orthopaedic Researches in Garches (France) and Peugeot/Renault Association made it possible to gather numerous related results; the corresponding runs were carried out in the framework of sundry researches and were mostly unpublished up to now. Among this data base, results were selected according to the following criteria:

—simulated frontal collision with a 3-point belt restraint

—head impact

—HIC value $\geq$ 1000. It was previously checked that in the sample, HIC $<$ 1000 did not contain noticeable head AIS values (superior to 2).

At present time, these piled up tests are not fully processed as regards computerization. The number of recorded acceleration channels is indicated in the Table 5 which summarizes the results, Figures 11 and 12 complete this Table; 3 HIC values are often given which are obtained from the accelerometers on right and left temples and on occipital bone respectively. It results in a better estimate of the HIC value at the center of gravity, that everyone can appreciate in a fourth column.

These high values of HIC are mainly due to the high severities of these collisions.

As a conclusion, in reported experiments, under the

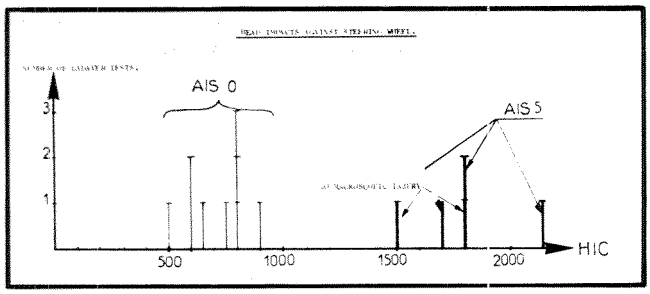


Figure 11. Frontal Collisions: Cadavers restrained by a 3-point belt 50 kph impact speed 65 kph drivers.

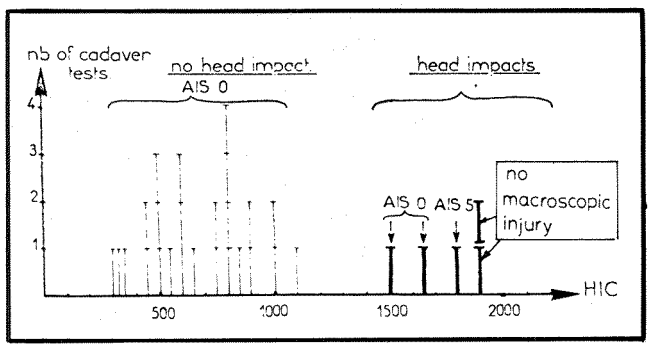


Figure 12. Frontal Collisions: Cadavers restrained by a 3-point belt 50 kph impact speed 65 kph—right front passengers.

conditions of a 3-point belt restraint in frontal impact, HIC values up to 1500 (and slightly more) are recorded when a head impact occurs, without occurrence of any AIS > 2 head and neck injuries.

EXPERIMENTS WITH RESTRAINED DUMMIES

These experiments are useful as far as an accurate injury reference is available, which can be associated to the results of measurements performed on the dummy. This only condition is not sufficient. The remark related to padded and unpadded head impacts inside a car has also to be kept in mind. Some data are related to series of reconstructions, some others are related to individual accident cases. In this later case, particularly, one has to check the similarities between the impacts sustained by the dummies and by the cadavers or the real victims.

Otherwise the conclusions are doubtful. However, the dummy can mitigate the impact severity, relatively to human beings, in some cases. This rule is not an absolute one.

Patrick (12) released the results of a combined program of accident investigation staged collisions and simulated collisions involving 3-point harnessed occupants in frontal collisions.

With a Sierra 1050 dummy and velocities up to 40 mph, the equation for the HIC was:

$$HIC = 92.8\ BEV - 1789$$

(BEV = Barrier Equivalent Velocity)

giving 1000 at 30 mph and 3130 at 53 mph. But there were no AIS 3 head injuries in his sample: head injuries

Table 5. Frontal collisions with 3 pt belted cadavers—cases of head impacts.

Test #	Test Type	Impact speed °kph	Stopping distance mm	Place	γ** Number	HIC left temple	HIC right temple	HIC occipital bone	HIC minimum estimated	Skull AIS	Brain AIS	Type impact observations
10	sled + car body	64	660	D	5	2011	3050	—	1800	0	NI	Forehead/hub
126/1	sled + car body	65	1000	D	9	6816	1791	5952	1800	0	4	Forehead/hub
2	sled + car body	50	480	D	5	> *1719	> *3314		1700	6	NI	hub + rim skull basis circ. fract.
115-1	car	50	900	D	6	—	1623	2365	1500	0	NI	forehead/hub + rim
13	sled + car body	62	540	P	6	2340	3490		2100	6	NI	skull basis circ. fracture
60-2	car/cart† oblique	60		P	9	2240	3460	2160	1900	2	NI	forehead/rim
8	sled + car body	65	660	P	5	2100	2310	—	1900	0	NI	top of head/ dashboard
117-4	sled + car body	50	505	rear	9	1945	1830	2640	1800	0	5	forehead/top of front seat; neck influence
124-2	sled + car body	66.5	1020	P	9	1790	1990	2765	1650	0	0	
126-2	sled + car body	65	1000	P	8	—	1585	2525	1500	0	0	

No Injuries Recorded Below 1500

Abbreviations and Notes
N.I. = No vascular injection, but no gross macroscopic injury in the mentioned cases.
* = 2 components only.
† = Each vehicle.
**i.e. = Number of correct acceleration measurements, after the test.

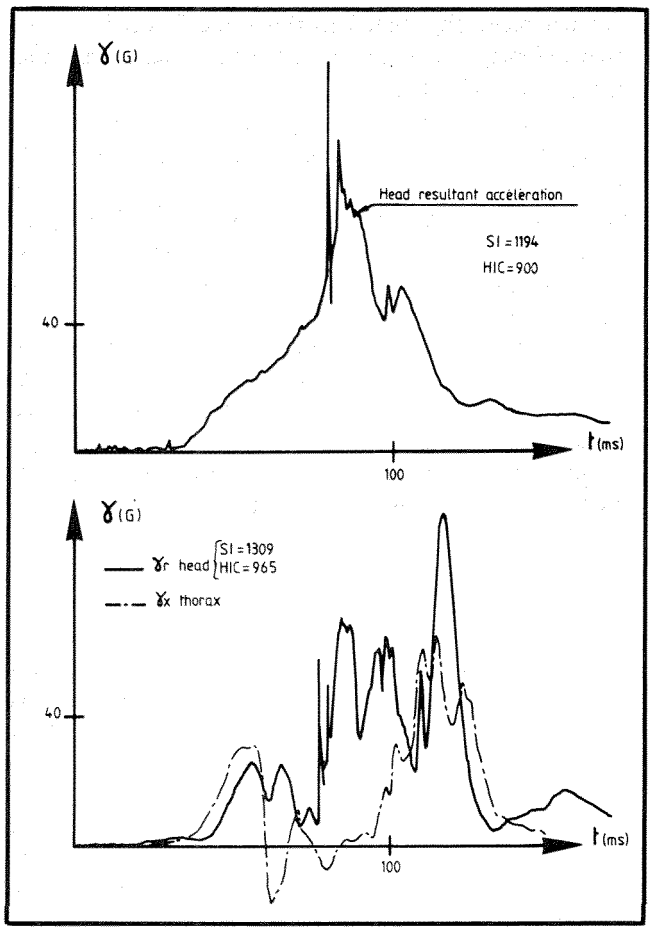


Figure 13. Example of low HIC with incorrect restraints—See text.

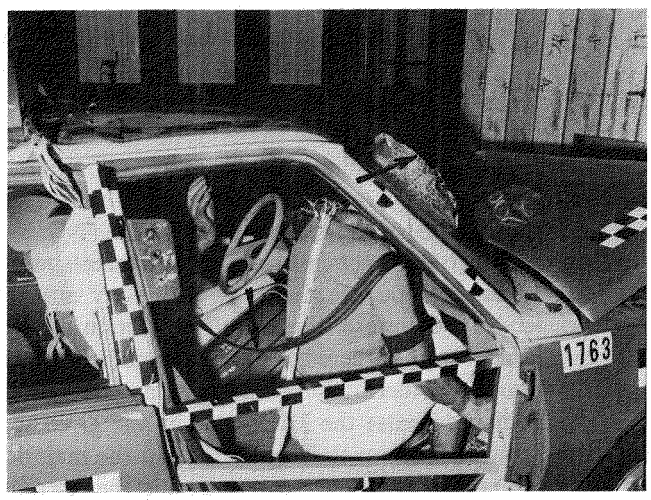


Figure 13 bis. Low HICd with failure of the experimental prototype belt. (Corresponds to Figure 13, above).

such as a webbing breakage, HIC can remain below 1000. Figure 13 shows the results of 2 tests under the same conditions as in Figure 7. Above, the restraint was concentrated in the upper part of the thorax by raising the B-pillar anchorage point and allowing more pelvis forward displacement. It resulted in a sufficiently low HIC; however, the webbing acted on the neck during the collision. Below is another case: webbing broke during the collision; due to the lack of head rotation, HIC remained at a low level.

3. A protection criterion that matches the tolerance level of the weaker population does not afford the maximum overall protection benefit for the whole population at risk. Further work is needed in that field; for example, J.A. Searle (26) proposed mathematically an optimum between 50% and 80% of the median tolerance, for another similar problem.
4. In all that precedes, the HIC computation which was considered, as a matter of fact, was like in US Standard 208. This point is emphasized because several ways for computing HIC exist. However, the arguments of this paper show that only the impact phase of the deceleration pulse is likely to produce injuries. Therefore, an HIC computation limited to the contact phase between the head and a part of the vehicle interior is sound. It raises some technical problems which are in process of solution.
5. Recent papers (31)(32) claimed for a correspondence between HIC 1000 and AIS 3. Their rationale is the following: accident analyses (33) allow characteristics recorded in a given type of frontal collisions to be related to AIS values.

   In parallel, the characteristics associated with the same particular type of accident (AC) can be translated in terms of "dummy loadings" and hence give a basis for injury criteria. These DL (dummy loadings) are deduced from the characteristics of accidents by a simple two-dimensional mathematical model (10 degrees of freedom), which is claimed to have been validated by full size dummy tests. The reliability of the results with regard to HIC may be contested.

   In accident data, there were 318 restraint occupant of all sizes with 178 having an AIS between 1 and 6 for the head, of which 115 were AIS 1. There remains 6 AIS 3, 9 AIS 4, 3 AIS 5 in relation to the "AC" or "EAC" (equivalent accident characteristics) which are used to define the dummy criteria.

   Even if all the characteristics of accidents having an influence were accurately recorded, the statistical basis is insufficient.

   Even if the mathematical model is valid for a given accident or several accidents, the HIC is a function of a resultant acceleration which can only be poorly simulated. In effect:

   —the model is two-dimensional;
   —the mathematical simulation of the neck is not sufficiently accurate in models (number or articulations, reaction torque of the joints at the limit of the range of motions, etc. . . .).
   —the simulation of impacts can only be made with a perfect knowledge of the dynamic laws of load-de-

were separated from facial injuries; for these latter, there was a fractured mandible rated AIS 3.

"It should be stressed that 3130 is a tolerable value", was his conclusion, since he locates the tolerance at AIS 3 level.

Of the already mentioned Cesari's paper in 23rd Stapp Car Crash Conference (22) which deals with accident reconstructions, the following table, where the AIS 0 cases were suppressed, can be excepted.

Each line corresponds to one reconstruction.

Head AIS real victim	Height real victim	H.I.C. dummy
2	1.57	293
3	1.85	450
2	1.63	2777
1	1.65	316

Only the case AIS 3 will be discussed here, because of the interest of this level of severity. The vehicle deformations "appeared slightly less important than those of the actual accident"; some differences in the heights of the victim and of the dummy can be also noted. These facts are not a criticism; they emphasize the paramount importance of every detail to achieve an accurate reproduction. Belt slack, driver's position, steering wheel orientation and so on. Consequently, comparisons of *similar samples* of real accidents and of simulations may be useful to get some ascertainty. This case needed to be confirmed (by the way, the cadaver HIC in a similar reconstruction previously noted was 2412, associated to AIS 0).

KOB reconstructions (23), as regards frontal collisions, display the results of 2 accidents which were reconstructed three times with dummy and with cadavers. Unfortunately, the severities of the real accidents are rather low and no head AIS $>$ 1 can be claimed.

Reported experiments with restrained dummies do not display sufficient data to suggest a modification of HIC 1500 statement.

OTHER TYPES OF SEVERE HEAD ACCELERATIONS IN TRAFFIC ACCIDENTS

They are mainly due to lateral collisions and to accidents involving pedestrians. In lateral collisions, one can distinguish 2 types of circumstances. On one hand, when the head strikes a part of the side wall and is mainly decelerated by this impact; on the other hand, when the head undergoes no impact, what gives the whole loading to the neck.

In case of impact, and with a sufficient pressure distribution, the tolerance level previously applies and an HIC 1500 is reasonable; the use of a correct lateral impact dummy prevents from any transposition problem. When no impact occurs, a neck tolerance problem may arise. Further research, related to this topic, is needed; it will involve firstly accident data before any other development of transducers and dummies.

As regards pedestrians, they are for the most part, hit on their side, when crossing a road. Their head strikes generally a part of the vehicle, which can be the bonnet, or the windscreen surroundings. The head impact is a lateral one, where no problem with the neck arises, as it was told previously for a class of lateral impacts; the situations of pedestrians and of side collisions victims are comparable. As regards pedestrians, the violence of their head impacts are conditioned by the technology of the dummy; with a suitable dummy, like a modified lateral impact dummy, the tolerance level previously defined applies, and therefore like for lateral impacts, the value of 1500 not to be exceeded for HIC is reasonable.

DISCUSSION

1. HIC was often criticized as regards its correlation with injuries. One of the most comprehensive study was made by Newman (3). He found the absence of correlation between numerous HIC values and corresponding AIS levels.

   However, the reported cases encompassed a lot of different surrogates and many types of accidents; one can find simultaneously tests using obsolete dummies, cadavers and mathematical modeling. Correspondences may exist, if they do, between one type of surrogate which undergoes one given type of accident, and the associated AIS value, given by one method.

   Here a HIC/AIS correlation was never claimed; only a threshold in the cases of a very large majority of impacts was proposed.
2. In frontal collisions, some prefer HIC 1000 to HIC 1500 because their opinion is that HIC 1000 offers a better protection. If the limits concerning body loadings could be managed independently, it could be right. As a matter of fact, the results of measurements made on the sundry body segments of a dummy are not independent; therefore, the *overall* protection offered by all the criteria gathered has to be considered firstly.

   Without considering the dummy, many possibilities exist which decrease the HIC value in one given test while lowering the overall safety level in the majority of collision circumstances: concentrating the restraint forces on the upper part of the thorax, making these forces as high as tolerated or, on the contrary, defining a very weak restraint which prevents the head rotation; one can also increase the trend to submarine and the severity of knee impacts. It emphasizes the interest of a complete and homogeneous set of injury criteria.

   Besides, the 2 above mentioned kinds of methods for diminishing the HIC work properly, except as regards safety. More, if a failure of the restraint occurs,

flection of impacted surfaces, and this in the direction of movement.

—effects due to intrusion, and steering wheel displacements are not properly simulated.

By the way, it was noted here previously that mathematical modeling seemed to yield lower HIC values than full-scale testing.

These inexactitudes lead to errors even in supposing that, at the top of the thorax, the impact of acceleration is perfectly simulated. It will be remembered furthermore that a variation of 17.6% of acceleration figure modifies by 50% the HIC for the same time period.

This recent study, therefore, does not justify the HIC of 1000.

CONCLUSIONS

—When no head impact occurs in present frontal collisions, there is no need of a particular head protection criterion.

—HIC 1000 is matched to rigid impacts of short duration onto the head with an unrestrained body, and it is not matched to car environment.

—HIC 1500 is a sufficient estimate of head tolerance to direct impact in frontal and lateral directions.

—In frontal collisions, when occupants are restrained, HIC 1500 corresponds to a less severe head impact + injury risk when compared to an unrestrained occupant who receives the same HIC value.

—Full-scale experiments with cadavers and dummies support the HIC 1500 statement.

—A different approach is suggested for facial protection.

—Computation of HIC during head contact period is desirable.

ACKNOWLEDGEMENTS

Accidentological section of this paper could be issued thanks to the work of C. Thomas and G. Faverjon.

This study uses results obtained by carrying out research contracts with the French Administration (A.T.P.) and, more recently, with E.E.C. This text commits them in no way.

REFERENCES

1. C. W. Gadd, "Use of a Weighted Impulse Criterion for Estimating Injury Hazard", in 10th Stapp Car Crash Conference, 1966, SAE.
2. J. Versace, "A Review of the Severity Index", in 15th Stapp Car Crash Conference, 1971, SAE.
3. J. A. Newman, "Head Injury Criteria in Automotive Crash Testing", in 24th Stapp Car Crash Conference, 1980, SAE.
4. A. Eiband, "Human Tolerance to Rapidly Applied Accelerations: a Summary of the Literature", NASA Memorandum 5-19-59 E, June 1959.
5. C. W. Gadd, "Tolerable Severity Index in Whole-Head, non-Mechanical Impact", in 15th Stapp Car Crash Conference, 1971, SAE.
6. V. R. Hodgson, L. M. Thomas, "Comparison of Head Acceleration Injury Indices in Cadaver Skull Fractures", in 15th Stapp Car Crash Conference, 1981, SAE.
7. C. Got et al., "Results of Experimental Head Impacts on Cadavers", in 22nd Stapp Car Crash Conference, 1978, SAE.
8. A. M. Nahum, R. W. Smith, "An Experimental Model for Closed Head Impact Injury", Proceedings of 20th Stapp Car Crash Conference, SAE paper 760 825, 1976, SAE.
9. A. M. Nahum, R. W. Smith, C. C. Ward, "Intracranial Pressure Dynamics During Head Impact", Proceedings of 21st Stapp Car Crash Conference, SAE, 1977.
10. R. L. Stalnaker, J. W. Melvin, G. S. Nusholtz, N. M. Alem, J. B. Benson, "Head Impact Response", Proceedings of 21st Stapp Car Crash Conference, SAE, 1977.
11. L. M. Patrick, N. Bohlin, A. Andersson, "Three-Point Harness Accident and Laboratory Data Comparison", S.A.E. paper 741 181, 18th Stapp Car Crash Conference, SAE, 1974.
12. G. Schmidt, D. Kallieris, J. Barz, R. Mattern, "Results of 49 Cadaver Tests Simulating Frontal Collision of Front Seat Passengers", 18th Stapp Car Crash Conference, SAE, 1974.
13. J. R. Cromack, H. H. Ziperman, "Three-Point-Belt Induced Injuries: A Comparison Between Laboratory Surrogates and Real World Accident Victims", 19th Stapp Car Crash Conference, SAE, 1975.
14. L. M. Patrick, R. S. Levine, "Injury to Unembalmed Belted Cadavers in Simulated Collisions", 19th Stapp Car Crash Conference, SAE, 1975.
15. D. Cesari, M. Ramet, "Comparison Between In-the-Field Accidents and Reconstructed Accidents with Dummies and with Cadavers", 19th Stapp Car Crash Conference, SAE, 1975.
16. A. Fayon, C. Tarrière, G. Walfisch, C. Got, A. Patel, "Thorax of 3-Pt Belt Wearers During a Crash (Experiments with Cadavers), 19th Stapp Car Crash Conference, SAE, 1975.
17. G. Schmidt, D. Kallieris, J. Barz, R. Mattern, J. Klaiber, "Neck and Thorax Tolerance Levels of Belt-Protected Occupants in Head-on Collisions", 19th Stapp Car Crash Conference, SAE, 1975.
18. M. J. Walsh, D. J. Romeo, "Results of Cadaver and Anthropomorphic Dummy Tests in Identical Crash

Situations", 20th Stapp Car Crash Conference, SAE, 1976.
19. M. J. Walsh, B. J. Kelleher, "Evaluation of Air Cushion and Belt Restraint Systems in Identical Crash Situations Using Dummies and Cadavers", 22nd Stapp Car Crash Conference, SAE, 1978.
20. N. M. Alem, B. M. Bowman, J. W. Melvin, J. B. Benson, "Whole-Body Human Surrogate Response to Three-Point Harness Restraint", 22nd Stapp Car Crash Conference, SAE, 1978.
21. D. Cesari, M. Ramet, "Evaluation of Human Tolerance in Frontal Impacts", 23rd Stapp Car Crash Conference, SAE, 1979.
22. D. Cesari, in a"Unfall und Sicherheitsforschung Strassenverkehr", Heft 34, 1982, p. 24, edited by "Bundesanstalt für Strassenwesen", Bereich Unfallforschung, Köln.
23. H. Schmikat, R. Weissner, G. Schmidt, "A Comparison Between Volkswagen Automatic Restraint and 3-pt Automatic Belt on the Basis of Dummy and Cadaver Tests", 18th Stapp Car Crash Conference, 1974, SAE.
24. C. Tarrière, Y. C. Leung, A. Fayon, C. Got, A. Patel, P. Banzet, "Field Facial Injuries and Study of their Simulation With Dummy", 25th Stapp Car Crash Conference, 1981, SAE.
25. J. A. Searle, J. Bethell, G. Baggaley, "The Variation of Human Tolerance to Impact and Its Effect on the Design and Testing of Automotive Impact Performance," 22nd Stapp Car Crash Conference, 1978, SAE.
26. C. Tarrière, G. Walfisch, A. Fayon, C. Got, F. Guillon, A. Patel, J. Hureau, "Acceleration Jerk and Neck-Flection Angle: Their Respective Influences on the Occjurrence of Brain Injury", Agard Conference, Köln, 1982.
27. N. M. Alem et al., "Whole body response research program", Final report HSRI, Apr. 1978—Report N° UM-HSRI, 77-39.
28. J. Brinn, S. E. Staffeld, "Evaluation of Impact Test Accelerations;" A Damage Index For the Head and Torso", 14th Stapp Car Crash Conference, SAE paper 700902.
29. SAE J 885, Apr. 1980.
30. K. Langwieder et al., "Comparison of Passenger Injuries on Frontal Car Collisions with Dummy Ratings in Equivalent Simulations," 23rd Stapp Car Crash Conference.
31. F. Kramer, H. Appel et al., "Evaluation of Protection Criteria by Combining Results of Computer and Experimental Simulations with Results of Accident Investigation", 5th Conference IRCOBI, 1980, Secrétariat IRCOBI, 109 Av, S, Allende, 69500—Bron, France.
32. HUK Data.
33. D. Lestrelin et al., "PRAKIMOD": Mathematical Simulation, 8th International Technical Conference on E.S.V., Wolfsburg, 1980.

Possible Positions and Postures of Unrestrained Front-Seat Children at Instant of Collision

F. MONTALVO, R. W. BRYANT and H. J. MERTZ
General Motors Corporation

ABSTRACT

The development of any front-seat passenger inflatable restraint system should consider the added deployment forces applied to occupants who may be close to the instrument panel at the time of deployment. A major factor influencing occupant position and posture is the effect of preimpact braking which often occurs prior to the collision. Most susceptible to preimpact braking are small, unrestrained children who can move off the front edge of the seat during hard braking and be near or against the instrument panel in a variety of different positions and postures at the instant of collision. Based on an analysis of hard-braking tests conducted with anesthetized baboons and child dummies, 13 positions are identified as being representative of the expected child positions. An estimate is given that, of the 149 small children (infants through four years old) expected to be unrestrained front-seat occupants in collisions of sufficient severity to deploy an inflatable restraint system per million car-years of exposure, 51 of them will be in one of these 13 positions near the instrument panel at the instant of collision.

INTRODUCTION

Animal studies (1, 2, and 3) have shown that there is a potential for serious head, neck, thorax, and abdomen injuries when animals are placed close to the instrument panel and a passenger inflatable restraint cushion is deployed. In order to assess the performance of various inflatable restraint system concepts relative to these potential injury modes, knowledge of expected child positions and postures near the instrument panel at the instant of collision is needed. This paper describes how estimates

of reasonable child positions and postures were determined, as well as a procedure that was used to estimate the number of children who would be expected to be in each of these positions at the time of deployment of an inflatable restraint system per million car-years of exposure.

CHILD POSITIONS AND POSTURES NEAR INSTRUMENT PANEL

Child positions and postures near the instrument panel at the instant of a collision are dependent on the riding positions and postures of children and the degree of preimpact braking that occurs prior to the collision event. Estimates of child riding positions and postures were obtained from a report prepared by Opinion Research Corporation (ORC) under a contract with the National Highway Traffic Safety Administration (NHTSA) (4). The report summarizes the observations that were made of child occupants during a survey of cars stopped for traffic lights in 19 metropolitan areas from July to December 1979. The data collected for each child occupant included: age, sex, seated position, posture (sitting, standing, etc.), occupant location (on seat or floor), orientation of the occupant's knees (facing forward, biased left or right), and usage of restraints. Table 1 summarizes the results of the survey for unrestrained, front-seat children estimated to be one to four years old. Described in the table are the child's posture; whether the child was on the seat or on the lap of another front-seat occupant; the orientation of the child's knees; and support of the child's back. The positions of the child's arms were assumed. The number of children observed in each position is given. The table is ordered by frequency of observed child position with the more-frequent position listed first. Each child position is assigned a line number for ease of reference. Table 2 is a similar summary for unrestrained, front-seat children estimated to be less than one year old. A total of 1604 unrestrained, front-seat children, ranging in age from infant to four years old, were observed. Thirteen hundred were one to four years old and 304 were less than one year old. Fifty-one different positions were observed for the older children, and 31 positions were noted for the younger children.

To aid in determining the possible positions and postures that children in these various riding positions could be forced to assume as a result of preimpact braking, a series of hard-braking tests was conducted using anesthetized baboons and a child dummy that were representative in stature and weight of a three-year-old child.

Table 1. Front-seat ride positions of one to four-year-old children based on ORC survey (4)

Line	ORC Cases	Posture	Child is on	Location of Child on Seat/Floor	Knee Direction O'Clock	Back is to	Arm Position
1	331	Sitting	Seat	Rearward	12:00	Seat	Down
2	109	Sitting	Seat	Forward	12:00	Nothing	Up, hands on sill
3	106	Standing	Seat	Forward	12:00	Nothing	Up, hands on I/P
4	95	Standing	Seat	Rearward	12:00	Seat	Down
5	89	Sitting	Seat	Forward	1:30	Nothing	Up, hands on I/P
6	87	Sitting	Lap	Rearward	12:00	Person	Down
7	80	Standing	Seat	Mid	3:00	Nothing	Up, hands on sill
8	55	Sitting	Lap	Rearward	10:00	Seat	Down
9	51	Kneeling	Seat	Mid	3:00	Nothing	Up, hands on sill
10	30	Standing	Seat	Rearward	10:30	Seat	Down
11	27	Sitting	Seat	Rearward	10:30	Seat	Down
12	27	Sitting	Lap	Forward	12:00	Nothing	Up, hands on I/P
13	27	Sitting	Lap	Forward	1:30	Nothing	Up, hands on sill
14	24	Sitting	Seat	Mid	9:00	Door	Down
15	17	Standing	Floor	Rearward	12:00	Nothing	Up, hands on sill
16	16	Standing	Lap	Mid	6:00	Nothing	Down
17	14	Kneeling	Lap	Mid	3:00	Nothing	Up, hands on sill
18	12	Kneeling	Seat	Forward	12:00	Nothing	Up, hands on I/P
19	11	Standing	Lap	Rearward	1:30	Person	Down
20	10	Lying	Seat	Rearward	Down	Nothing	Up
21	9	Lying	Lap	Mid	Up	Person	Down
22	8	Kneeling	Lap	Mid	1:30	Person	Up, hands on sill
23	7	Standing	Floor	Rearward	3:00	Nothing	Up, hands on sill
24	6	Kneeling	Seat	Rearward	12:00	Seat	Down
25	5	Sitting	Floor	Rearward	3:00	Nothing	Down
26	5	Lying	Seat	Rearward	12:00	Seat	Down
27	4	Lying	Lap	Mid	Down	Nothing	Down
28	3	Sitting	Lap	Mid	9:00	Door	Down
29	3	Standing	Floor	Rearward	12:00	Seat	Down
30	3	Standing	Lap	Forward	12:00	Nothing	Down
31	3	Kneeling	Seat	Mid	9:00	Door	Down
32	3	Lying	Seat	Rearward	Up	Seat	Down
33	2	Sitting	Seat	Mid	12:00	Person	Down
		(Between adult's legs)					
34	2	Sitting	Seat	Mid	10:30	Person	Down
35	2	Standing	Seat	Rearward	12:00	Door	Down
		(Torso twisted toward driver)					
36	2	Standing	Seat	Rearward	9:00	Door	Down
37	1	Sitting	Seat	Rearward	12:00	Door	Down
		(Torso twisted toward driver)					
38	1	Sitting	Floor	Rearward	12:00	Seat	Down
39	1	Sitting	Floor	Forward	12:00	Nothing	Down
40	1	Sitting	Floor	Mid	9:00	Door	Down
41	1	Sitting	Floor	Rearward	10:30	Person	Down
		(Between adult's legs)					
42	1	Sitting	Lap	Mid	12:00	Seat	Down
		(Adult sideways on seat facing outside window, legs folded)					
43	1	Standing	Seat	Mid	12:00	Person	Down
		(Between adult's legs)					
44	1	Standing	Seat	Rearward	10:30	Person	Down
45	1	Standing	Lap	Rearward	12:00	Person	Down
46	1	Kneeling	Seat	Rearward	1:30	Seat	Down
47	1	Kneeling	Seat	Mid	10:30	Person	Down
48	1	Kneeling	Floor	Rearward	3:00	Nothing	Down
49	1	Kneeling	Lap	Mid	12:00	Seat	Down
		(Adult sideways on seat facing side window, legs folded)					
50	1	Kneeling	Lap	Forward	12:00	Nothing	Up, hands on I/P
51	1	Lying	Seat	Forward	12:00	Nothing	Up
		(Or torso is twisted)					

Table 2. Front-seat ride positions of children less than one yeare old based on ORC survey (4)

Line	ORC Cases	Posture	Child is on	Location of Child on Seat/Floor	Knee Direction O'Clock	Back is to	Arm Position
1	59	Sitting	Lap	Rearward	10:30	Person	Down
2	56	Lying	Lap	Rearward	Up	Person	Down
3	52	Sitting	Lap	Rearward	12:00	Person	Down
4	17	Sitting	Lap	Rearward	6:00	Nothing	Down
5	17	Sitting	Seat	Rearward	12:00	Seat	Down
6	14	Standing	Lap	Rearward	6:00	Nothing	Down
7	13	Sitting	Lap	Forward	12:00	Nothing	Up on I/P
8	12	Standing	Lap	Rearward	10:30	Person	Down
9	8	Lying	Seat	Rearward	Up	Seat	Down
10	8	Lying	Lap	Rearward	Down	Nothing	Up
11	7	Kneeling	Lap	Rearward	6:00	Nothing	Down
12	6	Sitting	Seat	Rearward	9:00	Nothing	Down
13	4	Sitting	Seat	Mid	12:00	Person	Down
		(Between adult's legs)					
14	4	Sitting	Seat	Rearward	9:00	Person	Down
15	4	Standing	Seat	Mid	6:00	Nothing	Down
16	3	Sitting	Seat	Forward	12:00	Nothing	Down
		(Legs over edge of seat with adult's hands around waist)					
17	3	Lying	Seat	Mid	Down	Nothing	Up
18	2	Sitting	Floor	Rearward	1:30	Person	Down
19	2	Standing	Lap	Rearward	12:00	Person	Down
20	2	Kneeling	Lap	Rearward	10:30	Person	Down
21	1	Sitting	Seat	Rearward	1:30	Seat	Down
22	1	Sitting	Lap	Mid	12:00	Seat	Down
		(Adult sideways on seat with legs folded, facing two o'clock)					
23	1	Sitting	Lap	Rearward	9:00	Door	Down
24	1	Standing	Seat	Rearward	12:00	Seat	Down
25	1	Standing	Seat	Mid	10:30	Person	Down
		(Between adult's legs)					
26	1	Standing	Lap	Mid	12:00	Nothing	Down
		(Adult holding infant's balance)					
27	1	Kneeling	Seat	Rearward	3:00	Nothing	Down
28	1	Kneeling	Lap	Mid	12:00	Seat	Down
		(Adult sideways on seat with legs folded, facing two o'clock)					
29	1	Lying	Seat	Rearward	12:00	Seat	Down
30	1	Lying	Floor	Rearward	10:30	Seat	Down
		(Lying on left side with knees on chest--folded upward)					
31	1	Lying	Lap	Rearward	12:00	Person	Down
		(On right side)					

The results of these tests are described in a paper by Stalnaker, et al. (5). The various child surrogates were placed in the high-frequency riding positions noted in Table 1, and their trajectories in response to hard braking were determined by analyzing high-speed movies of the braking event. Based on these analyses, 13 child positions were identified as being representative of reasonable child positions near the instrument panel. Characterizations of these positions are shown in Figure 1 and are denoted as the "Z-Positions".

NUMBER OF CHILDREN IN THE VARIOUS Z-POSITIONS

In order to determine the number of children that may be in any one of the 13 Z-positions at the instant of collision, per million car-years of exposure, estimates for the following parameters are needed.

1. N = Number of unrestrained, front-seat children that can be expected to be in collisions of sufficient severity to deploy an inflatable restraint system, per million car-years of exposure.
2. $(F)_{RPJ}$ = The relative frequency of each ride positions identified in Tables 1 and 2 for infant through four-year-old children.
3. $(PZI)_{RPJ}$ = The probabilities that a child will be in various Z-positions at the instant of collision for each ride position.

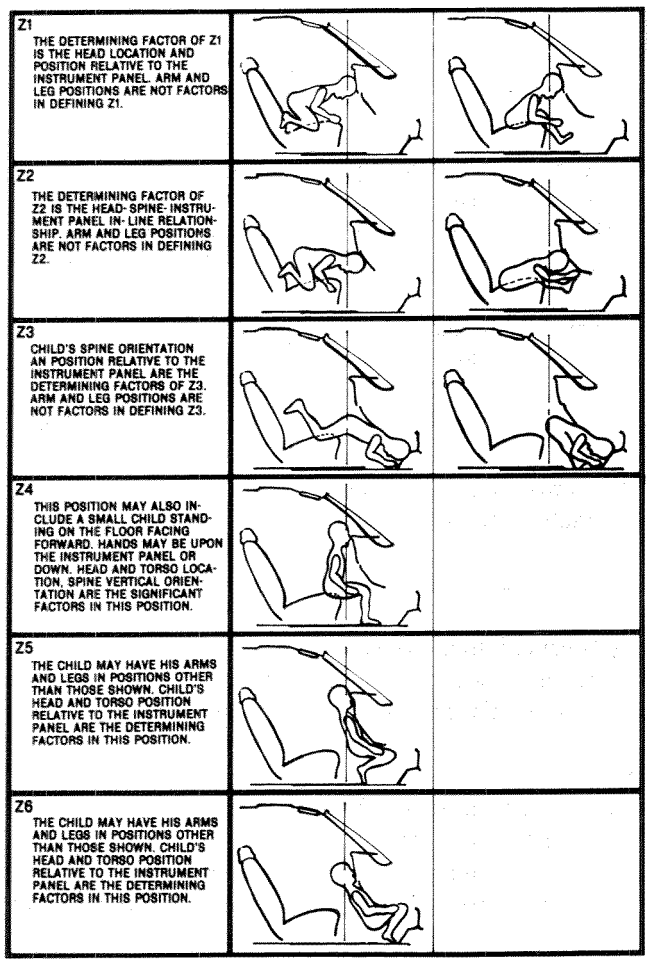


Figure 1. Thirteen child positions (Z-positions) identified as reasonable positions for children near the instrument panel at the instant of collision.

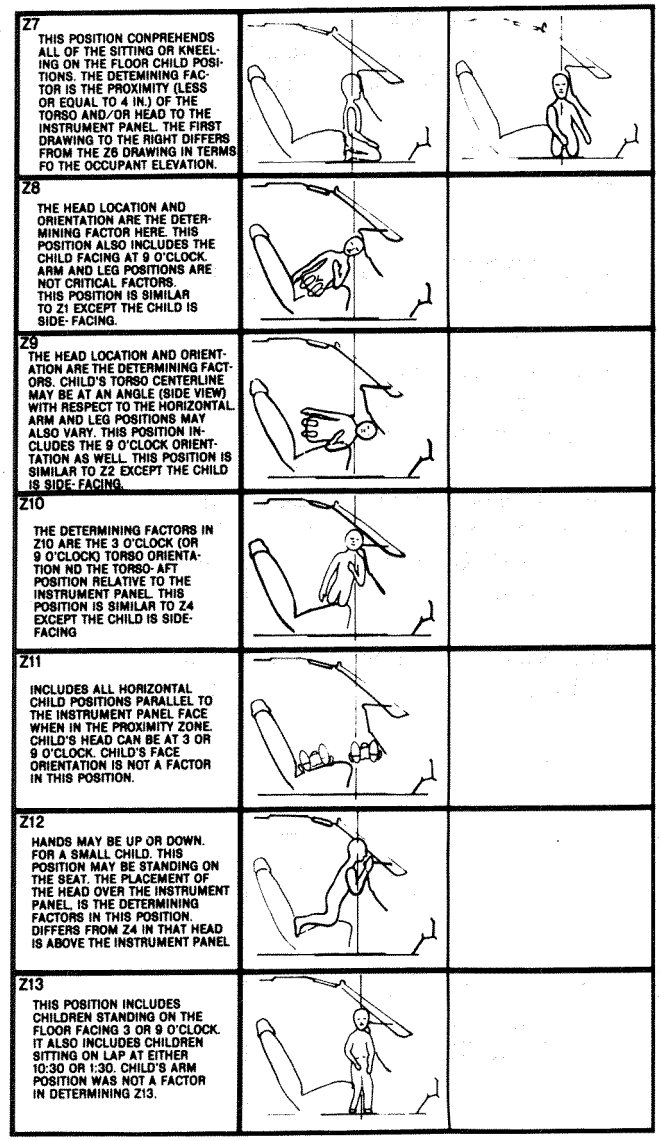


Figure 1. (Continued). Thirteen child positions (Z-positions) identified as reasonable positions for children near the instrument panel at the instant of collision.

With these estimates, the number of children expected to be in a given Z-position can be calculated by,

$$N_{ZI} = \Sigma_{RPJ} (F)_{RPJ} \cdot N \cdot (PZI)_{RPJ}$$

Estimate for N

An estimate for N can be obtained by multiplying the number of collisions that would be of sufficient severity to deploy an inflatable restraint system per million car-years of exposure, N_D, by the probability of a child (infant to four years old), P_C, being in such an accident.

$$N = N_D \cdot P_C$$

Accident data from the GM Motors Insurance Corporation (MIC) file were used to estimate N_D and P_C. Photographs of car damage were used to estimate the number of collisions (M_{DC}) that might have resulted in a deployment of an inflatable restraint system if such a system had been installed in the cars. A deployment-type collision was defined as an accident where the primary direction of impact was between ten and two o'clock with an estimated equivalent barrier speed of 12 miles per hour or greater. For these types of collisions, the number of front-seat children (M_C), infant to four years old, were counted. N was estimated by projecting M_{DC} to a million car-year exposure based on an estimate of the frequency of occurrence of injury accidents per million car-years. This calculation gave an estimate for N_D of 3732 deployments per million car-year exposure. P_C was taken as the ratio of M_C divided by M_{DC}, or 0.040. Using these values for N_D and P_C in the above equation, N was estimated to be 149 unrestrained, front-seat children (infant to four years old) involved in collisions of sufficient severity to deploy an inflatable restraint system, per million car-years of exposure.

Estimate for $(F)_{RPJ}$

The relative frequency of each ride position was calculated by dividing the number of children observed in a given position (see Tables 1 and 2) by 1604, the total number of children observed.

Estimate for $(PZI)_{RPJ}$

To determine the probabilities that a child would be in various Z-positions at the instant of collision for each ride position, estimates of the frequency and duration of preimpact braking and the times that the child would enter and leave the appropriate Z-positions during the braking event for each ride position had to be obtained.

The Cornell Aeronautical Laboratory (CAL II-A, CAL II-B), Highway Safety Research Institute (HSRI), and Oakland County, Michigan (OAKLAND) Multi-Disciplinary Accident Investigation-level (MDAI) data files were used to estimate the relative frequency of preimpact braking (FPIB) in deployment-type accidents. These accident data files contain information on preaccident traveling speed, as well as vehicle speed at impact. The difference between these two speeds was assumed to be the vehicle slow-down speed as a result of preimpact braking. A search of these data files produced 1633 accident case cars where information concerning any accident-avoidance maneuver was given, as well as traveling and impact speeds. Of these 1633 case cars, a total of 1061 (65 percent) had "brake" or "brake and steer" coded as an accident-avoidance maneuver.

The velocity changes noted for the various accidents were used to estimate the corresponding braking times by assuming that the average deceleration level was a constant 0.75 g's. A curve, estimating the probability that an accident, which is severe enough to deploy an inflatable restraint, would have various levels of preimpact braking, was generated and is shown in Figure 2. Note that this curve reflects the previous observation that 65 percent of these accidents will have some level of preimpact braking.

Estimates of the times that a child enters and leaves a given Z-position, after the start of braking for each ride position, were based on analysis of the kinematics of anesthetized animal tests by Stalnaker, et al. (5), which were used to identify the various Z-positions. The animal tests showed that the fore-aft seat position had a major influence on the resulting Z-positions and the times that the animals entered and left a given Z-position. Since the Opinion Research Corporation report (4) did not specify the seat position for the various ride positions, it was assumed that their observations were equally divided between seat full forward and full rearward. Once estimates were obtained for the times a child would enter and leave the various Z-positions for each ride position, the corresponding probabilities that an accident would occur during these times were obtained from Figure 2.

Estimate of N_{ZI}

The data used to calculate N_{ZI} can be visualized as a matrix of 13 columns and 164 rows as shown in Table 3. Each column represents one of the 13 Z-positions. Each

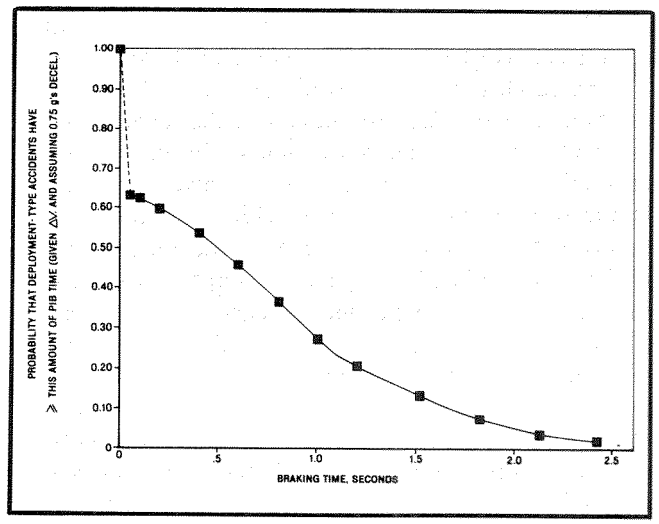


Figure 2. Probabilities that deployment-type accidents have various amounts of preimpact braking.

Table 3. Format used to calculate the number of children expected to be in each Z-position at the instant of collision for deployment-type accidents per million car-years exposure.

Line	ORC Children/ Total Children	Estimated Number of Children 10^6 C-Y	Factor for Seat Position	Possible Child Positions Near Instrument Panel, N_{ZI} Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Not in Proximity
1	331/1604	149	0.5	0.0414/0.636	0.0575/0.884	0.1475/2.268											0.7536/11.586
2	109/1604	149	0.5				0.0290/0.147	0.0683/0.346	0.0417/0.211	0.4570/2.314							0.4040/2.045
3	106/1604														0.5176/2.548		0.4824/2.375
4	95/1604	149	0.5	0.0380/0.168	0.0684/0.302	0.1154/0.509											0.7782/3.434
5	89/1604	149	0.5				0.0686/0.284	0.1803/0.745	0.2700/1.116	0.0487/0.201							0.4324/1.787
⋮																	
164	1/1604	149	0.5														1.000/0.046
Totals (N_{ZI} and Not in Proximity)				9.539	1.443	3.445	9.506	2.541	1.586	5.435	1.841	0.213	3.269	0.176	8.557	3.158	98.389

row represents one of the possible 164 ride positions (82 ride positions for seat full forward and 82 ride positions for seat full rearward).

To illustrate how Table 3 was developed, consider Line 4. According to Line 4 of Table 1, 95 of the 1604 children were observed in this position. And in Table 3 the "149 children per million car-years" is the value of N discussed previously. The factor, "0.5", accounts for the assumption that half of the 95 children were sitting on seats that were full rearward. (There will be a separate line for the calculations assuming the seat was full rearward.) The top line numbers for Line 4 under the various Z-positions represent the probabilities that the child will be in each of the various Z-positions at the time of collision. For this ride position, it was estimated that the probabilities of a child being in the Z1, Z2, or Z3 position at the time of collision are 0.038, 0.0684, and 0.1154, respectively. The probability of a child being in any of the other Z-positions is zero. The last column of the table gives the probability that the child will not be in any of the Z-positions (not in the proximity of the instrument panel) at the time of collision and is 0.7782 for Line 4. The numbers under the probabilities for Line 4 are estimates of the number of children (infant through four years old) that can be expected per million car-years of exposure. These numbers were calculated by multiplying the various probabilities by the frequency of the ride position (95/1605 $\times$ 0.50) and the number of children (149 infants through four-year-olds) expected to be in accidents of sufficient severity to deploy an inflatable restraint system per million car-years of exposure. Thus, for Line 4, the number of children per million car-years exposure expected to be in Z1, Z2, and Z3 positions are 0.168, 0.302, and 0.509, respectively. These types of calculations were carried out for each of the 164 lines.

An estimate for the total number of children expected to be in a given Z-position was obtained by adding the number of children in the corresponding Z column. The results of these summations are tabulated at the bottom of each Z column. For example, it is estimated that there will be 9.539 children (infants through four-year-olds) in the Z1 position at the instant of collision per million car-years of exposure.

The results of these calculations for each Z-position are summarized in Figure 3. Note that the most-frequent Z-positions are Z1, Z4, and Z12. The least-frequent are Z9 and Z11. Also, note that of the 149 unrestrained, front-seat children (infant through four years old) who are expected to be in accidents that would be of sufficient severity to deploy an inflatable restraint system per million car-years exposure, a total of 51 of them are expected to be in the proximity of the instrument panel at the time of collision.

DISCUSSION

Several difficulties were encountered in identifying possible positions and postures close to the instrument panel of unrestrained, front-seat children at the instant of collision and estimating the number of children expected to be in each position per million car-years of exposure. The accident data files used to estimate preimpact braking times gave only estimates of velocity changes. Any error trend in these estimates will affect the shape of the curve of Figure 2 and, consequently, the probabilities used for

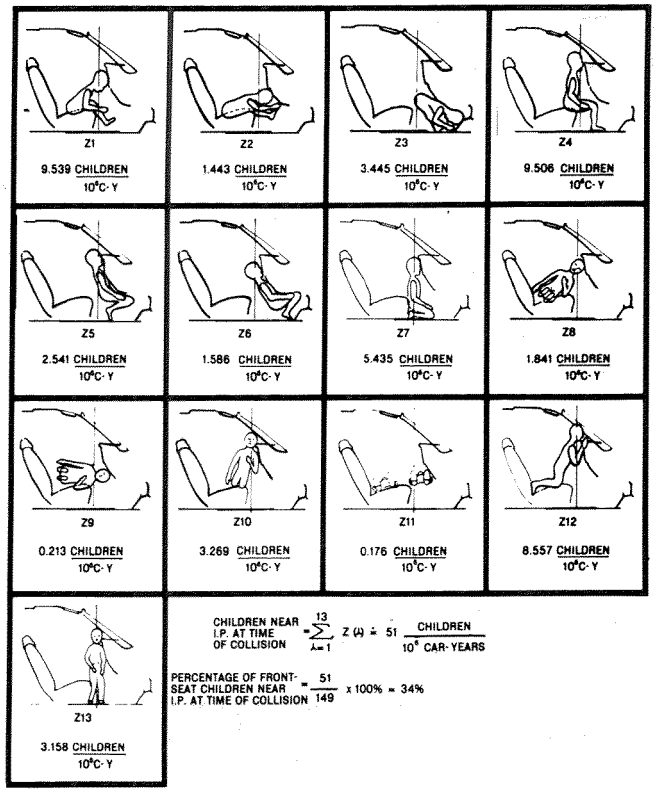


Figure 3. Number of children expected to be in the various Z-positions at the instant of collision per million car-years exposure.

determining the number of children expected to be in each Z-position.

Animal kinematic data were used to estimate the times children would enter and leave various Z-positions for a given ride position. Stalnaker, et al. (5), noted that the animals' kinematics were characteristic of relaxed or sleeping children and that different kinematics would be expected of children who tense their muscles in anticipation of the collision event. Consequently, the estimates given for the number of children in the various Z-positions are biased toward relaxed and sleeping children.

SUMMARY

Based on a million car-years of exposure, it was estimated that there would be 3732 cars involved in collisions of sufficient severity to deploy an inflatable restraint system, if the cars were so equipped. In these accidents there would be 149 unrestrained, front-seat children ranging in ages from infant to four years old. Of these children, 51 of them would be close to the instrument panel at the time of collision, either due to their initial ride position or due to preimpact braking. Thirteen positions and postures were identified as being characteristic of reasonable child positions close to the instrument panel at the instant of collision. Estimates of the number of children expected to be in each position, per million car-years of exposure, are given. This information should be useful in assessing the performance of various passenger inflatable restraint concepts relative to the question of the potential of injuries to children who may be close to the instrument panel in a collision where an inflatable restraint is deployed.

LIST OF REFERENCES

1. Patrick, L. M., and Nyquist, G. W., "Airbag Effects on the Out-of-Position Child", Society of Automotive Engineers, United States, Publication SAE 720442, May 1972.
2. Aldman, B.; Anderson, A.; and Saxmark, O., "Possible Effects on Air Bag Inflation on a Standing Child", Proceedings of the International Meeting on Biomechanics of Trauma in Children, Lyon, France, September 17-19, 1974.
3. Mertz, H. J.; Driscoll, G. D.; Lenox, J. B.; Nyquist, G. W.; and Weber, D. A., "Responses of Animals Exposed to Deployment of Various Passenger Inflatable Restraint System Concepts for a Variety of Collision Severities and Animal Positions", Proceedings of the Ninth Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, November 1-4, 1982.
4. "Child Restraint and Occupant Position Data—Survey of Cars in the Traffic Population, July-December 1979", Opinion Research Corporation Report prepared for the United States National Highway Traffic Safety Administration, March 1980.
5. Stalnaker, R. L.; Klusmeyer, L. F.; Peel, H. H.; White, C. D.; Smith, G. R.; and Mertz, H. J., "Unrestrained, Front Seat, Child Surrogate Trajectories Produced by Hard Braking", Proceedings of the 26th Stapp Car Crash Conference, Publication SAE 821165, October 1982.

Frontal Impact Component Test Evaluation of Current Anthropomorphic Test Device Technology

ROGER A. SAUL
National Highway Traffic Safety Administration
Vehicle Research and Test Center
East Liberty, Ohio

ABSTRACT

This paper presents the component test results of a program designed to evaluate frontal impact anthropometric test device hardware and instrumentation advancements which have been made since the development of the Part 572 dummy. In addition to the Part 572, the GM Hybrid III and Association of Peugeot-Renault dummies are included in the evaluation. The component test results presented in this paper describe the temperature sensitivity, biofidelity, repeatability, durability, and symmetry characteristics of the dummies in frontal impacts.

INTRODUCTION

The Part 572 dummy was standardized as an automotive test device in the early 1970's. It is specified as the occupant for Federal Motor Vehicle Safety Standard 208 frontal rigid barrier crash testing; and has also been used in frontal research, development, and evaluation programs. This dummy represents the "state-of-the-art" in hardware development, instrumentation, and associated injury criteria at the time FMVSS 208 was issued. Anthropomorphic test device (ATD) technology has advanced in several areas since that time due to the effort and resources invested by private industry, the National Highway Traffic Safety Administration, and foreign governments. The purposes of this program are:

i) to evaluate current dummy hardware and instrumentation technology, and
ii) to select a dummy for use in Agency research, development, and assessment programs.

Two dummies, the GM Hybrid III (1) and the APR'81 (2) (Association of Peugeot-Renault), have had the most significant advancements. These two and the Part 572 are included in this evaluation program. The project is comprised of two evaluation phases: component and system level. The approach being taken is as follows:

1. Initial Dummy Calibration—Each dummy was thoroughly tested prior to evaluation testing to ensure that it had been manufactured according to its specifications.
2. Component Level Evaluation—As described below, a series of tests were conducted on the various dummy body components.
3. Dummy Calibration Checks—The dummy calibrations were checked following the component level testing.
4. Systems Level Evaluation—A series of HYGE sled tests are being conducted in 3-point belt restraint and distributed loading systems. The dummies are also being tested in an unrestrained environment.

This paper discusses only the component level evaluation results.

TEST MATRIX DEVELOPMENT

Biofidelity, repeatability, and reproducibility are, of course, the primary factors of consideration for dummy evaluation. It has also been shown that the dummy responses may be sensitive to temperature (3), impact orientation (4), and age of the ATD materials (3). Reproducibility (comparative response of multiple ATDs) and material aging were not included as factors in establishing the test matrix for this study.

The component test matrix to evaluate dummy biofidelity was constructed to assess the dummy frontal performance through a series of tests which, although relatively simple, could be directly compared to the biomechanics data. A review of the literature published since standardization of the Part 572 was made to establish these biomechanics performance criteria. Those shown in Table 1 were selected as being the most appropriate for component test comparisons, but it should be noted that these are largely based on cadaver testing. While the similitude of the cadaver to the living human has not been established, the cadaver data have generally been accepted as the best available data for biofidelity. A recent paper by Patrick (5), however, would indicate that there are differences between cadaver thorax response and human response. It should be recognized, therefore, that the component test evaluations of the dummies for biofidelity will actually be a determination of fidelity to cadaver based data.

The sensitivity of dummies to temperature variations was investigated by Seiffert and Leyer (3) through a series of component calibration and full system sled tests with the Part 572 dummy in 1975 over a temperature range of 68-140°F. Significant dependencies of the calibration test results were observed over this wide temperature range, and the dummy motion was found to be different in the system tests. One of the conclusions made by Seif-

Table 1. Summary of Biomechanic Performance Criteria Sources.

Body Region	Source	Data Collection Methodology	Subject Response Measurements
Head	Hodgson et. al. (6,7,8)	Whole cadaver pallet drop tests; head impacts to load cell	Resultant Head Acceleration
Neck	Mertz et. al. (9,10)	Whole cadaver and volunteer sled tests in flexion and extension	Moment about Occipital Condyle vs. Head Rotation
Thorax	Neathery (11)	Whole cadaver rigid pendulum impact	Impact Force vs. Sternal Deflection
Femur	Horsch et. al. (12)	Rigidly mounted cadaver femur and lower legs	Peak Impact Force

fert and Leyer was that a temperature range should be specified for restraint system crash tests. Most of the crash tests conducted by the NHTSA specify that the temperature of the dummy be stabilized at a level between 66 and 78°F (13,14). Consequently, dummy response variations due to temperature within this range were of primary concern in the present study. Temperature sensitivity tests were conducted on the dummy head and thorax sections at three temperatures; those being 72°F as the median, and 65 and 80°F taken for the extremes.

The effect of impacting the Part 572 dummy head, thorax, and knees at various angles to determine response differences was reported by Daniel, et al.(4). They found that the dummy responses in these body regions could vary significantly depending upon the impact orientation. Of particular interest in the present study was the indication that the dummy response was not necessarily symmetrical (i.e., the response resulting from an impact at a certain angle was not duplicated when the dummy was impacted from the same angle on the opposite side). Although the dummy response resulting from one angle should not be expected to match the response from another, it is not unreasonable to expect the dummy to perform symmetrically. Evaluations of the dummy symmetrical properties were made by conducting impacts to the head, thorax, and knees at an angle of 15° orientation from both the left and right side of the dummies.

Repeatability was evaluated by repeating each test for biofidelity, temperature sensitivity, and symmetry three times for each of the dummies. Although it has been suggested that a relatively large number of repeat tests may be required to provide a statistically adequate sampling (15), the component test environment is relatively simple and not as susceptible to test set-up variations as more sophisticated testing might be.

Specific component tests to evaluate the durability of the dummy components were not included as a part of the test matrix design. Damaged parts were noted during the course of testing, however, and this became a factor in evaluating the dummy performance.

To summarize, the component test matrix was designed to evaluate the Part 572, APR '81, and Hybrid III dummies for biofidelity, temperature sensitivity, symmetry, repeatability, and durability. Tests were conducted on the head, neck, thorax, and knees (femurs) to evaluate these factors. Since the APR '81 dummy differs from the Part 572 in the thorax only; the APR '81 head, neck, and femur responses on the component level were assumed to be identical to the Part 572 responses. The component test matrix is summarized in Table 2, showing the dummies used and the evaluation factors considered by each test series.

TEST PROCEDURES

Prior to conducting the component test series, the Part 572 and Hybrid III dummies were calibrated. Post-test calibrations were conducted upon completion of the component tests. The APR dummy was subjected to 14 and 22 fps thorax impact tests before and after the component tests. Since calibration specifications are not available for the APR device, it was assumed to be in "calibration". The dummies were soaked at the test temperature for a minimum of four hours prior to testing. The temperature gradient in the dummy was monitored with thermocou-

Table 2. Component Test Matrix.

Test Series	Evaluation Factor				Dummies Tested		
	Repeatability	Biofidelity	Temp. Sensitivity	Symmetry	Part 572	APROD '81	Hybrid III
Head Drop 8.4 fps	X	X			X		X
Head Drop 6.3 fps	X	X			X		X
Neck Extension Mini-sled 24 fps	X	X			X		X
Neck Flexion Mini-sled 32 fps	X	X			X		X
Thorax Impact 14 fps, 72°F	X	X	X		X	X	X
Thorax Impact 20 fps, 72°F	X	X			X	X	X
Thorax Impact 22 fps, 72°F	X	X			X	X	X
Knee Impact 11#, 6.9 fps	X	X			X		X
Knee Impact 51-1/2#, 6.9 fps	X				X		X
Head Impacts 7.8 fps, 65°F	X		X		X		X
Head Impacts 7.8 fps, 72°F	X		X		X		X
Head Impacts 7.8 fps, 80°F	X		X		X		X
Thorax Impacts 14 fps, 65°F	X		X		X	X	X
Thorax Impacts 14 fps, 80°F	X		X		X	X	X
Head Impact 7.8 fps, ± 15°	X			X	X		X
Thorax Impact 14 fps, ± 15°	X			X	X	X	X
Knee Impact 11#, ± 15°	X			X	X		X

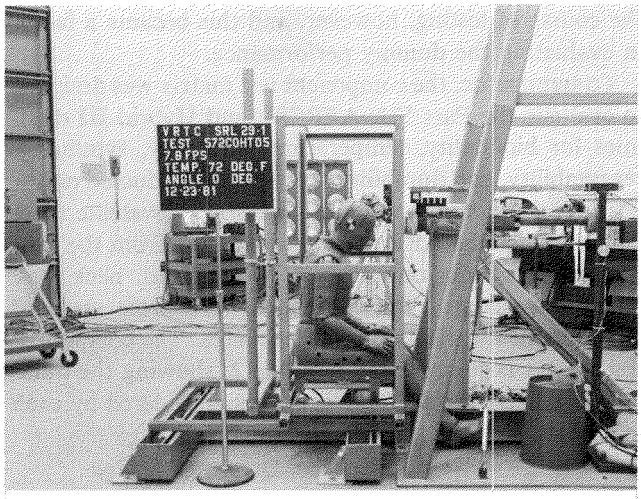


Figure 1a. Fully alligned head impact set up.

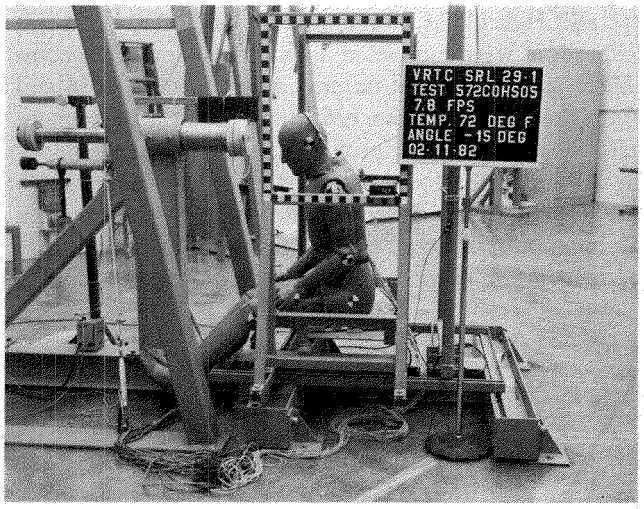


Figure 1b. Symmetry test hard impact set up.

ples placed in the dummy head and thorax for the temperature sensitivity tests to ensure stabilization at the test temperature. Except as noted below, all data were analog filtered at SAE J211 Class 1000 and digitized at 8000 Hz. The data were then digitally filtered to the appropriate SAE channel class. Specific details of the various test series are described below.

The head drop tests to assess the dummy head biofidelity were conducted using a Part 572 head calibration fixture. The procedure was identical to the calibration procedure except for the drop height. The 8.4 fps impacts were dropped from a height (measured between the rigid surface and the dummy forehead) of 13.15 inches. The 6.3 fps impacts were dropped from a 7.4 inch height.

A linear transfer pendulum was used to impact the dummy heads for temperature sensitivity and symmetry evaluation. The impacting velocity of the 51.5 lb ram was nominally 7.8 fps and measured by a light trap just prior to impact with the dummy. The ram impacting surface was 6 inches in diameter. The dummies were positioned such that the orientation of the head relative to the impacting surface was identical to the calibration specifications (i.e., the forehead was the impact location and the dummy nose was ½ inch posterior). The test set up is shown for a Part 572 in Figure 1a. The dummy positioning for the head symmetry tests was the same as described above, except that the seat was rotated ±15° and then translated to allow the contact point of the dummy to occur on the piston centerline (see Figure 1b).

The linear transfer pendulum was also used to conduct the thoracic impact tests. The temperature sensitivity, biofidelity (72°F temperature baseline), and symmetry tests were conducted at nominally 14 fps impact velocity. Biofidelity tests were also conducted at 20 and 22 fps impact speeds. The dummy thoraxes were positioned as specified in their respective calibration procedures. The set ups are shown in Figures 2a and b for the Part 572

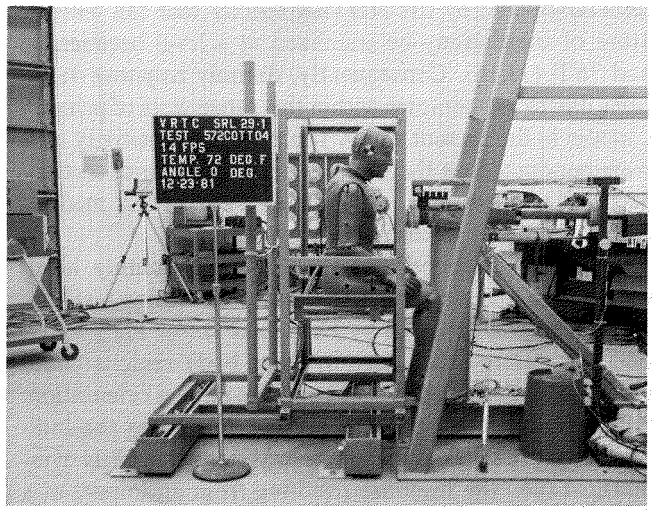


Figure 2a. Thorax temperature sensitivity and biofidelity test set up.

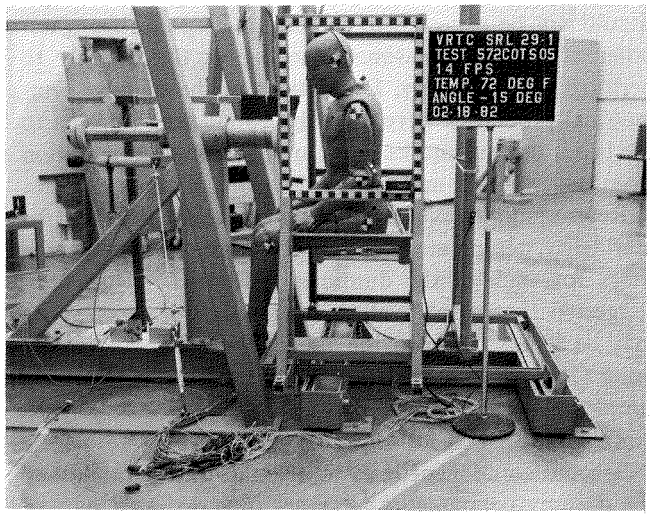


Figure 2b. Thorax symmetry test set up.

Table 3. Mini-Sled Head/Neck Deceleration Pulse Criteria.

Test Configuration	Test Velocity (fps)	Average Test Deceleration (g's)	Stopping distance (in)
Flexion	32	17	10
Extension	24	6	17

dummy. The symmetry tests were conducted using the same dummy positioning; seat rotation and translation were similar to the head symmetry procedure.

A mini-sled was used to test neck flexion and extension properties. The sled's fluid impact accelerator (16) (Figure 3) was used as a velocity generator to propel the mini-sled platform (Figure 4) along the rails until engagement with a roller tape mechanism (Figure 5). The tapes were designed to control the sled deceleration with an essentially square wave pulse as described in Table 3. The angular motion of the heads were determined through photographic film digitization.

The 11 pound knee impact tests were conducted identically to the Hybrid III knee calibration test. The knee was rigidly mounted onto the test fixture (see Figure 6) and impacted at 6.9 fps by the 11 pound pendulum supported by four wires. The pendulum impacting acceleration (and force) were filtered to SAE J211A Channel Class 600 to be consistent with the calibration procedure. It should be noted that the cadaver data (12) were filtered at Class 1000. The 52 pound knee impact tests were conducted with the linear transfer pendulum per Part 572 calibration procedures. The test set up is illustrated in Figure 7.

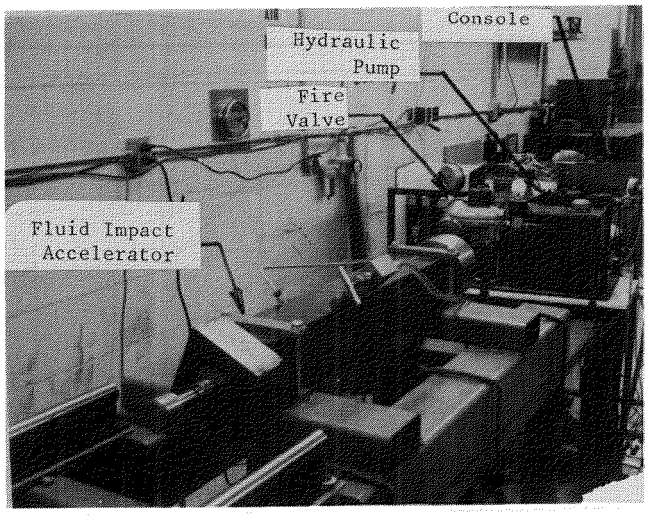


Figure 3. Mini-sled fluid impact accelerator.

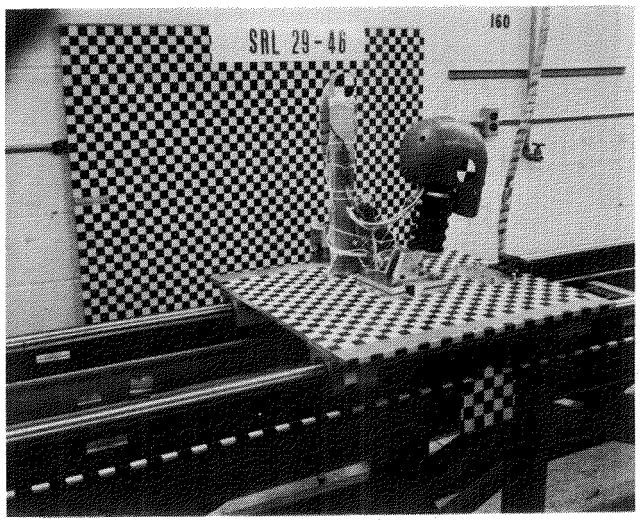


Figure 4. Mini-sled platform.

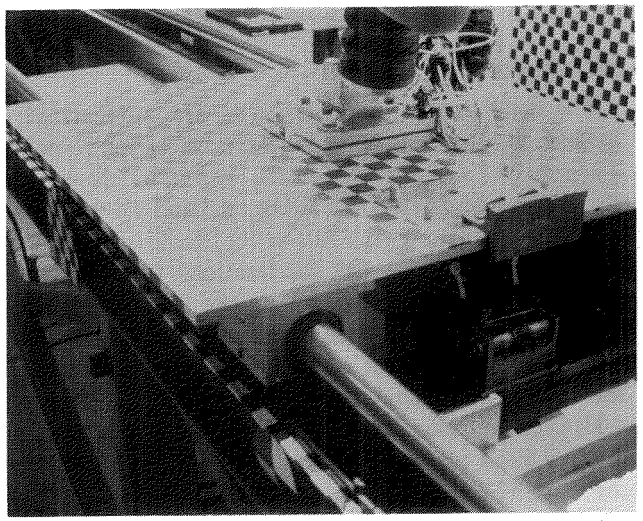


Figure 5a. Roller tape mechanism at platform engagement.

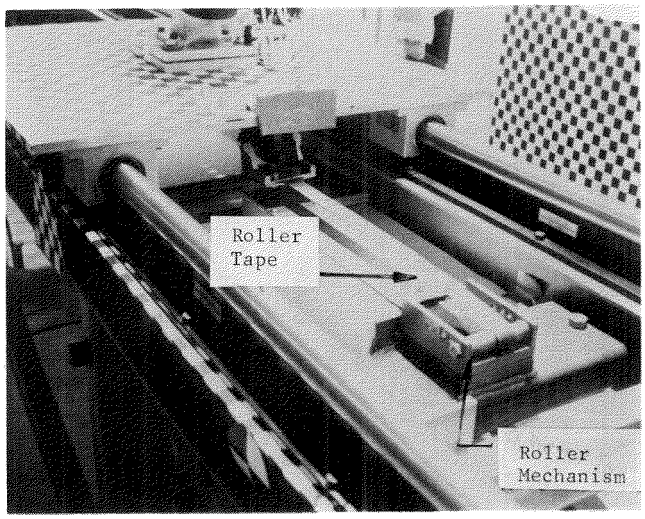


Figure 5b. Roller tape mechanism after energy absorption.

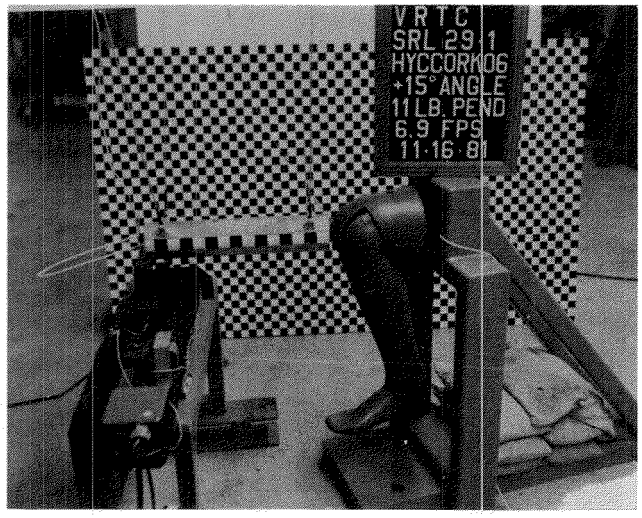


Figure 6. 11 pound knee impact test set up.

Table 4. Head drop biofidelity results.

Test Series	Test Number	Test Date	Drop Velocity (fps)	Peak Resultant Acc. (G's)	Peak Lateral Acc. (G's)	HIC	Cadaver Peak Acc. Response (G's)
Part 572 13.15 in	572COHDG1	7-14-82	8.4	302.23	1.73	1033.35	230
	572COHDG2	7-15-82	8.4	291.65	4.56	945.02	
	572COHDG3	7-19-82	8.4	291.31	2.31	945.39	
Hybrid III 13.15 in	HYCCOHDG1	7-21-82	8.4	229.15	5.47	626.43	
	HYCCOHDG2	7-21-82	8.4	246.13	5.73	694.29	
	HYCCOHDG3	7-22-82	8.4	245.41	1.69	717.45	230
Part 572 7.4 in	572COHDG4	7-19-82	6.3	182.52	0.93	357.87	115
	572COHDG5	7-19-82	6.3	184.91	1.76	365.26	
	572COHDG6	7-26-82	6.3	179.96	0.77	348.71	
Hybrid III 7.4 in	HYCCOHDG4	7-22-82	6.3	144.81	3.49	251.44	
	HYCCOHDG5	7-22-82	6.3	146.29	3.51	260.79	
	HYCCOHDG6	7-22-82	6.3	139.83	3.59	236.54	115

RESULTS AND DISCUSSION

Biofidelity

The head impact biofidelity data are summarized in Table 4. On the basis of peak head acceleration response, it is apparent that the Hybrid III head more closely simulates the cadaver response at both 6.3 and 8.4 fps impact velocities than the Part 572 (APR) headform. As might be expected from the peak accelerations, the HIC values for the Hybrid III are lower than the Part 572. While a HIC value of approximately 1000 is obtained for the Part 572 dummy under test conditions simulating cadaveric skull fracture threshold levels, the Hybrid III produces a HIC of approximately 700. Although the Hybrid III dummy head produces a more cadaveric response than the Part 572, a performance criterion of HIC equal to 1000 does not appear appropriate for the Hybrid III if skull fractures are to be limited.

The Hybrid III is the only dummy which currently has neck instrumentation capable of measuring performance according to the criteria established by Mertz. (Although a neck transducer has been manufactured for a Part 572 dummy, the necessary modifications to the neck molding have not yet been proven adequate in NHTSA tests.) The Hybrid III flexion and extension performance is shown, respectively, in Figures 8 and 9, and show generally good agreement with the results published by Foster et al. (1). The flexion loading corridor includes the effects of chin contact to the torso. The tests on the mini-sled did not have chin contact, explaining the lack of neck torque above 60 ft lb. The comparison of the Part 572 and Hybrid III head rotation in Figures 10 and 11 indicates good agreement in flexion, but the Part 572 neck is considerably stiffer than the Hybrid III in extension.

The response of the three dummies to thoracic impact at 14 fps are demonstrated in Figures 12-14. The APR and Hybrid III dummies have the greatest amount of

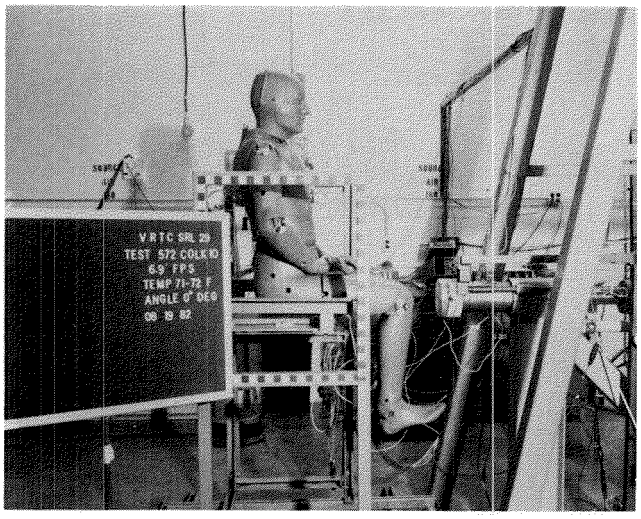


Figure 7. 52 pound knee impact test set up.

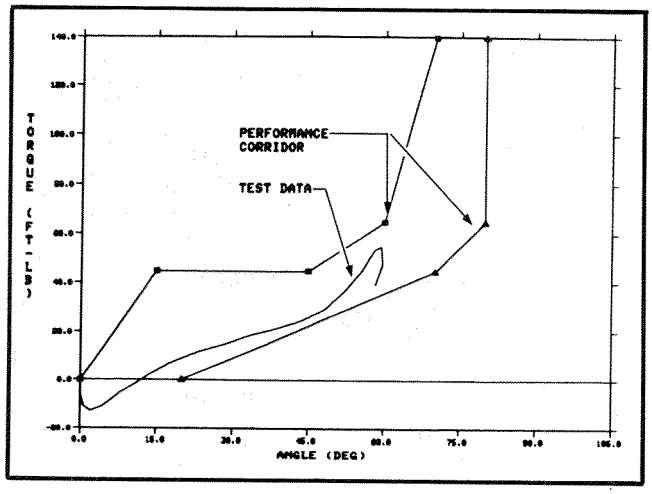


Figure 8. Hybrid III neck flexion response.

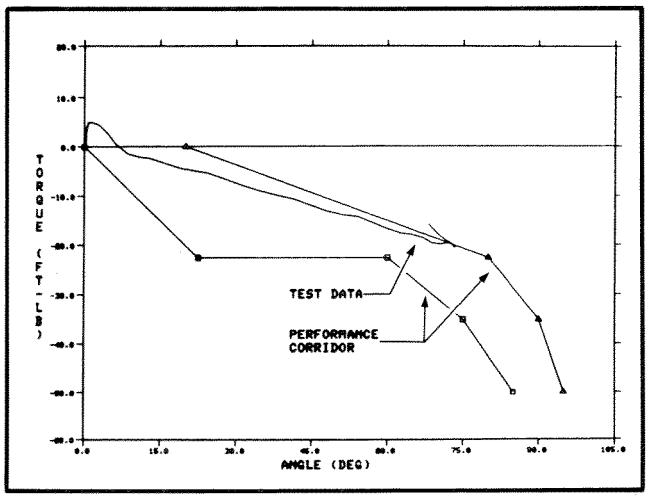


Figure 9. Hybrid III neck extension response.

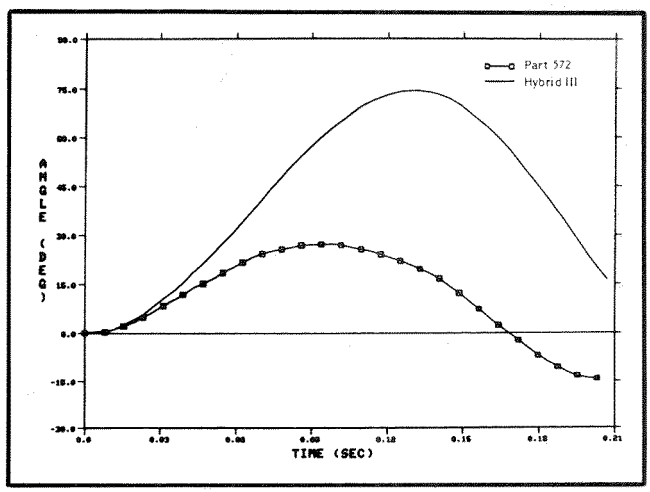


Figure 11. Part 572 versus Hybrid III extenison response.

deflection (approximately 1.25 inches), but require approximately an additional 0.6 inch deflection to meet the minimum deflection criterion specified by the corridor. The Hybrid III peak force level, however, is in better agreement with the corridor. The Hybrid III response under 22 fps thoracic impacts is almost entirely within the corridor, whereas the Part 572 and APR both have force levels considerably higher and sternal deflections lower than the performance corridor (Figures 15-17). From Figures 12-17, it is apparent that the Hybrid III dummy most closely simulates the response corridor derived from the cadaver data.

The 11 lb fully aligned knee impact biofidelity test results are summarized in Table 5. Since the Hybrid III knee calibrations are based on these cadaver data, it is not surprising that the Hybrid III agreement with the cadaver data is better than the Part 572 knee impact results. The lower Hybrid III peak pendulum impact forces are also observed for the 52 lb impacts (Table 6) with data filtered at 1000 Hz cutoff frequency. When

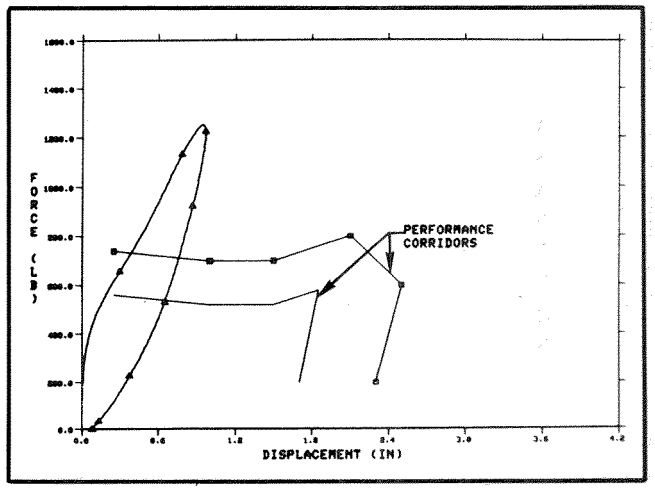


Figure 12. Part 572 thorax biofidelity, 14 FPS.

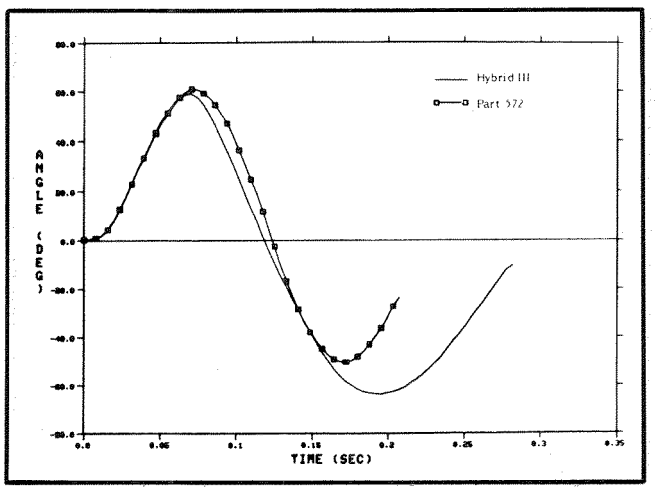


Figure 10. Part 572 versus Hybrid III flexion response.

Table 5. Aligned 11 lb. knee impact test results.

Test Series	Test Number	Test Series Peak Pendulum Force (lbs.)	Mean Peak Pendulum Force Mean (lbs.)	Cadaver Response (lbs.)
Hybrid III	HYCCALK08	1331.5		
Left Knee	HYCCALK09	1359.9	1356.2	1282.
0° Impact	HYCCALK10	1377.3		
Hybrid III	HYCCARK07	1327.6		
Right Knee	HYCCARK08	1358.4	1353.7	1282.
0° Impact	HYCCARK09	1375.2		
Part 572	572COLK07	2516.9		
Left Knee	572COLK08	2475.9	2465.20	1282.
o° Impact	572COLK09	2402.8		
Part 572	572CORK07	2217.7		
Right Knee	572CORK08	2151.4	2180.60	1282.
o° Impact	572CORK09	2172.7		

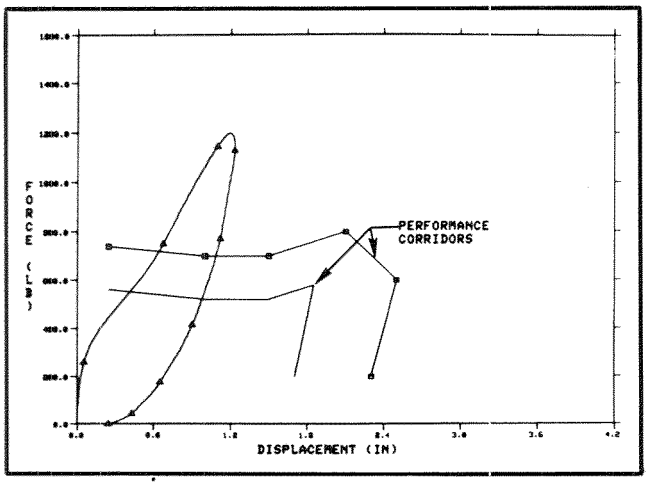


Figure 13. APR thorax biofidelity, 14 FPS.

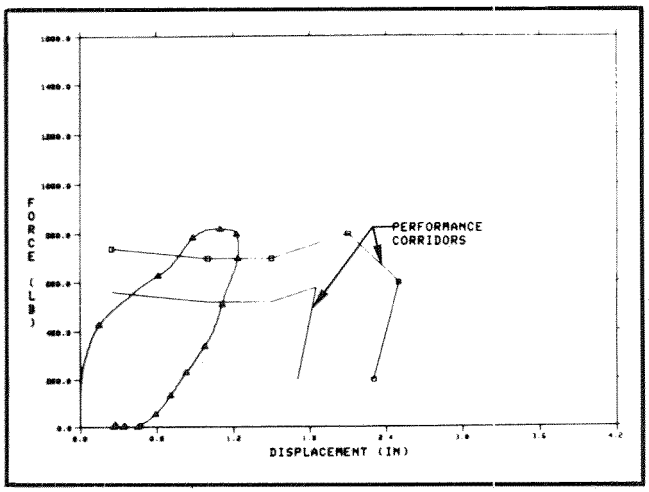


Figure 14. Hybrid III thorax biofiedlity, 14 FPS.

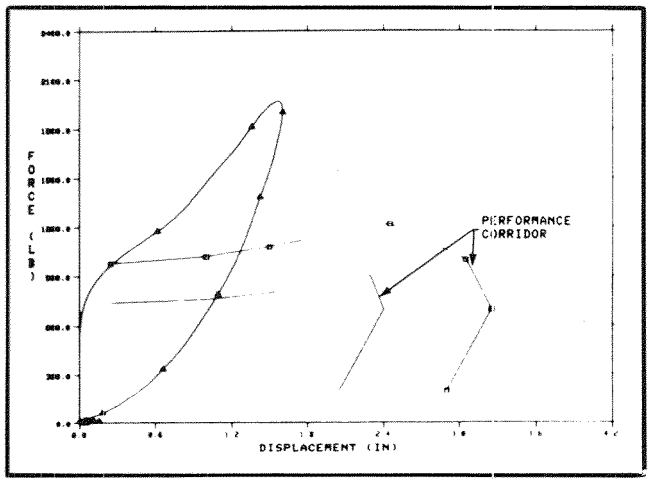


Figure 15. Part 572 thorax biofidelity, 22 FPS.

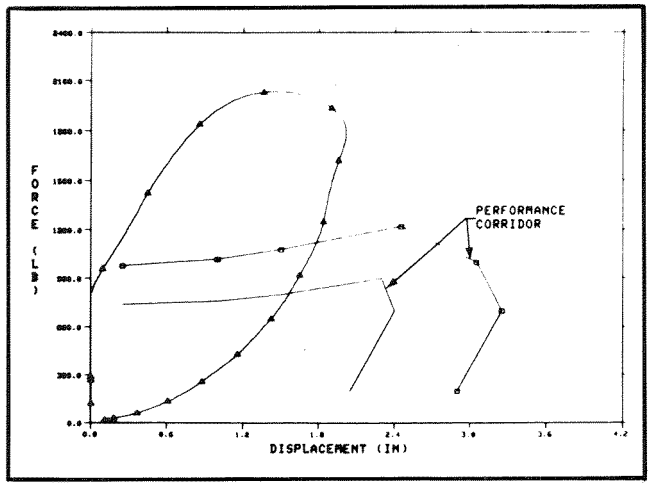


Figure 16. APR thorax biofidelity, 22 FPS.

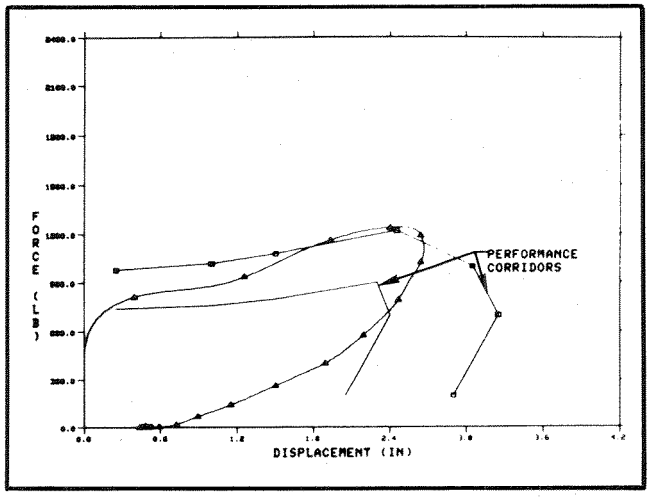


Figure 17. Hybrid III thorax biofidelity, 22 FPS.

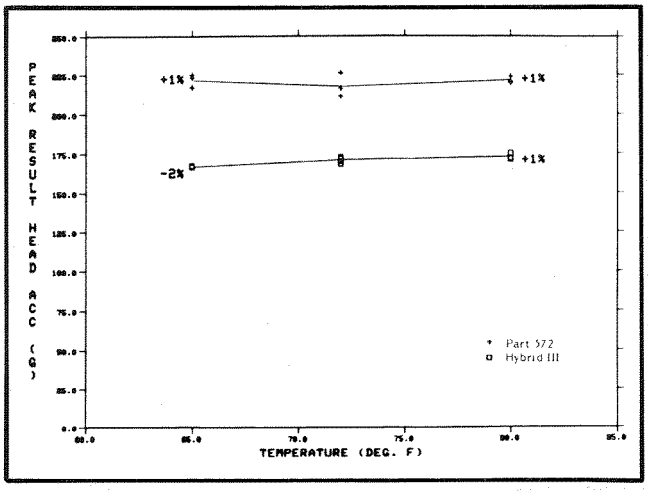


Figure 18. Head impact temperature sensitivity.

Table 6. Transfer pendulum knee impact results.

Test Series	Test Number	Test Date	Velocity (fps)	Peak Femur Load (lbs) (1000 Hz filtered)	Peak Femur Load (lbs) (100 Hz filtered)	Peak Pendulum Force (lbs) (100 Hz filtered)
Part	572COLK10	8-19-82	6.86	2457	788	965
572	572COLK11	8-19-82	6.90	2865	846	1051
Left Knee	572COLK12	8-19-82	6.90	2876	846	1055
Part	572CORK10	8-20-82	6.89	2149	805	962
572	572CORK11	8-20-82	6.92	2571	851	1025
Right Knee	572CORK11	8-20-82	6.89	2539	850	1038
Hybrid	HYCCOLK07	8-19-82	6.89	1523	863	1022
III	HYCCOLK08	8-19-82	6.93	1651	868	1046
Left Knee	HYCCOLK09	8-19-82	6.92	1649	868	1015
Hybrid	HYCCORK07	8-18-82	6.88	1503	866	983
III	HYCCORK08	8-18-82	6.89	1461	865	1012
Right Knee	HYCCORK09	8-18-82	6.88	1464	848	1009

filtered at 100 Hz, the peak pendulum force is nearly identical for the two dummies indicating that the lower responses for the Hybrid III are due to knee padding rather than structural differences.

Temperature Sensitivity

Results of the head impact temperature sensitivity tests are shown in Figure 18. The test data indicate that neither the Part 572 nor Hybrid III headforms have responses which are sensitive to temperature variations over the standard range of testing. The Part 572 peak resultant head acceleration response at 80°F and 65°F was 1% higher than at 72°F, and the Hybrid III head acceleration response ranged only from 2% lower at 65°F to 1% higher at 80°F. These percentage deviations from the 72°F response are also shown on Figure 18.

The thorax response variations due to temperature changes were much more significant (Figures 19 and 20). The chest acceleration response for all three dummies was consistent in a trend of reduced peak acceleration at 80°F, and increased acceleration at 65°F. The total acceleration response variation range for the Part 572 was 14% compared to 24% and 35% for the APR and Hybrid III, respectively. Somewhat more pronounced response variation occurred for the three dummies for sternal deflection. Consistent with the acceleration response, the trend for all three dummies was one of increased deflection for increasing temperature. The total sternal deflection response variation range for the Part 572 was only 9%; while the APR range was 19%, and the Hybrid III ex-

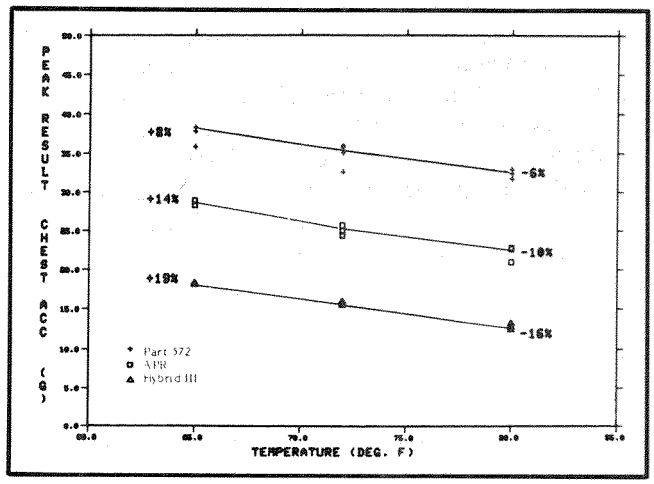


Figure 19. Thorax impact chest acceleration temperature sensiitivity.

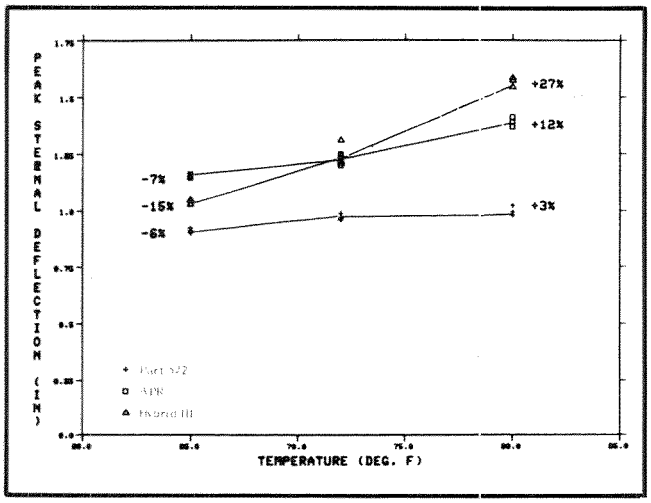


Figure 20. Thorax impact sternal deflection temperature sensitivity.

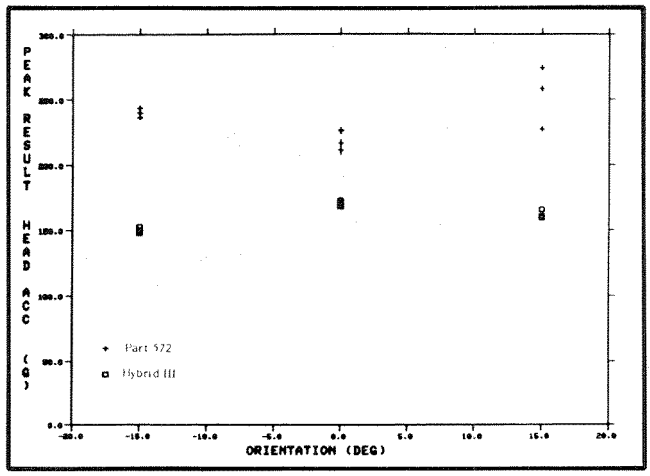


Figure 21. Head symmetry—acceleration response.

perienced a 42% change in sternal deflection between 65 and 80°F. The acceleration and sternal deflection variations from 72°F are shown in Figures 19 and 20.

The sensitivity of the dummy thorax deflection to temperature appears to be related to the damping material/steel thickness ratio of the rib designs. The steel thickness for the Part 572 dummy is 0.125 inch compared to 0.058 and 0.078 inch thicknesses for the APR and Hybrid III, respectively. The damping material thickness ranges from 1/4 inch for the Part 572 to approximately 0.4 inch for the Hybrid III. The damping material/steel thickness ratio is nearly two and one-half times greater than the Part 572 for the Hybrid III. The ratio for the APR dummy is comparable to the Hybrid III; but is not as sensitive to temperature, possibly due to a different rib attachment design.

These response variations for both the APR and the Hybrid III dummies over this temperature range are clearly unacceptable for normal engineering practice. To be useful as automotive test devices, both the APR and Hybrid III require either design changes to the thorax to reduce the temperature sensitivity, or temperature conditions controlled to a range of approximately 5°F (reducing variability to 15% or less). A third alternative would be to monitor the dummy thoracic temperature and make adjustments to the response accordingly. However, the assumption for this alternative is that each batch of rib damping material has the same sensitivity to temperature.

Symmetry

The symmetry features of the three dummies did not prove to be significantly different for impacts at ± 15° from fully aligned. The head symmetry tests (Figure 21) resulted in approximately a 5% difference between the + 15° and − 15° acceleration response on the Part 572 compared to a 7% difference on the Hybrid III. It was also noted that the Part 572 aligned impact response was slightly lower than the off-center response, whereas the Hybrid III aligned response was slightly higher.

The thorax symmetry test results are presented in Figures 22 and 23. The Part 572 chest acceleration had the greatest amount of difference between the + 15° and − 15° impacts. It had an 11% difference compared to less than 2% for the APR and Hybrid III dummies. Sternal deflection was not measured in either the APR or Part 572 dummy symmetry tests since their measurement devices were not designed for such impact configurations. The Hybrid III sternal deflection was measured, but exhibited only a 3% response difference from a +15° and − 15° impact location. As was the case for the head symmetry tests, the aligned thorax responses were only slightly different from the off-centered impacts. The impact responses for both the Part 572 and the Hybrid III dummies was slightly higher for the aligned impacts, and the APR was slightly lower.

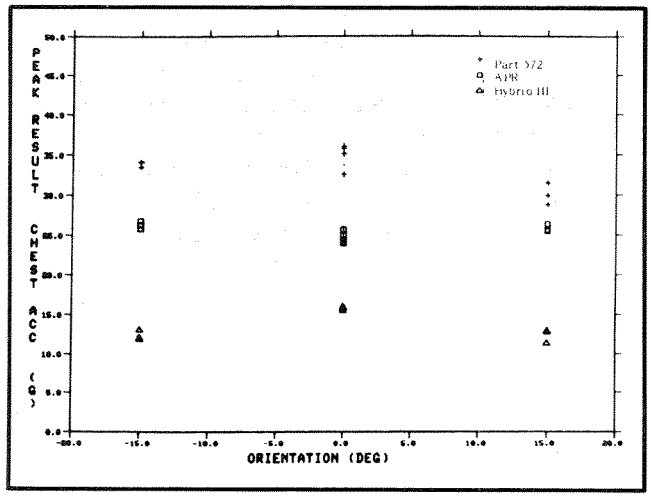


Figure 22. Thorax symmetry—chest acceleration response.

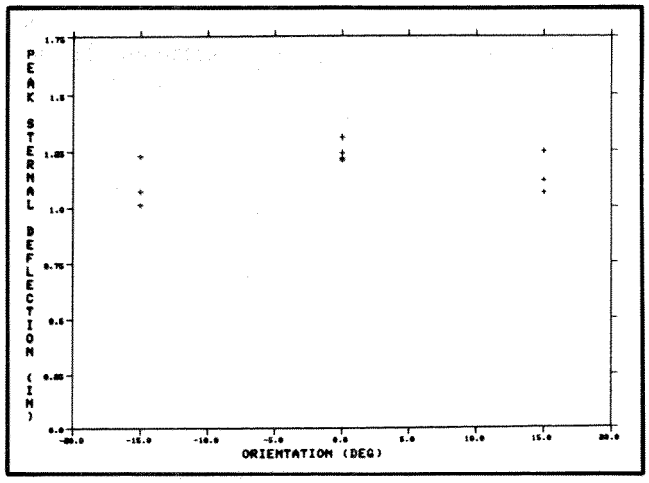


Figure 23. Thorax symmeltry—Hybrid III chesst deflection.

The knee symmetry test results are shown in Figure 24. The Hybrid III had smaller differences in the + 15° and − 15° femur load responses than did the Part 572.

REPEATABILITY AND DURABILITY

Each character on Figures 18-24 represents a particular test, and the scatter is an indication of the dummy repeatability under the various test conditions. Review of these figures indicates that the repeatability of all three dummies is good, and not a major concern in the overall evaluation.

Durability of the Part 572 dummy is superior to the Hybrid III and APR dummies based on a comparison of the pre- and post-test dummy calibrations. The Part 572 dummy maintained its calibration throughout the component testing; whereas the APR dummy changed by approximately 15%, and the Hybrid III dummy thorax displacement increased by 30% (at 14 fps pendulum impact velocity). The increased Hybrid III thorax displacement was most likely caused by cracks which had begun to form in the rib damping material during the component tests.

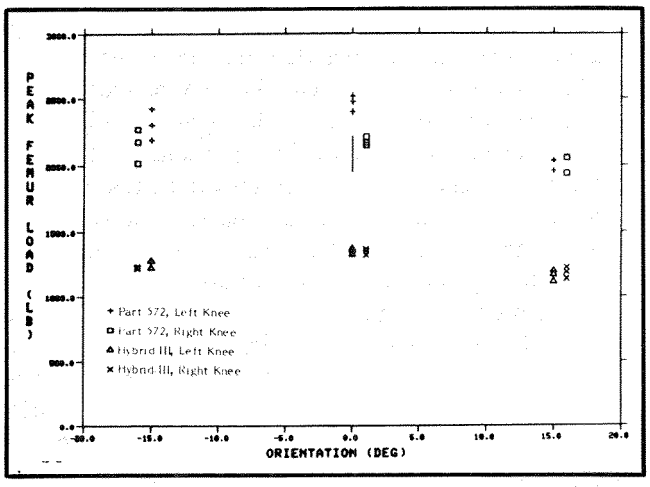


Figure 24. 11 pound knee symmetry test results.

CONCLUSIONS

Based on the component tests which were conducted on the Part 572, APR '81, and Hybrid III dummies, the following conclusions are made:

—The Hybrid III dummy exhibits the best fidelity to cadaver based data. It is noted, however, that the similitude of cadaver based data to living humans remains to be established.

—The APR dummy thorax experiences deflections which are more cadaver-like than the Part 572, but the peak force levels are much higher than cadaver data.

—The Hybrid III and APR dummy thorax responses have greater sensitivity to temperature than the Part 572, and either design modification or a tightly controlled temperature environment is necessary to make them suitable as automotive test devices.

ACKNOWLEDGEMENTS

The discussion and conclusions in the paper represent the opinions of the author and not necessarily those of the NHTSA. Many people have made significant contributions to the project including Tom MacLaughlin, Rolf Eppinger, and Mark Haffner. The author would also like to acknowledge Ed McGhee, Gerda England, and Susan Weiser for their efforts in the project and manuscript preparation.

REFERENCES

1. Foster, J. K., Kortge, J. O., Wolanin, M. J., "Hybrid III—A Biomechanically-Based Crash Test Dummy," Twenty-First Stapp Car Crash Conference, SAE Paper No. 770938, 1977.
2. Fayon, A., Leung, Y. C., Stalnaker, R. L., Walfisch, G., Balthazard, M., Tarrière, C., "Presentation of a Frontal Impact and Side Impact Dummy, Defined From Human Data and Realized From a "Part 572" Basis," Seventh ESV Conference, June 5-8, 1979.
3. Seiffert, U. W. and Leyer, H. E., "Dynamic Dummy Behavior Under Different Temperature Influence," Twentieth Stapp Car Crash Conference, SAE Paper No. 760804, 1976.
4. Daniel, R. P., Trosien, K. R., Young, B. O.,"The Impact Behavior of the Hybrid II Dummy," Nineteenth Stapp Car Crash Conference, SAE Paper No. 751145, 1975.

5. Patrick, L. M., "Impact Force Deflection of the Human Thorax," Twenty-Fifth Stapp Car Crash Conference, SAE Paper No. 811014, 1981.
6. Hodgson, V. R. and Thomas, L. M., "Breaking Strength of the Human Skull versus Impact Surface Curvature," Report No. HS-801-002, Final Report, November 1973.
7. Hodgson, V. R. and Thomas, L. M., "Comparison of Head Acceleration Injury Indices in Cadaver Skull Fracture," Fifteenth Stapp Car Crash Conference, 1971, SAE Paper No. 710854.
8. Hodgson, V. R. and Thomas, L. M., "Head Impact Response," SAE Vehicle Research Institute Report, VRI 7.2, 1975.
9. Mertz, H. J. and Patrick, L. M., "Strength and Response of the Human Neck," Fifteenth Stapp Car Crash Conference, SAE Paper No. 710855, 1971.
10. Mertz, H. J., Neathery, R. F., and Culver, C. C., "Performance Requirements and Characteristics of Mechanical Necks," Human Impact Response, October 2-3, 1977, Plenum Press.
11. Neathery, R. F., "Analysis of Chest Impact Response Data and Scaled Performance Recommendations," Eighteenth Stapp Car Crash Conference, SAE Paper No. 741188, 1974.
12. Horsch, J. D. and Patrick, L. M., "Cadaver and Dummy Knee Impact Response," Automobile Engineering Meeting, SAE Paper No. 760799, October 18-22, 1976.
13. Laboratory Procedure for FMVSS 208, "Occupant Crash Protection" TP-208-05, July 10, 1981.
14. Laboratory Procedure for Vehicle Assessment, FMVSS 212, 219, and 301-75, IP-212-02, April 29, 1980.
15. McAdams, H. T., "The Repeatability of Dummy Performance," Human Impact Response, October 2-3, 1972, Plenum Press.
16. Monk, M. W. and Sullivan, L. K., "Side Impact Sled and Padding Development," Report No. DOT-HS-805-889, Appendix I, February 1981.

Responses of Animals Exposed to Deployment of Various Passenger Inflatable Restraint System Concepts for a Variety of Collision Severities and Animal Positions

H.J. MERTZ
General Motors Corporation

G. D. DRISCOLL and J. B. LENOX
Southwest Research Institute

G. W. NYQUIST and D. A. WEBER
General Motors Corporation

ABSTRACT

This paper summarizes the results of tests conducted with anesthetized animals that were exposed to a wide range of passenger inflatable restraint cushion forces for a variety of impact sled—simulated accident conditions. The test configurations and inflatable restraint system concepts were selected to produce a broad spectrum of injury types and severities to the major organs of the head, neck and torso of the animals. These data were needed to interpret the significance of the responses of an instrumented child dummy that was being used to evaluate child injury potential of the passenger inflatable restraint system being developed by General Motors Corporation. Injuries ranging from no injury to fatal were observed for the head, neck and abdomen regions. Thoracic injuries ranged from no injury to critical, survival uncertain. Graphs are presented that show associations between the severity of the animal injuries by body region and selected measured animal responses and restraint system-accident characteristics. Caution must be used in interpreting the significance of these injuries relative to the expected performance of passenger inflatable restraint systems since aggressive restraint system concepts and accident conditions were selected for some tests in order to produce severe injuries.

INTRODUCTION

An important consideration in the development of a passenger inflatable restraint system is to assess the significance of the interactions that may occur between deploying cushions and children who may be close to the instrument panel at the time of deployment (1-8). Analyses by Takeda and Kobayashi (8), Stalnaker et al. (9) and Montalvo et al. (10) have demonstrated that children may be close to the instrument panel in a variety of positions and postures at the instant of a collision either due to their precrash "seated" position or due to the effects of preimpact braking. Tests sponsored by General Motors at Wayne State University (1) and by Volvo at Chalmers University (7) have shown that it is possible to produce significant brain, heart, liver and spleen injuries in anesthetized animals exposed to the impacts of deploying cushions of several concepts of passenger inflatable restraint systems. In the GM program, anesthetized

baboons and chimpanzees were used as child surrogates. The Volvo program used anesthetized pigs. Unfortunately, no attempt was made in either program to develop a test device (instrumented child dummy) to aid in understanding the relationships between the observed animal injuries and the cushion-collision interaction forces. However, these programs did demonstrate the need to consider such interactions in the development of passenger inflatable restraint systems (2,3).

When General Motors started its development of a second-generation passenger inflatable restraint system, the interaction between the deploying cushion and the "out-of-position" child was again identified as a topic requiring further study. Concurrent with their inflatable restraint development program, GM initiated a program to develop a test device (an instrumented, 3-year-old child dummy) that could provide measures of the various cushion interaction forces thought to be associated with the type of injuries observed in the previous animal test programs. Such an instrumented child dummy was developed by GM (11) and was used extensively in their second-generation, passenger inflatable restraint development program. While the child dummy provided measurements to make relative comparisons between different passenger inflatable restraint concepts, no biomechanical data existed that would allow intepretations of the dummy responses relative to the severities of injuries that a child might experience in similar exposure environments. An animal test program was needed to provide such a basis. This paper presents the results of the test program that was conducted to obtain the animal injury data. Correlations between the observed animal injuries and corresponding child dummy response measurements are not discussed in this paper. That analysis is the subject of a separate paper by Mertz and Weber (12).

PROGRAM SCOPE

The program conceived was to subject anesthetized animals to a broad range of passenger cushion deployment-simulated collision exposure environments. The specific animal exposure environments were to be selected from child dummy tests that produced a wide range of dummy responses. It was anticipated that test conditions selected by this process would produce a wide range of animal injury types and severities that could be associated with the measured dummy responses.

Southwest Research Institute (SwRI) was contracted by GM to carry out the animal testing portion of the animal injury-child dummy response correlation study. The specific test conditions, test hardware, and animal positions were prescribed by GM based on their child dummy test results. SwRI was responsible for conducting the animal tests and documenting the types and severities of the injuries experienced by the animals.

Physiological measurements such as electrocardiogram (ECG), aortic blood pressure, evoked response, pinch withdrawal and palpebral reflex were made. Blood samples were drawn for gas analysis to aid in assessing the significance of pulmonary injuries. Since past experience had shown that serious internal organ trauma in animals may not be clinically diagnosed (1), all surviving animals were sacrificed usually 24 hours posttest, and gross necropsies were performed. Histopathology was done on the brain, spinal cord, heart and lungs.

A team of medical specialists was formed by SwRI to assess the significance of the observed animal injuries. The team consisted of a neurophysiologist, a neuropathologist, a cardiac pathologist, a cardiologist, a pulmonary specialist and a SwRI Senior Research Physician who served as the medical team leader. The medical specialists were directed to assess the severity of the animal injuries as if the injuries had occurred to a three-year-old child. In addition, each specialist was asked to develop a "dictionary" for his specialty that would describe the types of lesions observed and the injury severity ratings ascribed to the injuries. These dictionaries were to be "living" documents; that is, the specialists were encouraged to revise them based on the results of control tests that were conducted during the program. The medical team leader was responsible for the final injury severity ratings assigned to each test animal.

Each animal injury was assigned two injury severity values. One described the short-term consequences of the injury in terms of threat-to-life (TL value) and the other described the long-term consequences in terms of the potential for permanent impairment (PI value). General descriptions of the TL and PI severity classifications are given in Table 1. The TL descriptors were taken from "The Abbreviated Injury Scale—1980 Revision" (13). However, the injury descriptions contained in the dictionaries developed by the medical specialists are more detailed than those given by The Abbreviated Injury Scale, since each animal was necropsied and much more detailed injury information was available than would be available for a similar human injury. On the other hand, very little data were available on the long-term consequences of the animal injuries, since the animals were usually sacrificed 24 hours postimpact. For the most part, the PI ratings were based on the medical specialist's judgment of the most probable long-term consequences of the various injuries. While the PI ratings are quite subjective, they do serve an important need to rank the severities of brain, cervical spine and heart injuries relative to the potential for permanent impairment of major body functions.

To provide mechanical indicators of the severity of the various exposure environments, accelerometers were attached to the heads and torsos of the animals. The placement and procedure used to mount the accelerometers were chosen so as to not induce injury during the impact

Table 1. General descriptions of threat-to-life (TL) and permanent impairment (PI) injury severity classifications.

TL VALUE	DESCRIPTION OF THREAT-TO-LIFE CATEGORIES
0	NO INJURY
1	MINOR (NOT LIFE-THREATENING)
2	MODERATE (NOT LIFE-THREATENING)
3	SERIOUS (NOT LIFE-THREATENING)
4	SEVERE (LIFE-THREATENING, SURVIVAL PROBABLE)
5	CRITICAL (LIFE-THREATENING, SURVIVAL UNCERTAIN)
6	MAXIMUM (NOT SURVIVABLE)

PI VALUE	DESCRIPTION OF PERMANENT IMPAIRMENT CATEGORIES
0	NO INJURY
1	MINOR (POTENTIAL FOR SOME IMPAIRMENT OF MINOR BODY FUNCTION)
2	MODERATE (SOME IMPAIRMENT OF MINOR BODY FUNCTION)
3	MAJOR (POTENTIAL FOR IMPAIRMENT OF MAJOR BODY FUNCTION, IF UNTREATED)
4	SUBSTANTIAL (PARAPLEGIA)
5	EXTENSIVE (QUADRIPLEGIA)
6	TOTAL (IRREVERSIBLE COMA/DEATH)

or compromise the animal's ability to withstand the impact.

CARE AND USE OF ANIMALS

Southwest Research Institute (SwRI) Animal Medicine Program and Facilities are approved by the American Association for Accreditation of Laboratory Animal Care and the United States Department of Agriculture. Approval by these organizations is based on guidelines of the Animal Welfare Act of 1970 and the Guide for Care and Use of Laboratory Animals. In addition, all protocols involving animal care and testing are subjected to a review by the SwRI Animal Care Committee. This program was reviewed and approved by the SwRI committee as well as the General Motors Corporation Animal Use Committee.

TEST PROTOCOL

Preimpact

Two to three days prior to a test, two pigs whose weights were within the desired range of 15 ± 1 kg were selected as test candidates from the pig herd maintained at SwRI for the test program. These animals were sedated, weighed, depilated and given a physical examination by the veterinarian. Radiographs were taken of each animal and were examined for possible skeletal fractures and abnormal bone growth. On the day of the test, one of the pigs was selected as the test pig, the other serving as the backup. The test pig was sedated and an extensive set of anthropometric measurements was made. Then the animal was anesthetized and incisions were made to expose both femoral arteries. A blood pressure catheter was inserted into one femoral artery and was advanced towards the heart to the level of the xiphoid process. A 16-gauge catheter was placed in the other femoral artery for the purpose of drawing blood samples for gas analyses.

Just prior to transporting the animal to the sled facility, an accelerometer mounting bracket was applied to the animal's nose using two screws located in the midsagittal plane and a wire wrapped around the plate through the animal's mouth. A polyurethane foam solution was injected between the plate and the snout, and when cured, provided a stable accelerometer mounting bracket.

At the test facility the animal was connected to the physiological monitoring equipment and monitored at 15-minute intervals for one hour prior to the placement of the animal on the impact sled. At each interval the following parameters were recorded: blood pressure, 6-lead ECG, heart rate, respiration, rectal temperature, reflex responses to toe and ear pinch, palpebral reflex, pupil size and reactivity to light, and muscle tonus. Drugs were administered in sufficient dosages to produce an animal that was immobile and had adequate pain suppression while retaining good neurological response levels for the physiological testing.

During this hour monitoring period, the accelerometers and the tethering harness were attached to the animal. Four uniaxial accelerometers were mounted to the nose bracket. Three of these accelerometers were positioned with their sensitive axes orthogonal with two of the axes lying in the midsagittal plane of the animal's head. The fourth accelerometer was mounted with its sensitive axis lying in the midsagittal plane, oriented parallel to the sensitive axis of the ventro-dorsal accelerometer and positioned 38 mm closer to the tip of the animal's snout. Two configurations of accelerometers were used for the torso. For the first configuration, a triaxial accelerometer package was attached to the animal's spine at the level of the sixth thoracic spinous process using a nylon strap that encircled the animal's chest. After several tests, it became apparent that this configuration had the potential to injure the thoracic spinous process during rebound into the seat for some of the animal positions. To alleviate this condition, a second configuration consisting of four uniaxial accelerometers was developed. Three of the accelerometers were mounted to the sternum, one each at the presternal protuberance, mid sternum, and xiphoid process. Their sensitive axes were oriented ventral-dorsally, normal to the sternum. The fourth accelerometer was mounted to the thoracic spine at the level of the sixth spinous process. Its axis was oriented ventral-dorsally, normal to the spine. All four accelerometers were encased in individual, thin rubber disks that were held in place

by tape that encircled the animal's thorax. This configuration produced no indications of inducing any injury to the animal.

After the one-hour monitoring period was completed, blood was drawn for gas analysis and a complete set of visual and somatosensory evoked responses were taken. The animal was then taken to the sled and placed in the desired position. The animal was held vertically by a tether that was released just prior to cushion deployment. Its buttocks were supported by the seat, floor or foam blocks depending on the choice of animal position. Longitudinal and lateral position of the animal was maintained by paper tape that prevented the animal from translating rearward during the time the sled was being accelerated to the desired velocity, yet let the animal translate forward freely during the collision simulation. The tape was easily torn by the deploying cushion or by the rebound of the animal and had no effect on the animal's kinematics in response to the deploying cushion.

Once the animal was positioned it usually took ten minutes to balance and calibrate the instrumentation and go through the sled firing procedure. During this time the animal's position and physiological responses were continually monitored. Drugs were administered as required to assure a motionless animal with acceptable physiological response levels.

Postimpact

After the impact, the sled was moved under an exhaust fan to change and filter the interior air of the body buck, a safety procedure used when a number of tests are contemplated using sodium azide inflators. When visible emissions had abated, the body buck was opened and a preliminary examination of the animal was done by the attending medical doctor or veterinarian, who wore a respirator. Photographs were taken of the animal's position. The animal was then removed from the buck, sponged off and carried to the medical observation table where the physiological monitoring equipment was reconnected. The one-hour monitoring procedure described under preimpact was repeated. Two full sets of evoked responses were obtained during this period for comparison with the pretest data.

At the end of the one-hour postimpact monitoring period, blood was drawn for gas analysis. The blood pressure catheter was removed and the incision closed. The animal was transported to the SwRI X-ray facility where a full set of postimpact radiographs were taken. From the X-ray facility, the animal was returned to its holding cage for observation. At the end of the observation period (usually 24 hours), the animal was sedated and blood was drawn for gas analysis. Then, the animal was transported to the Necropsy laboratory where it was sacrificed and the gross necropsy was performed by the veterinary pathologist.

TEST CONDITIONS

The test conditions were selected by GM based on their analysis of child dummy tests that they had conducted at GM. For each animal test conducted at SwRI, a similar child dummy test was conducted at GM. This procedure was used to allow associations to be drawn between the observed animal injuries and corresponding measured child dummy responses. A summary of the test conditions is given in Table 2.

Simulated Crash Pulses—Three different sled deceleration pulse shapes were used during the test program. The severity of these simulated collisions can be described by their mean sled decelerations and velocity changes. Two constant-deceleration pulse shapes were used. The most severe pulse had a 14.5 g deceleration level with a change in velocity of 56 km/h. The other had a constant deceleration level of 8.4 g with a velocity change of 33.6 km/h. The third pulse shape was more trapezoidal and represented a car-to-car impact of longer duration. It had a mean deceleration level of 4.3 g and a velocity change of 28.5 km/h, and this was the mildest collision pulse used. The sled pulse used for each animal test is listed in Table 2.

Animal Positions—Seven basic animal positions, each representing a possible child position (9, 10), were used in the deployment tests. Examples of each position are shown in Figures 1 through 7. Table 3 provides descriptions of each position, distances between landmarks on the animal and the interior that were used in positioning the animals, and rationales for selecting each position for testing. Figure 8 shows the locations of the animal positioning landmarks relative to car interior landmarks. Deviations from these nominal dimensions were made during the course of the program in an effort to maximize the severity of the cushion/animal interaction. The nominal position and deviation for each animal test are given in Table 2.

Positions 1, 6 and 7 were used in preliminary tests that were conducted to select the animal species to be used as the principal surrogate for the test program. In the actual test program only Positions 1-5 were used. Position 6 was not used because the preliminary tests showed that the interaction between the animal and cushion was unpredictable for this position. In one test, the cushion deployed over the top of the animal's head. In a second test of the same position, the cushion deployed under the animal's chin. Position 5 was used instead of Position 6 in the test program in order to eliminate this inconsistency of cushion-animal interaction. Position 7, a side-facing position of the animal, was not used in the test program because the preliminary tests showed that the injury types and severities for this position were comparable to those of Position 1, the front-facing equivalent of Position 7.

Inflatable Restraint Systems—A summary of the inflatable restraint system concepts used for the various

Table 2. Summary of test conditions.

ANIMAL NUMBER	SLED KINEMATICS		INFLATABLE RESTRAINT SYSTEM					ANIMAL POSITION			SEAT	
	VEL. (km/h)	ACC. (G)	INFLATOR TYPE	INFLATOR ACTUATE (ms)	CUSHION TYPE	FOLD TYPE	COVER TYPE	NOMINAL	DEVIATIONS FORE-AFT (mm)	DEVIATIONS UP-DOWN (mm)	TYPE	POSITION
PIG 8	50.8	13.2	2	22	2	3	NONE	1	0	0	MODIFIED	FORWARD
PIG 9	54.9	14.3	2	20	2	1	NONE	1	0	6U	MODIFIED	FORWARD
PIG 10	56.8	14.8	2	20	2	2	NONE	1	0	0	MODIFIED	FORWARD
PIG 12	56.5	14.8	2	20	2	3	NONE	1	0	0	MODIFIED	FORWARD
PIG 13	56.8	14.8	2	20	2	1	NONE	2	19A	13U	MODIFIED	REAR
PIG 14	57.0	14.9	2	21	2	1	NONE	2	0	0	MODIFIED	REAR
PIG 15	57.0	14.8	2	20	2	3	NONE	1	16F	25U	MODIFIED	FORWARD
PIG 16	56.6	14.7	2	21	2	3	2	3	0	0	STD.	REAR
PIG 17	55.9	14.6	2	21	2	1	2	3	0	0	STD.	REAR
PIG 18	54.5	14.0	3	20	1	1	1	2	0	0	MODIFIED	REAR
PIG 19	33.3	8.4	4	28	1	1	1	2	44F	25D	MODIFIED	REAR
PIG 21	33.6	8.5	3	28	1	1	1	3	44F	13D	STD.	REAR
PIG 22	33.8	8.5	3	28	1	1	1	2	44F	25D	MODIFIED	REAR
PIG 23	33.8	8.4	3	18	1	1	1	2	0	0	MODIFIED	REAR
PIG 24	55.7	14.2	5	20	3	3	3	1	0	0	MODIFIED	FORWARD
PIG 25	34.0	8.6	5	28	3	3	3	1	0	0	MODIFIED	FORWARD
PIG 26	33.6	8.5	5	28	3	3	3	3	13F	0	STD.	REAR
PIG 29	33.6	8.5	6	29	4	1	3	2	0	0	MODIFIED	REAR
PIG 35	34.2	8.6	5	26	4	1	3	2	0	0	MODIFIED	REAR
PIG 38	33.7	8.6	5	28	4	1	3	2	0	0	MODIFIED	REAR
PIG 41	32.9	8.3	5	36	4	1	3	2*	13A	25U	MODIFIED	FORWARD
PIG 44	33.5	8.5	5	28	4	1	3	2*	0	25U	NONE	PADDING
PIG 46	32.9	8.3	3	0	1	1	1	3	44F	13D	STD.	REAR
PIG 47	33.4	8.3	3	29	1	1	1	3	44F	13D	STD.	REAR
PIG 51	33.6	8.3	7	27	5	4	3	1	6F	0	MODIFIED	FORWARD
PIG 52	33.8	7.8	7	28	5	4	3	3	6F	0	STD.	REAR
PIG 67	34.6	8.8	9	28	5	4	3	3	3F	3U	STD.	REAR
PIG 68	32.6	8.2	8	28	6	4	3	4	0	0	STD.	MID
PIG 69	34.2	8.6	8	27	6	4	3	3	6F	0	STD.	REAR
PIG 70	33.2	8.4	9	29	5	4	3	2	6F	0	MODIFIED	REAR
PIG 72	33.4	8.5	9	28	5	4	3	2	3F	25U	MODIFIED	REAR
PIG 80	28.3	4.2	10	25	7	5	3	3	30F	0	STD.	REAR
PIG 81	28.5	4.3	10	25	7	5	3	1	51F	3U	MODIFIED	REAR
PIG 83	28.8	4.3	10	25	7	5	3	3	41F	51D	STD.	REAR
PIG 84	28.8	4.3	10	25	7	5	3	2	51F	0	MODIFIED	REAR
PIG 85	28.9	4.3	10	25	7	5	3	4	0	0	STD.	MID
PIG 87	28.4	4.2	10	25	7	5	3	3	57F	51D	STD.	REAR
PIG 88	28.6	4.4	10	25	8	5	3	3	60F	51D	STD.	MID
PIG 89	28.4	4.2	10	25	8	5	3	2	51F	0	STD.	REAR
PIG 91	28.7	4.3	10	25	8	5	3	1	32F	38U	STD.	REAR
PIG 93	28.4	4.2	10	25	8	5	3	4**	-	-	STD.	MID
PIG 94	28.1	4.3	10	25	8	5	3	4	0	0	STD.	MID
PIG 151	28.6	4.2	10	25	8	5	3	5	0	0	STD.	MID
BAB 6	55.9	14.3	2	20	2	1	2	3	13F	6U	STD.	REAR
BAB 7	28.3	4.2	10	25	8	5	3	4	0	0	STD.	MID
BAB 8	28.6	4.2	10	25	8	5	3	5	0	0	STD.	MID

NOTES: * LOWER TORSO RESTRAINED BY STRAP
** TETHER SUPPORT RELEASED PRIOR TO SLED DECELERATION. PIG NOT IN POSITION 4 AT TIME OF CUSHION DEPLOYMENT.

animal tests is given in Table 2. Ten different types of inflators were used in combinations with eight types of cushions, four types of cushion folds, and three types of covers. Inflators 1, 3 and 4 were compressed gas inflators. The other inflators used sodium azide to generate the cushion inflation gases. All ten inflators had different gas flow characteristics. Cushions 1 through 4 were "circular cylinder designs" of diferent volumes and incorporated an internal knee restraint cushion (2). Cushions 5-8 were different concepts of "L-shaped" cushions (14). Fold 1 was an "accordion" fold that was symmetrically folded on top and bottom. This fold allowed the cushion to be deployed horizontally rearward. Folds 2-5 were different versions of a "top pleated" fold. These were asymmetrically folded with the bottom most part of the cushion being the layer nearest the cushion door. This type of fold restricted the initial rearward movement of the cushion and resulted in a more upward cushion trajectory. Cover 1 was a foam-filled construction. Covers 2 and 3 were injection moldings of different lengths and cross-sectional shapes.

Front Seat Description—Production type seats were used for the tests. In some instances, the seat cushion and frame had to be modified in order to place the animal in the desired position. For these tests, the front of the seat frame was removed and the thickness of the cushion padding was adjusted to give the desired seat height. Table 2 gives a summary of the seat positions and indicates whether or not the seat was modified for the various tests conducted.

ANIMAL SPECIES SELECTION

The primary consideration for the selection of an animal species to be used as the child surrogate for the test program was that its weight and size be comparable to a 3-year-old child, since that size child dummy was being used by GM in their passenger inflatable restraint system development program (11). Three animal species, the chimpanzee, the baboon and the pig, were considered as candidates for the animal model. Based on comparable

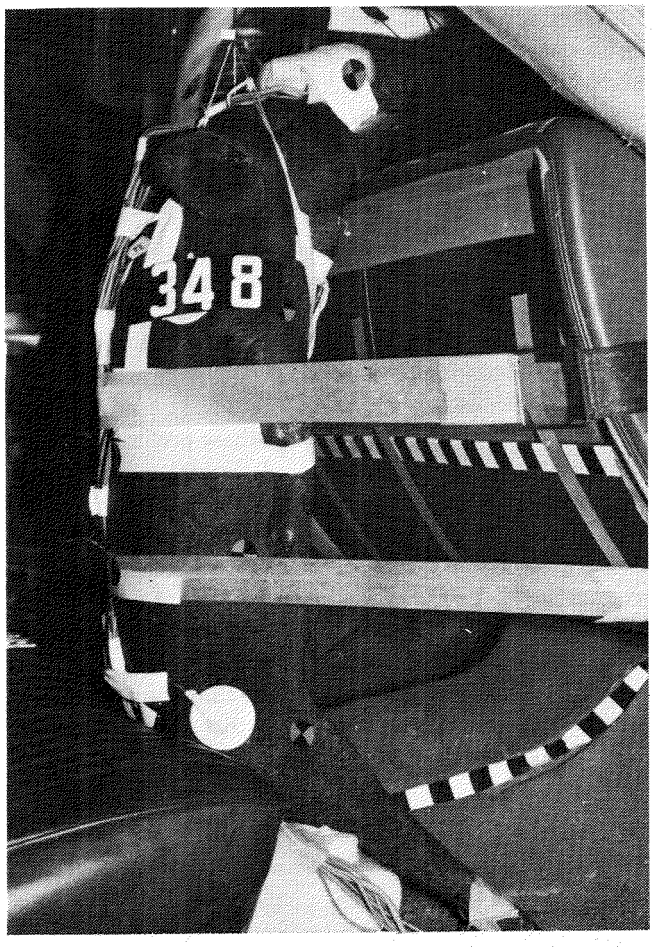


Figure 1. Animal position 1.

size and shape, the chimpanzee was the most logical choice. However, the test protocol required that each animal be impacted only once and necropsied for injury identification. This procedure required that a large quantity of animals be available for testing in order to meet the program objective of producing a broad spectrum of injury types and severities. A sufficient quantity of chimpanzees was not available to meet this program requirement. Consequently, only the baboon and pig were considered as possible animal models for this program.

The pig was selected as the animal model for the 3-year-old child for the following reasons:

i) it was available in large enough quantities to support the test program,
ii) it had more favorable anthropometric characteristics for its chest and abdomen than the baboon,
iii) its physical stage of development was similar to a 3-year-old child's, and
iv) it appeared to be more susceptible to injury than the baboon based on the results of a preliminary test program.

Limited testing was to be done with baboons for comparison purposes. The following is a detailed discussion of the reasons the pig was selected as the primary animal model for the test program.

Size and Shape Considerations—Table 4 gives typical size and shape measurements for the baboon, pig and a 3-year-old child of comparable weights. The pig was considered the preferred animal model over the baboon for investigating the potential for child thoracic and abdominal injuries since the breadths and circumferences of its chest and abdomen compare more favorably to the child's. Both the pig and the baboon have a major anthropometric deficiency as a child thoracic injury model in that their chest depth-to-width ratios are the inverse of the child's. Because of this geometric difference, both animals' fore-aft chest stiffnesses are much greater than the child's resulting in greater force levels required to produce compression type injuries to the thoracic organs.

For assessing the potential for child neck injuries, the pig has an advantage over the baboon since its head-neck length compares more favorably to the child's. However, both species have a number of major deficiencies as neck injury models. The pig has no chin protuberance for interacting with the deploying cushion since its neck attaches to the rear of its skull, resulting in its snout being somewhat aligned with its cervical spine. In contrast, the

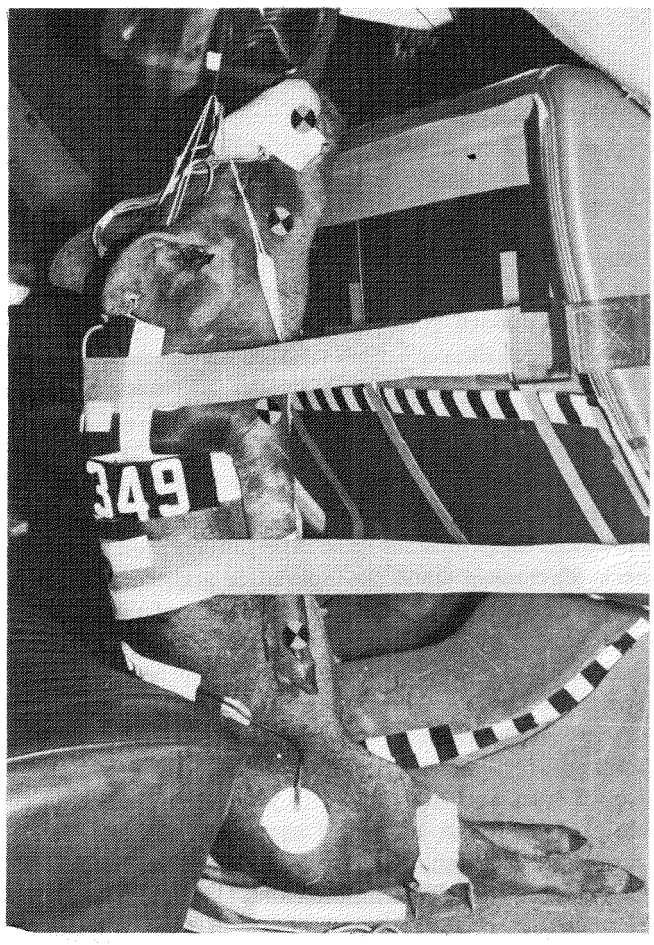


Figure 2. Animal position 2.

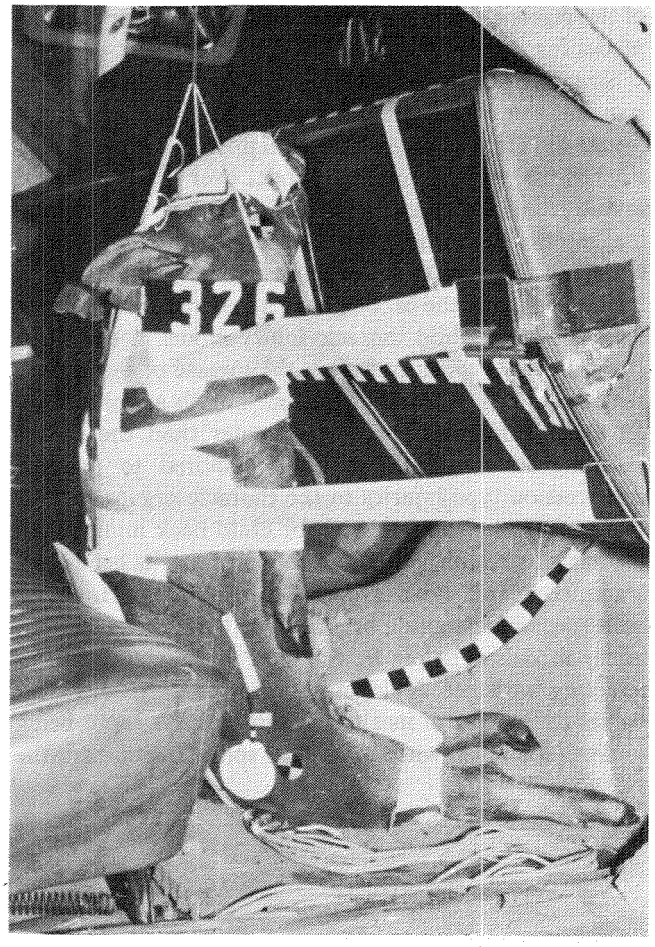


Figure 3. Animal position 3.

baboon's neck attaches to the base of the skull similar to the human. However, its long muzzle provides an accentuated, simulated chin protuberance. The fore-aft range of motion of the pig's head-neck structure is much less than the child's, resulting in a smaller degree of rearward motion required to produce a hyperextension neck injury. The baboon can undergo a greater degree of hyperextension than the child. The pig's neck circumference is twice as large as the child's due to its large dorsal neck muscles. However, these muscles have little influence on its head-neck kinematics since the animal is anesthetized. The cervical vertebrae of the pig and child are of similar size.

Neither animal species is considered a good model for assessing the potential for child brain injuries since their brains are much smaller in size than a child's.

Physical Development Consideration—The ages of a baboon and pig of comparable weight of a 3-year-old child are 4.3 years and 10 weeks (0.19 years), respectively (Table 4). To estimate an age of equivalent physical development for these animals, the animal's age was multiplied by the ratio of the ages that humans (15.5 years) and the animals (baboon—4.0 years and pig—0.7 years) begin to produce mature sperm. These calculations gave equivalent physical development ages of 16.6 and 4.2 years for the baboon and pig, respectively. Based on this analysis, the state of physical development of a pig and a 3-year-old child of similar weight are quite comparable. The baboon's physical development is much more advanced.

Injury Susceptibility Consideration—To determine if either species was more susceptible to injury than the other, a preliminary test series was conducted using 5 pigs and 5 baboons. Four pigs and four baboons were tested in Positions 1 and 7 with two of each species exposed in each of the two positions. A single test of each species was conducted in Position 6. Examples of these animal positions are shown in Figures 1, 6 and 7. The inflatable restraint system used for these preliminary tests consisted of Inflator 1, Cushion 1, Fold 1 and Cover 1. The sled pulses were characterized by a 13.6 g plateau and a 50 km/h velocity change. The cushion was actuated 21 ms after the beginning of the simulated collision event. A standard bench seat was used in the full forward position for these tests. The injury types and severities produced by these exposures are given in Table 5.

For Positions 1 and 7, the cushion-animal involvements were quite similar and produced similar types of injuries.

Figure 4. Animal position 4.

Table 5. Summary of animal injuries and severities for the preliminary test series.

BODY REGION INJURED ORGANS	ANIMAL POSITION 1				ANIMAL POSITION 7				ANIMAL POS. 6	
	PIG 1 (TL)	PIG 3 (TL)	BAB 1 (TL)	BAB 3 (TL)	PIG 2 (TL)	PIG 4 (TL)	BAB 2 (TL)	BAB 4 (TL)	PIG 5 (TL)	BAB 5 (TL)
HEAD										
BRAIN	6	2	3	3	2	3	3	2	6	3
NECK										
CERVICAL SPINE/CORD	4	0	0	3	0	3	0	0	4	2
TRACHEA	3	0	0	3	0	2	2	3	0	2
THORAX										
THORACIC SPINE	0	0	0	3	0	3	3	0	0	3
RIBS	0	2	0	0	0	0	0	0	2	0
HEART	3	0	0	0	0	3	0	0	0	0
LUNGS	3	2	1	0	1	1	3	1	3	0
ABDOMEN										
DIAPHRAGM	2	2	0	0	0	2	0	0	0	0
LIVER	4	2	2	3	3	3	3	1	2	0
GALL BLADDER	0	0	0	3	0	0	0	0	0	0
SPLEEN	0	3	3	3	0	4	0	0	1	0
INTESTINES	0	0	2	2	0	0	2	2	1	0
MESENTERY	1	2	1	1	0	1	0	0	1	0
KIDNEY	0	0	0	1	0	0	0	0	0	0
BLADDER	0	0	1	0	0	0	0	0	0	0

Figure 6. Animal position 6.

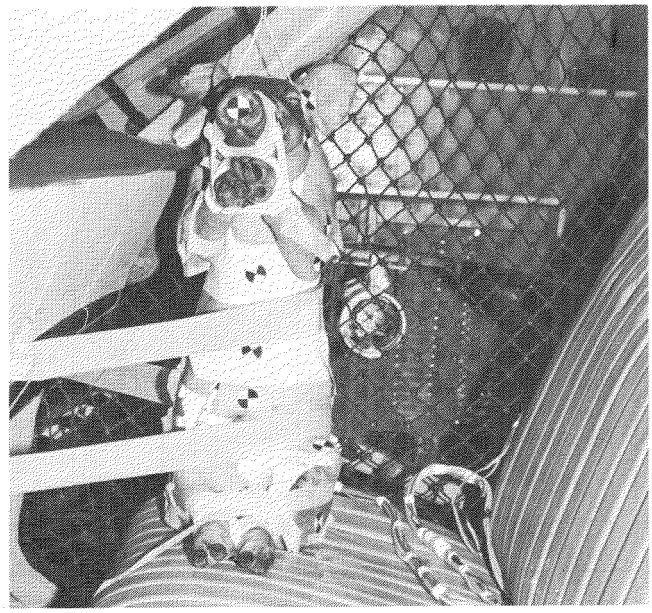


Figure 7. Animal position 7.

Table 3. Description of Animal Positions.

ANIMAL POSITION			ANIMAL TO INSTRUMENT PANEL REFERENCE		SELECTION RATIONALE
POS. NO.	FIG. NO.	DESCRIPTION	REFERENCE POINTS	DISTANCE (mm)	
1	1	SPINE VERTICAL, HEAD ABOVE I.P. BROW, XIPHOID 50 MM ABOVE CENTERLINE OF INFLATOR.	XIPHOID TO INFLATOR CENTERLINE	325 REAR 50 ABOVE	• EXPOSE ABDOMEN TO DEPLOYING CUSHION/COVER. • EXPOSE HEAD AND NECK TO UPWARD DEPLOYING L-CUSHION DESIGN.
2	2	SPINE VERTICAL, SNOUT ON I.P. BROW, XIPHIOD AT SAME LEVEL OF INFLATOR CENTER-LINE.	XIPHIOD TO INFLATOR CENTERLINE	300 REAR 0 ABOVE	• EXPOSE THORAX TO DEPLOYING CUSHION/COVER.
3	3	SPINE VERTICAL, SNOUT AT I.P. BROW, PRESTERNAL PROTUBERANCE AT LEVEL OF TOP OF COVER.	PRESTERNAL PROTUBERANCE TO INFLATOR CENTERLINE	290 REAR 115 ABOVE	• EXPOSE HEAD/NECK TO DEPLOYING CUSHION/COVER.
4	4	SIMILAR SNOUT & PRESTERNAL PROTUBRANCE LOCATIONS AS POSITION 3, LOWER TORSO ROTATED FORWARD PARALLEL TO COVER.	PRESTERNAL PROTUBERANCE TO INFLATOR CENTERLINE	240 REAR 115 ABOVE	• EXPOSE HEAD/NECK AND TORSO TO DEPLOYING CUSHION/COVER.
5	5	SPINE 30° TO HORIZONTAL, SNOUT MIDWAY BETWEEN TOP OF COVER AND I.P. BROW.	TIP OF SNOUT AND I.P. PANEL	AGAINST I.P. PANEL	• EXPOSE HEAD/NECK TO UPWARD DEPLOYING L-CUSHION DESIGN.
6	6	SPINE HORIZONTAL, SNOUT JUST ABOVE TOP OF COVER.	TIP OF SNOUT & I.P. PANEL	AGAINST I.P. PANEL	• EXPOSE HEAD/NECK TO COMPRES-SION LOADING OF DEPLOYING CUSHION/COVER.
7	7	SAME AS POSITION 1 EXCEPT ANIMAL IS FACING LEFT INSTEAD OF FORWARD, SHOULDER AGAINST I.P. BROW.	XIPHIOD TO INFLATOR CENTERLINE	325 REAR 100 ABOVE	• EXPOSE SIDE OF ABDOMEN TO DEPLOYING CUSHION/COVER • DETERMINE EFFECT OF ORIENTA-TION OF INJURY TYPE AND SEVERITY.

Table 4. Typical size, shape and mass measurements for 15 kg pigs, baboons, and children.

MEASUREMENT	AVERAGE OF 5 PIGS	AVERAGE OF 4 BABOONS	3-YEAR-OLD MALE CHILD	
			VALUE	REF.*
AGE (YEARS)	0.19	4.3	3	-
EQUIVALENT CHILD AGE (YEARS)**	4.2	16.3	3	-
MASS (kg)	14.9	15.2	14.9	15
SEATED HEIGHT (mm)	746	641	592	15
HEAD-NECK LENGTH (mm)	241	147	226	15
HEAD WIDTH (mm)	111	110	136	15
FORE-AFT HEAD MOTION (DEG)	45	110	105	12
NECK CIRCUMFERENCE (mm)	421	271	243	15
CHEST CIRCUMFERENCE (mm)	529	509	516	15
CHEST BREADTH (mm)	138	110	165	15
CHEST DEPTH TO BREADTH RATIO	1.33	1.44	0.67	15
ABDOMINAL CIRCUMFERENCE AT UMBILICUS (mm)	580	392	486	15
ABDOMINAL BREADTH AT UMBILICUS (mm)	147	125	165	15

NOTES:

* NUMBERS REFER TO PAPERS IN LIST OF REFERENCES.

** EQUIVALENT CHILD AGE = $\frac{\text{HUMAN PUBERTY AGE}}{\text{ANIMAL PUBERTY AGE}}$ x (ANIMAL TEST AGE)

The pig, however, appeared to experience more severe injuries. For Position 6, the animal-cushion interactions were quite different. The cushion deployed under the pig's snout driving the animal upwards and rearwards, hyper-extending its neck. For the baboon, the cushion deployed

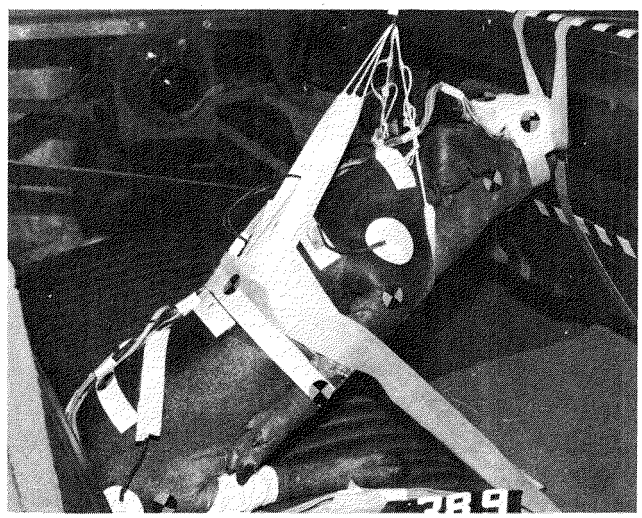


Figure 5. Animal position 5.

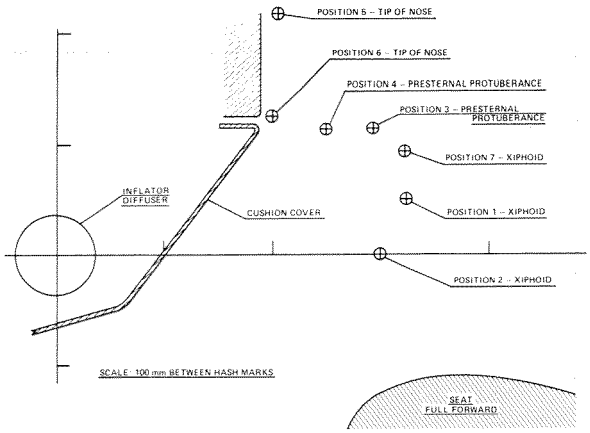


Figure 8. Locations of animal positioning landmarks relative to car interior landmarks.

over its head and there was minimum cushion-animal interaction. Based on these limited tests, the pig appeared more susceptible to injury than the baboon.

TEST RESULTS

Forty-three pigs and three baboons were subjected to the deploying cushion-collision interaction forces. The means and standard deviations of pertinent size, shape and mass measurements of these animals are given in Table 6. A summary of test results is given in Table 7 for each animal exposed to the deployment-collision forces for the test conditions given in Table 2. The peak internal inflator pressure is given in Table 7 for all the gas generating inflators. No pressures are listed for Inflators 3 and 4 which used compressed gas. Care should be exercised in interpreting the HIC and peak resultant head acceleration values since head acceleration was not measured at the center of gravity of the animal's head. Overall injury severity ratings in terms of threat-to-life (TL) and threat-of-permanent impairment (PI) are given for the body regions of the head, neck, thorax and abdomen.

For the pig tests, threat-to-life injuries ranging from 0 to 6 were observed for the head, neck and abdominal regions. Thoracic injuries ranged from TL equal to 0 to 5. The most significant pig injuries were subdural brain hemorrhages, partial transection of the cervical cord, rupture of the apical odontoid ligament, excessive straining of the membranes and ligaments surrounding the atlas-occipital region, cervical spine fractures, lung and heart contusions, persistent abnormal ECG readings, extensive rib fractures, liver tears, and lumbar spine fractures. Five of the animals (Pigs 8, 14, 15, 16 and 17) died as a result of their injuries. These test results indicate that the primary program objective of obtaining a wide spectrum of injury types and severities to the head, neck and torso regions was achieved.

The three baboon tests provided results similar to those observed in the preliminary test series. The baboon injury types were similar to the pigs, but the severities were somewhat less.

Caution must be used in interpreting the significance of these animal injuries relative to the expected performance of passenger inflatable restraint systems in general. It must be remembered that the objective of the study required using very aggressive passenger inflatable restraint system concepts for some of the tests in order to produce severe injuries to the animals. Because severe injuries were produced does not imply that all passenger inflatable restraint system concepts are aggressive. The fact is animals were exposed to several passenger inflatable restraint system concepts that were much less aggressive than the systems used to produce many of the severe animal injuries.

DISCUSSION OF RESULTS

Significant Animal Injuries

Head Injuries—Seven of the forty-six animals had significant (TL or PI ratings equal or greater than 3) head injuries. A summary of these injuries is given in Table 8. Four of these animals (Pigs 8, 15, 16 and 17) suffered fatal brain injuries. A photograph of the brain of Pig 8 is shown in Figure 9. Note the extensive subdural hemorrhage.

Table 6. Means and standard deviations of pertinent size, shape and mass measurements for the tested animals.

MEASUREMENT	PIGS			BABOONS		
	MEAN	STD. DEV.	COEFF. VAR.	MEAN	STD. DEV.	COEFF. VAR.
AGE (YEARS)	0.20	0.02	10%	5.2	0.8	15%
BODY MASS	15.7	1.0	6%	16.0	1.5	9%
BRAIN & SPINAL CORD	0.096	0.006	6%	0.183	0.005	3%
HEART	0.091	0.015	16%	0.068	0.007	10%
LIVER	0.490	0.078	16%	0.305	0.035	11%
SPLEEN	0.039	0.011	28%	0.028	0.019	68%
LEFT KIDNEY	0.044	0.006	14%	0.029	0.005	17%
RIGHT KIDNEY	0.042	0.006	14%	0.028	0.004	14%
SEATED HEIGHT	723	34	5%	661	13	2%
HEAD - NECK LENGTH	219	19	9%	125	6	5%
HEAD BREADTH	108	5	5%	110	6	5%
NECK CIRCUMFERENCE	448	28	6%	247	60	24%
STERNUM LENGTH	161	12	7%	159	12	8%
CHEST BREADTH	144	17	12%	112	17	15%
CHEST DEPTH	186	17	9%	146	7	5%
CHEST CIRCUMFERENCE	542	17	3%	499	54	11%
ABDOMINAL CIRCUM.	600	27	5%	463	11	2%
ABDOMINAL BREADTH	143	24	17%	143	16	11%

NOTES: BODY AND ORGAN MASSES GIVEN IN kg.
DIMENSIONS GIVEN IN mm.

Table 7. Summary of test results.

ANIMAL NUMBER	PEAK INFLATOR PRESSURE (Mpa)	HIC*	PK. HEAD RESULT. ACC.* (G)	PEAK V-D SPINE ACC. (G)	PEAK V-D STERNUM ACC.** (G)	PEAK BLOOD PRESSURE (mm Hg)	ANIMAL INJURY SEVERITY			
							HEAD (TL/PI)	NECK (TL/PI)	THORAX (TL/PI)	ABDOMEN (TL/PI)
PIG 8	19.0	--	--	--	--	375	6/6	6/6	5/3	0/0
PIG 9	14.4	--	--	114	--	570	2/1	0/0	3/1	3/2
PIG 10	17.0	19300	675	101	--	500	4/3	0/0	2/1	2/1
PIG 12	16.7	8570	350	120	--	310	2/0	4/4	3/2	2/1
PIG 13	18.4	1080	164	147	--	530	0/0	3/3	4/3	5/4
PIG 14	15.2	2470	143	152	--	600+	3/2	4/4	5/4	6/6
PIG 15	17.4	10300	494	132	--	490	6/6	6/6	4/2	4/4
PIG 16	16.1	22800	798	--	--	370	6/5	5/4	3/2	2/1
PIG 17	15.7	6270	264	--	--	600	5/4	5/4	4/3	4/2
PIG 18	--	7410	321	259	--	325	4/2	3/3	4/3	4/2
PIG 19	--	1760	146	--	--	390	0/0	2/1	1/0	1/0
PIG 21	--	5060	309	--	--	530	1/1	3/3	3/1	0/0
PIG 22	--	3790	240	--	--	610	2/1	4/4	2/1	3/1
PIG 23	--	--	--	--	--	280	0/0	3/1	3/1	2/1
PIG 24	6.0	--	--	93	--	190	2/2	3/4	2/1	2/1
PIG 25	6.8	1350	180	55	--	210	0/0	5/5	2/1	2/1
PIG 26	5.6	1120	133	48	--	210	2/1	4/4	2/1	0/0
PIG 29	7.1	1760	193	69	--	380	2/1	3/4	2/1	4/2
PIG 35	5.5	--	--	121	--	240	2/2	0/0	4/3	4/2
PIG 38	5.9	1980	136	104	--	390	2/2	0/0	3/2	0/0
PIG 41	4.7	433	94	79	--	230	2/1	0/0	1/0	0/0
PIG 44	4.6	102	53	--	--	210	0/0	0/0	1/0	0/0
PIG 46	--	897	194	--	--	360	2/2	0/0	1/0	2/1
PIG 47	--	1770	151	--	--	260	0/0	3/3	2/1	1/1
PIG 51	9.8	866	103	46	--	195	0/0	0/0	(3/2)	2/1
PIG 52	10.3	2140	175	61	--	235	1/0	3/4	2/1	2/1
PIG 67	11.0	1220	121	84	--	220	2/1	0/0	1/1	2/1
PIG 68	6.1	--	--	57	--	400	2/1	3/2	3/2	3/2
PIG 69	5.5	1270	137	60	--	200	0/0	0/0	1/0	0/0
PIG 70	11.1	1020	170	52	--	260	2/1	4/4	2/1	0/0
PIG 72	11.6	765	164	63	--	330	0/0	0/0	2/0	2/2
PIG 80	10.8	455	132	38	1040U	145	2/1	0/0	0/0	0/0
PIG 81	10.6	325	100	35	1260U	160	0/0	1/1	1/0	0/0
PIG 83	10.9	450	93	43	685U	178	1/1	0/0	1/0	0/0
PIG 84	11.3	765	190	97	1110U	110	0/0	3/3	1/0	0/0
PIG 85	9.7	2440	184	166	1400L	420	0/0	3/4	2/0	0/0
PIG 87	9.7	1400	252	78	1740M	205	0/0	2/1	1/0	0/0
PIG 88	8.9	620	168	62	1340L	255	1/0	0/0	1/0	1/1
PIG 89	9.4	345	107	63	1300L	220	0/0	0/0	2/1	0/0
PIG 91	9.2	335	76	27	1520M	220	1/0	0/0	1/0	0/0
PIG 93	9.7	1850	221	97	570U	480	0/0	3/4	2/1	1/1
PIG 94	9.3	3000	332	86	2220L	625	2/1	4/4	2/1	4/3
PIG 151	9.5	1015	128	23	103U	250	1/1	0/0	2/1	0/0
BAB 6	13.0	3480	167	--	--	400	1/1	0/0	2/1	2/1
BAB 7	9.7	4810	243	297	2340U	490	1/0	3/3	3/1	4/3
BAB 8	9.5	2650	215	30	1190L	270	0/0	2/1	2/0	3/2

NOTES:
* NOT MEASURED AT CENTER OF GRAVITY OF THE HEAD.
** ACCELEROMETER GIVING PEAK RESPONSE: U-UPPER, M-MID, L-LOWER.
( ) - THORACIC INJURY MAY HAVE OCCURRED PRETEST.

Neck Injuries—Twenty-four of the forty-six animals experienced significant neck injuries. Table 9 gives a summary of these injuries. Two of the animals (Pigs 8 and 15) suffered fatal neck injuries. Pig 8 had a subluxation of the atlanto-occipital joint with torn joint ligaments and extensive subdural and subarachnoid hemorrhages of the cervical cord. Pig 15 had a fracture of the dorsal arch of C5 including the articular process and a partial transection of the cervical cord at the level of C5.

The most frequent neck injury observed was hemorrhage within the atlas-occipital joint capsules and/or hemorrhage dorsal of the membrane covering the midsagittal-ventral aspect of the atlas-occipital junction. Such hemorrhages were observed in twenty of the twenty-four animals with significant neck injury and appeared to be a good indicator of the onset of damage to the apical odontoid ligament, the ligament extending from the tip of the odontoid process to the occiput. In a number of instances, hemorrhage of the apical odontoid ligament was observed and was rated as TL/PI = 3/4.

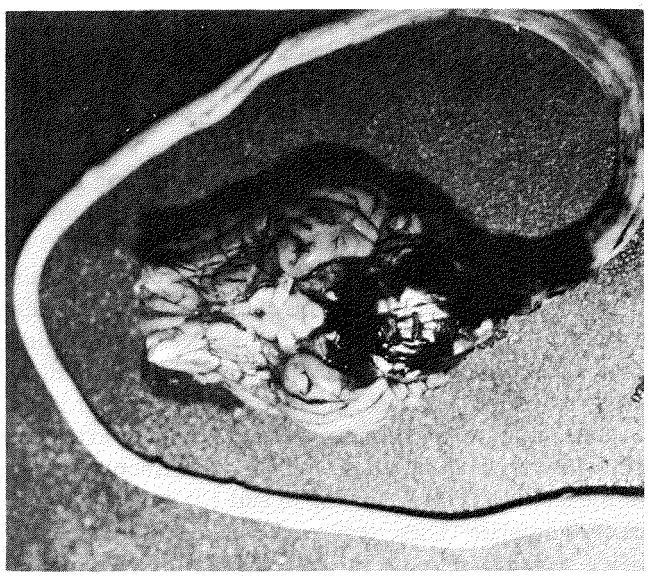


Figure 9. Brain of pig 8 showing extension subdural hemorrhage.

Table 8. Summary of animals with significant brain injuries.

ANIMAL NUMBER	HEAD INJURY SEVERITY (TL/PI)	INJURY DESCRIPTION	COMMENTS
8	6/6	DURAL SINUS LACERATION, EXTENSIVE SUBDURAL AND SUBARACHNOID HEMORRHAGE. NO PALPEBRAL REFLEX RESPONSE.	PIG DIED 12 MINUTES POSTIMPACT OF HEAD/NECK INJURIES.
15	6/6	SEVERE CONTUSION OF BRAIN STEM & CERVICAL CORD. NO PALPEBRAL REFLEX RESPONSE.	PIG DIED 2 1/4 MINUTES POSTIMPACT OF HEAD/NECK INJURIES.
16	6/5	SEVERE SUBDURAL & SUBARACHNOID HEMORRHAGE OF BRAIN STEM. ABSENT, DIMISHED, THEN ABSENT PALPEBRAL REFLEXES.	PIG DIED 39 MINUTES POSTIMPACT OF HEAD/NECK INJURIES.
17	5/4	DIFFUSE SUBARACHNOID HEMORRHAGE. ASYMMETRIC, THEN ABSENT PALPEBRAL REFLEXES. MARKED DEPRESSED RESPIRATION AND BLOOD PRESSURE.	PIG DIED 55 MINUTES POSTIMPACT OF APPARENT BRAIN STEM INJURY.
10	4/3	ACUTE BRAIN CONTUSION, ISCHEMIC, LEFT DORSAL TEMPORAL LOBE. ABSENT, THEN DEPRESSED PALPEBRAL REFLEXES.	
18	4/2	DIFFUSE BRAIN CONTUSION. PALPEBRAL REFLEXES DIMINISHED FOR 30 MINUTES POSTIMPACT.	RESPIRATION AND BLOOD PRESSURE DEPRESSED FOR 10 MINUTES POSTIMPACT.
14	3/2	PARENCHYMAL HEMORRHAGE. ASYMMETRIC, THEN ABSENT PALPEBRAL REFLEXES.	PIG DIED 24 MINUTES POSTIMPACT DUE TO BLOOD LOSS FROM SEVERELY LACERATED LIVER.

Fractures of the cervical spine were observed in three animals (Pigs 15, 17 and 68). Pig 15 had a fracture of the lateral arch of C5 including the articular process which resulted in partial transection of the cervical cord. This fracture was rated TL/PI = 5/4 because of the consequences of the fracture relative to severe damage to the cord. Pig 17 experienced a similar type fracture of C6 without involvement of the articular process or cord and was rated as TL/PI = 4/3. Both of these fractures were rated more severe than the rating given in the AIS-80 code (13) because of the potential for severe cord damage. Pig 68 experienced a simple fracture of the spinous process of C7 which was rated as TL/PI = 3/2.

Significant pathological changes in the cervical cord were found in only four of the twenty-four animals (Pigs 15, 25, 12 and 47) that had significant neck injuries. Pig 15 had the most severe cord trauma, a partial transection which was rated as TL/PI = 5/3. Pig 47 had cord damage rated as TL/PI = 3/3 without any evidence of cervical spine damage. It is difficult to understand how the cord could be damaged without attendant cervical spine damage. Perhaps the pathological observations of petechial hemorrhages is an artifact of the histology or necropsy protocol.

Thoracic Injuries—Sixteen of the forty-six animals had significant thoracic injuries. These injuries are summarized in Table 10. None of the animals experienced fatal thoracic lesions; however, Pigs 14 and 8 did suffer critical (TL/PI = 5/4 and 5/3, respectively) thoracic injuries. Pig 14 had extensive rib fractures, a first and second degree AV block followed by an incomplete right bundle branch block, and pathological damage to the heart and lungs. This animal died 24 minutes postimpact of blood loss from a severely lacerated liver. Pig 8 had a fracture of the body of T8, profound bradycardia and pathological damage to the heart and lungs. This animal died two minutes postimpact of fatal head and neck injuries.

Twelve of the sixteen animals had significant pathological damage to the heart. Six had significant lung damage. Significant changes in ECG occurred in five animals, including one baboon. Five animals had rib fractures with Pig 14 having the most extensive fractures. Three animals (Pigs 8, 18 and 68) had thoracic vertebral fractures. The heart lesion noted for Pig 51 may not have been related to the impact since histology indicated that it may have been an old injury.

In a number of cases, the overall thoracic injury rating is more severe than any of the individual ratings. These

Table 9. Summary of animals with significant neck injuries.

ANIMAL NUMBER	NECK INJURY SEVERITY (TL/PI)	CERVICAL SPINE			OTHER (TL/PI)
		SPINAL CORD (TL/PI)	ATLAS-OCCIPUT JOINT DAMAGE (TL/PI)	FRACTURE (TL/PI)	
PIG 8	6/6	2/2	6/6	0/0	
PIG 15	6/6	5/3	4/4	5/4	PARTIALLY SEVERED CERVICAL MUSCLE (3/3).
PIG 25	5/5	3/2	5/5	0/0	
PIG 16	5/4	2/1	4/4	0/0	
PIG 17	5/4	1/0	3/3	4/3	
PIG 26	4/4	2/1	4/4	0/0	
PIG 94	4/4	2/1	4/4	0/0	
PIG 70	4/4	0/0	3/4	0/0	HEMORRHAGE, ATLAS-AXIS JOINT (3/3).
PIG 22	4/4	0/0	4/4	0/0	
PIG 14	4/4	2/2	4/4	0/0	
PIG 12	4/4	3/2	4/4	0/0	HEMORRHAGEIC CERVICAL MUSCLE (3/2).
PIG 85	3/4	0/0	3/4	0/0	
PIG 52	3/4	0/0	3/4	0/0	
PIG 29	3/4	0/0	3/4	0/0	
PIG 24	3/4	0/0	3/4	0/0	
PIG 93	3/4	1/0	3/4	0/0	
BAB 7	3/3	0/0	3/3	0/0	
PIG 18	3/3	2/1	3/3	0/0	
PIG 13	3/3	0/0	3/3	0/0	
PIG 84	3/3	0/0	3/3	0/0	
PIG 21	3/3	0/0	0/0	0/0	HEMORRHAGE, ATLAS-AXIS JOINT (3/3).
PIG 47	3/3	3/3	0/0	0/0	
PIG 68	3/2	0/0	0/0	3/2	
PIG 23	3/1	0/0	0/0	0/0	CONTUSED MUCOSAL SURFACE, LARYNX (3/1).

Table 10. Summary of animals with significant thoracic injuries.

ANIMAL NUMBER	THORACIC INJURY SEVERITY (TL/PI)	THORACIC OBSERVATIONS				OTHER (TL/PI)
		LUNG DAMAGE (TL/PI)	HEART DAMAGE (TL/PI)	ECG (TL/PI)	RIB FRACTURE (TL/PI)	
PIG 14	5/4	3/1	3/2	4/4	3/2	
PIG 8	5/3	4/2	4/2	4/2	0/0	FRACTURE OF BODY OF T8 (3/3).
PIG 35	4/3	2/0	4/3	2/1	0/0	
PIG 18	4/3	2/1	3/2	3/2	2/1	FRACTURE OF SPINOUS PROCESSES OF T4-T7 (2/1).
PIG 17	4/3	3/1	3/2	3/3	2/1	
PIG 13	4/3	2/1	3/2	0/0	0/0	HEMORRHAGE, VENA CAVA (3/2).
PIG 15	4/2	4/2	3/1	0/0	0/0	
PIG 68	3/2	2/1	3/2	0/0	0/0	FRACTURE OF SPINOUS PROCESS OF T1 (2/1).
PIG 51	3/2	1/0	3/2	0/0	0/0	HEART LESION MAY NOT BE IMPACT RELATED.
PIG 38	3/2	2/1	3/2	0/0	0/0	
PIG 16	3/2	2/1	3/2	2/1	0/0	
PIG 12	3/2	0/0	3/2	0/0	1/0	
BAB 7	3/1	2/1	1/0	3/0	0/0	
PIG 23	3/1	2/1	2/1	0/0	0/0	BLOOD STAINED FORTH IN BRONCHI (3/1).
PIG 21	3/1	3/1	2/1	0/0	0/0	
PIG 9	3/1	3/1	1/0	0/0	0/0	

higher severity ratings reflect the possible synergistic effect of multiple significant thoracic injuries.

The most frequent gross cardiac pathology observations were subendocardial petechiae and/or eccyhmoses of the interventricular septum and/or papillary muscle of the left ventricle. Such hemorrhages were observed in both impacted animals and in non-impacted, control animals. Since it was not possible to separate the artifactually jinduced hemorrhages from impact-induced hemorrhages, all such hemorrhages were rated as impact induced. Changes in the animal handling and euthanasia techniques were instituted in an attempt to reduce the occurrence of artifactually induced hemorrhages.

Table 11. Summary of animals with significant abdominal injuries.

ANIMAL NUMBER	ABDOMINAL INJURY SEVERITY (TL/PI)	ABDOMINAL ORGANS						OTHER (TL/PI)
		LIVER (TL/PI)	DIAPHRAGM (TL/PI)	SPLEEN (TL/PI)	KIDNEY (TL/PI)	GALL BLADDER (TL/PI)	INTESTINE (TL/PI)	
PIG 14	6/6	6/6	3/1	0/0	0/0	0/0	0/0	
PIG 13	5/4	5/4	0/0	0/0	2/1	0/0	0/0	MESENTERY HEMORRHAGE (3/1).
PIG 15	4/4	4/4	3/1	0/0	0/0	0/0	0/0	
BAB 7	4/3	4/3	0/0	2/1	3/2	0/0	3/2	SEVERE HEMORRHAGE OF OMENTUM (3/2) & PORTAL VEIN (4/3).
PIG 94	4/3	4/3	2/1	0/0	0/0	0/0	0/0	
PIG 35	4/2	4/2	0/0	0/0	0/0	0/0	0/0	
PIG 29	4/2	4/2	0/0	0/0	0/0	2/1	0/0	
PIG 18	4/2	4/2	0/0	0/0	0/0	0/0	0/0	
PIG 17	4/2	4/2	0/0	0/0	0/0	0/0	0/0	
BAB 8	3/2	1/1	0/0	0/0	0/0	3/2	2/1	
PIG 68	3/2	3/2	0/0	0/0	2/1	0/0	0/0	
PIG 9	3/2	3/2	0/0	0/0	0/0	0/0	3/2	
PIG 22	3/1	3/1	0/0	0/0	0/0	0/0	0/0	

Abdominal Injuries—Thirteen of the forty-six animals, including two of the three baboons, had significant abdominal injuries (Table 11). The liver was the most frequently injured abdominal organ. Nine of the fourteen animals had lacerated lobes and/or junctional tears of the liver which were rated as TL equal to four or greater. Pig 14 died 24 minutes postimpact of blood loss from the severely lacerated liver shown in Figure 10. Pig 13 had a deep rent on the right lobe of the liver that resulted in ischemic necrosis of the parenchyma, peripheral to the tear, Figure 11.

Distribution of Various Mechanical Response Measurements Within Discrete Injury Classifications

For each animal, the mechanical response measurements listed in Table 7 were paired with threat-to-life (TL) injury severity ratings for selected body regions. HIC's were paired with the TL ratings for the head, peak

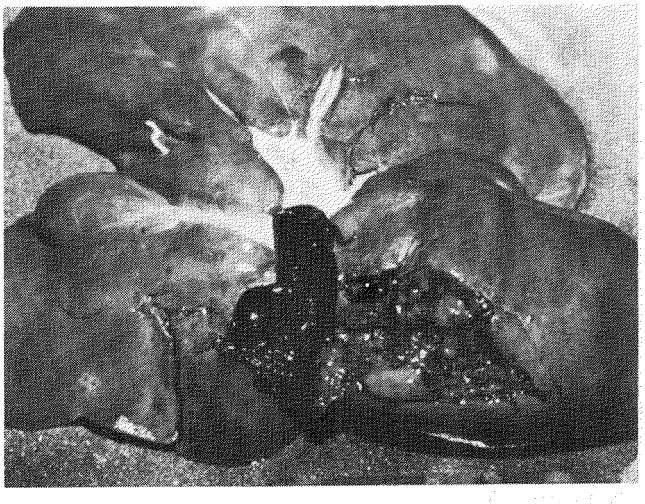


Figure 10. Severely lacerated liver of pig 14.

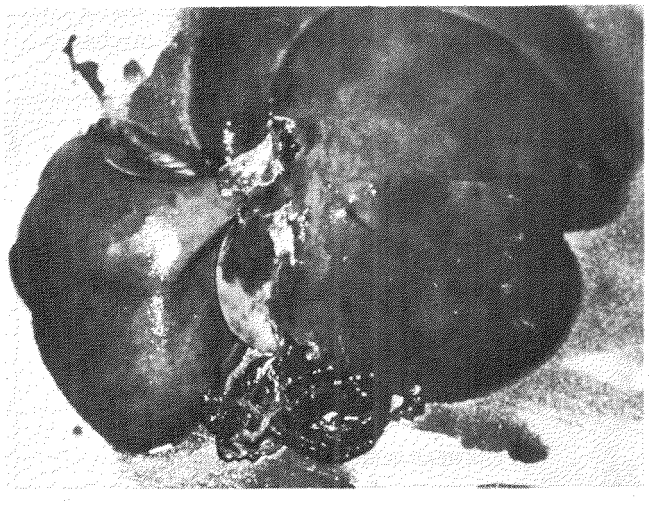


Figure 11. Ischemic necrosis of the liver of pig 13 peripheral to the laceration.

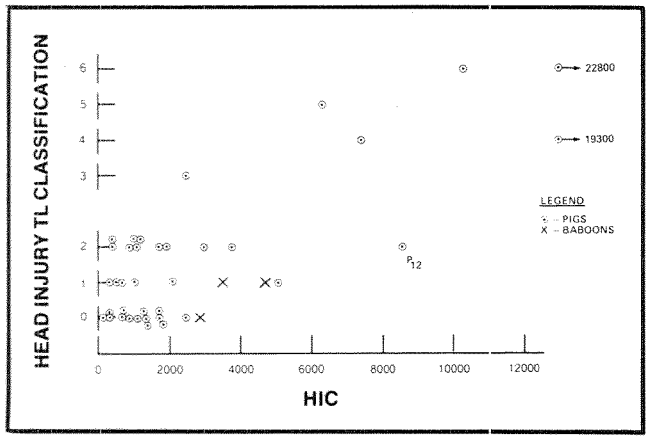


Figure 12. Distributions of head HIC values within the various head TL classifications.

resultant head accelerations with neck injury TL ratings, and peak ventro-dorsal thoracic spine accelerations with the thorax and the abdomen TL ratings. These pairings are displayed in Figures 12 through 15 for the body regions of the head, neck, thorax and abdomen, respectively. The thoracic injury rating for Pig 51 was not plotted since the injury could have occurred pretest. The thoracic and abdominal injury ratings for Baboon 8 were not plotted because the sensivity axis of the thoracic spine accelerometer was not aligned with the direction of the cushion-animal interaction force for the animal position that was used (see Figure 5). The TL ratings are shown as discrete classifications, ranked in terms of increasing injury severity. Linearity of severity should not be assumed between the integers assigned to the various classifications.

Note that for a given body region, many of the mechanical response ranges for the various discrete TL classifications overlap. Two possible reasons for these overlaps are: i) the animals have different levels of injury susceptibility, and ii) the measured response values chosen may not be the most appropriate indicators of the injury severity rating of the body region. It may be that a given injury type can be produced by a variety of mechanisms,

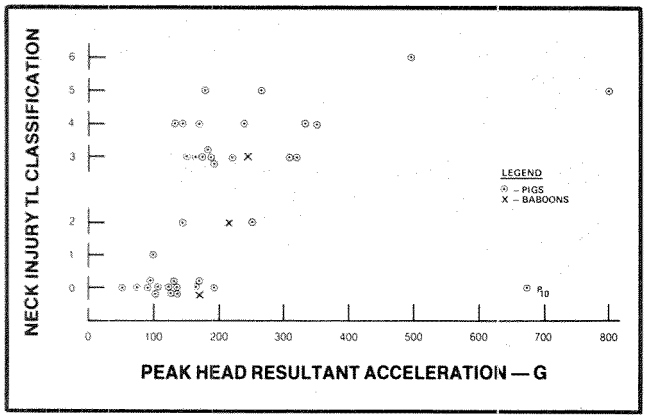


Figure 13. Distributions of head resultant acceleration values within the various neck TL classifications.

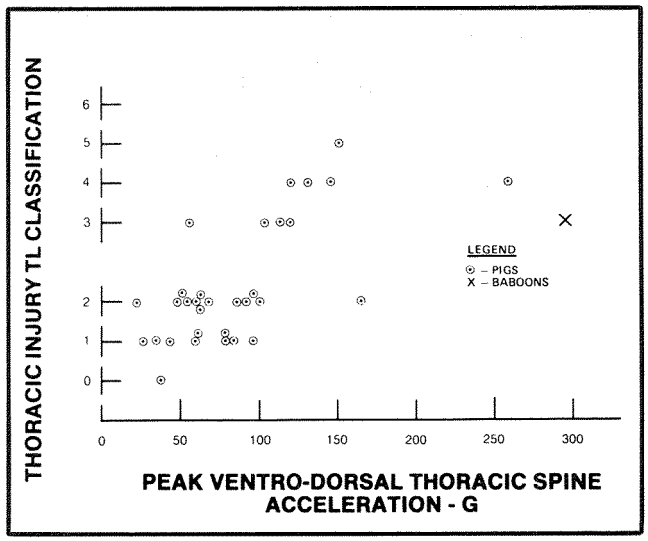


Figure 14. Distributions of peak ventro-dorsal thoracic spine acceleration values within the various thoracic TL classifications.

each related to a different physical parameter or combinations of parameters. The implication of these overlaps is that given a value of one of the measured responses, the injury severity classification for the corresponding body region is not uniquely defined. In such cases, one must speak of the probability for various levels of injury severity.

In several cases, an extreme of a mechanical response range for a given body region and injury severity classification appears to be an outlier. Such outliers could be due to a number of causes such as mechanical response measurement artifacts, undiagnosed injuries, or injuries that occur as the result of procedural techniques and not the test environment. For example, Pig 12 had a HIC of 8570, but only a moderate head injury (see Figure 12,

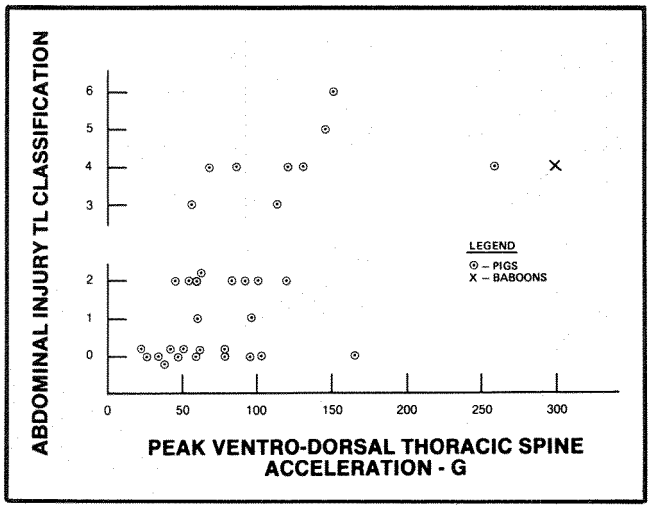


Figure 15. Distributions of peak ventro-dorsal thoracic spine acceleration values within the various abdominal TL classifications.

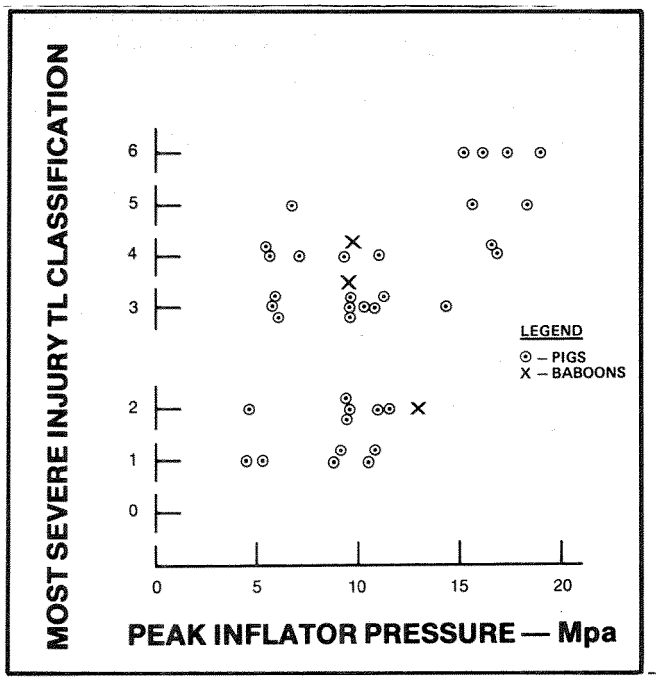


Figure 16. Association between peak inflator pressure and most severe injury.

TL = 2 Classification). The resultant head acceleration of Pig 12 had two distinct peaks and the HIC time interval contained both peaks. The HIC value for either peak, individually, would be lower and probably would be more representative of the severity of the head impact environment. As a second example of an outlier, Pig 10 had peak resultant head acceleration of 675 g's without any apparent neck injury (Figure 13, TL = 0 Classification). In this case, it is quite possible that Pig 10 had an undiagnosed neck injury since the dissection technique used to detect neck injuries was not developed until later in the program.

Peak inflator pressure was paired with the highest TL rating experienced by the animal. A plot of these pairings is given in Figure 16. Note the strong association between the more aggressive inflators (peak pressures of 15 Mpa or greater) and the more severe injuries (TL's of 5 and 6).

SUMMARY

Forty-six anesthetized animals (forty-three pigs and three baboons) were subjected to a variety of deploying cushion-collision interaction forces which produced a broad spectrum of injury types and severities to the major organs of the head, neck and torso of the animals. The severity of the animal injuries were rated as if the injuries were sustained by a 3-year-old child. For the pig tests, threat-to-life (TL) injuries ranging from no injuries (TL = 0) to non-survivable injuries (TL = 6) were identified for organs of the head, neck and abdomen. Thoracic organ injuries ranged from no injuries (TL = 0) to critical injuries (TL = 5). The more significant injuries were subdural brain hemorrhages, partial transection of the cervical cord, rupture of the apical odontoid ligament, excessive straining of the membranes and ligaments surrounding the atlas-occipital region with attendant hemorrhaging, cervical spine fractures, lung and heart contusions, persistent abnormal ECG readings, extensive rib fractures, liver tears and lumbar spine fractures. Five of the pigs died as a result of their injuries. Three baboons were used in the program and experienced similar, but less severe injuries than pigs that were exposed to similar test environments. The animal injury data were needed to interpret the significance of the responses of a specially instrumented child dummy (11) that was being used in GM's passenger inflatable restraint development program. That interpretation is the topic of a separate paper by Mertz and Weber (12).

ACKNOWLEDGEMENTS

The program described in this paper was a multi-disciplinary project requiring the efforts of many people. The authors would like to express their appreciation to the instrumentation, sled and animal care staffs of Southwest Research Institute for handling the many details of conducting the tests; to the medical specialists for their interpretation of the animal injuries and to the management and staffs of Passenger Inflatable Restraint group of Fisher Body and the Inflatable Restraint Project Center of Current Product Engineering of General Motors Corporation for their support of this project. A special note of thanks is given to Vernon Lancaster who handled the logistics of the test hardware and to Dr. K. D. Carey and Ned Zamora his assistant who conducted the animal necropsies.

LIST OF REFERENCES

1. Patrick, L. M. and Nyquist, G. W., "Airbag Effects on the Out-of-Position Child", 2nd International Conference on Passive Restraints, SAE 720442, 1972.
2. Campbell, D. D., "Air Cushion Restraint Systems Development and Vehicle Application", 2nd International Conference on Passive Restraints, SAE 720407, 1972.
3. Klove, E. H. and Olgesby, R. N., "Special Problems and Considerations in the Development of Air Cushion Restraint Systems", 2nd International Conference on Passive Restraints, SAE 720411, 1972.
4. Smith, G. R., Hurite, S. S., Yanik, A. J., and Greer, C. R., "Human Volunteer Testing of GM Air Cushions", 2nd International Conference on Passive Restraints, SAE 720443, 1972.
5. Wu, H., Tank, S. C., and Petrof, R. C., "Interaction Dynamics of an Inflating Air Bag and a Standing Child", SAE 730604, 1973.

6. Lundstrom, L. C., "Rati ıg Air Cushion Performance to Human Factors and Tolerance Levels", Fifth International Technical Conference on Experimental Safety Vehicles, 1974.
7. Aldman, B., Anderson, A., and Saxmark, O., "Possible Effects of Airbag In lation on a Standing Child", Proceedings of the Int rnational Meeting on Biomechanics of Trauma in Children, Lyon, France, 1974.
8. Takeda, H. and Kobaya hi, S., "Injuries to Children From Airbag Deployme ıt", 8th International Technical Conference on Ex perimental Safety Vehicles, 1980.
9. Stalnaker, R. L., Klus neyer, L. F., Peel, H. H., White, C. D., Smith, G. R., and Mertz, H. J., "Unrestrained, Front Seat, Child Surrogate Trajectories Produced by Hard Br king", Proceedings of the Twenty-Sixth Stapp Car Crash Conference, October 20-22, 1982.
10. Montalvo, F., Bryant, R W., Mertz, H. J., "Possible Positions and Postures of Unrestrained Front-Seat Children at the Instant f Collision", Proceedings of the Ninth International Technical Conference on Experimental Safety Vehicles, Nov. 1-4, 1982.
11. Wolanin, M. J., Mertz, H. J., Nyznyk, R. S., and Vincent, J. H., "Description and Basis of a Three-Year-Old Child Dummy for Evaluating Passenger Inflatable Restraint Concepts", Proceedings of the Ninth International Technical Conference on Experimental Safety Vehicles, Nov. 1-4, 1982.
12. Mertz, H. J., and Weber, D. A., "Interpretations of the Impact Responses of a 3-Year-Old Child Dummy Relative to Child Injury Potential", To Be Published.
13. The Abbreviated Injury Scale—1980 Revision, AAAM, Morton Grove, IL, 1980.
14. United States Patent 4290627, "L-Shaped Inflatable Restraint Cushion", Sept. 22, 1981.
15. Snyder, R. G., Schneider, L. W., Owings, C. L., Reynolds, H. M., Golomb, D. H., Schork, M. A., *Anthropometry of Infants, Children, and Youths to Age 18 For Product Safety Design*, SP450, SAE, Warrendale, PA, 1977.
16. Diffrient, N., Tilley, A. R., Bradagjy, J. C., "Design Requirements for Infants and Children", *Human Scale (TM) 1/2/3*, MIT Press, Cambridge, 1974.

Interpretations of the Impact Responses of a 3-Year-Old Child Dummy Relative to Child Injury Potential

H. J. MERTZ and D. A. WEBER
General Motors Corporation

ABSTRACT

An analysis is presented that was used to interpret the significance of response measurements made with a specially instrumented, 3-year-old child dummy that was used to evaluate child injury potential of the second-generation, passenger inflatable restraint system that was being developed by General Motors Corporation. Anesthetized animals and a specially instrumented child dummy, both 3-year-old child surrogates, were exposed to similar inflating-cushion, simulated collision environments. The exposure environments were chosen to produce a wide spectrum of animal injury types and severities, and a corresponding broad range of child dummy responses. For a given exposure environment, the animal injury severity ratings for the head, neck, thorax and abdomen are paired with dummy response values corresponding to these body regions. These data are used to develop relationships that can be used to predict the probability of an animal experiencing significant injuries to these body regions based on the child dummy response measurements. A rationale is developed for interpreting the predicted animal injury severities relative to child injury severities.

INTRODUCTION

A specially instrumented, 3-year-old child dummy (1) was used to evaluate the performance of the second-generation, passenger inflatable restraint system being developed by General Motors Corporation. While it was possible to assess the performances of various inflatable restraint concepts based on the relative magnitudes of the child dummy response measurements, no basis existed to interpret these measurements relative to child injury potential. In previous studies by General Motors Corporation (2) and Volvo (3), anesthetized baboons, chimpanzees and pigs were used as child surrogates to estimate the child injury potential of various passenger inflatable restraint concepts. Unfortunately, no attempt was made in either program to develop a test device (instrumented child dummy) to aid in understanding the relationships between the observed animal injuries and the cushion-collision interaction forces.

To develop a basis for interpreting the responses of the child dummy relative to child injury potential, an animal test program was again needed. The program proposed was to expose anesthetized animals and the specially instrumented child dummy to similar deploying cushion-collision interaction environments. Exposure environments were chosen to produce a wide range of animal injury types and severities, and a corresponding broad

spectrum of child dummy responses. This scheme would allow association to be made between the animal injury severity ratings for the head, neck, thorax, and abdomen and the dummy response measurements for the corresponding body regions. A detailed description of the animal test program and observed animal injuries is given by Mertz et al. (4). The following describes the analyses that were done of that animal injury data and the corresponding child dummy response data to estimate child injury potential due to inflating cushion-collision interactions.

PAIRED ANIMAL INJURY AND CHILD DUMMY RESPONSE DATA

Animal Tests

Forty-three pigs and three baboons were subjected to a spectrum of deploying cushion-collision interaction forces, with each animal being subjected to a single exposure (4). Physiological measurements made pre- and postimpact were: blood pressure, 6-lead ECG, heart rate, respiration, rectal temperature, visual and somatosensory evoked responses, reflex responses to toe and ear pinch, palpebral reflex, pupil size and reactivity to light, muscle tonus, and blood gases. Drugs were administered in sufficient dosages to assure that the animal was immobile and had adequate pain suppression while retaining good neurological response levels for the physiological testing. If the animal survived the exposure, it was sacrificed usually 24 hours posttest. A detailed gross necropsy was performed on all animals. Selected sections of the brain, spinal cord, heart and lungs were examined microscopically.

The resulting physiological and pathological data were evaluated by a team of medical specialists that consisted of a neurophysiologist, a neuropathologist, a cardiac pathologist, a cardiologist, a pulmonary specialist and a biomechanics specialist/physician who was the team leader. The medical specialists were directed to assess the severity of the animal injuries as if the injuries had occurred to a 3-year-old child. When all the injuries for a given animal had been rated, injury severity ratings in terms of threat-to-life (TL) and permanent impairment (PI) were assigned to the body regions of the head, neck, thorax and abdomen. For the head, neck and abdomen, the overall body region TL ratings ranged from no injuries (TL = 0) to nonsurvivable injuries (TL = 6). Thoracic injury severity ratings ranged from no injuries (TL = 0) to critical injuries (TL = 5). In the following analysis, these TL ratings for the four body regions of each animal will be paired with corresponding child dummy response measurements. The PI ratings will not be used in this paper.

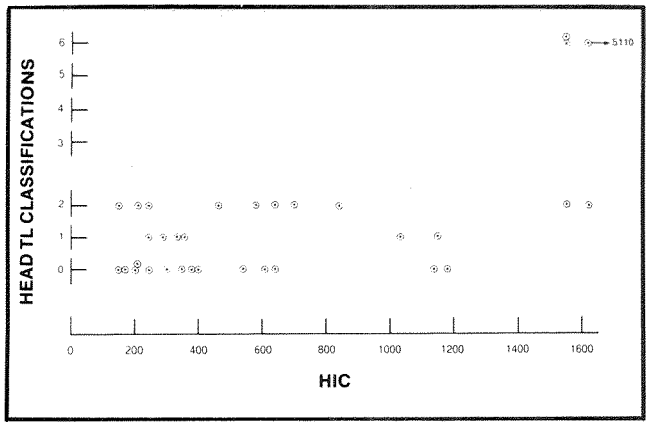


Figure 1. Paired child dummy HIC values and animal head TL values.

SELECTION OF CHILD DUMMY AND ANIMAL TEST DATA

For each animal exposed, a similar test was conducted using the instrumented child dummy. High-speed films of paired animal and dummy tests were reviewed to determine if the kinematics of the animal and dummy were similar. In a number of cases, gross differences in kinematics were noted. Data from those tests were excluded from the correlation analysis. A comparison of inflator characteristics was made between paired dummy and animal tests. In several cases, gross differences were noted in the performance of the inflators and the results of those tests were excluded from further analysis. The remaining paired animal and child dummy data were subjected to the following analysis.

ANALYSIS OF CHILD DUMMY AND ANIMAL TEST DATA

The head injury severity TL rating for each animal was paired with the child dummy HIC value that was measured in a similar exposure environment. These pairings are depicted in Figure 1. Similar pairings were done for the head TL ratings and peak child dummy neck tensions (Figure 2), the neck TL ratings and peak child dummy neck tensions (Figure 3), the thoracic TL ratings and peak child dummy upper-spine resultant accelerations (Figure 4) and maximum rate of chest compressions (Figure 5), and the abdominal TL ratings and peak child dummy lower-spine resultant accelerations (Figure 6) and maximum rate of abdominal compressions (Figure 7). Child dummy neck tensions were paired with head TL ratings (Figure 2) because the significant head injuries that were produced in the test program were subdural hemorrhages that appeared to be related to rapid rearward displacement of the animal's head relative to its torso. Neck tension along with HIC were thought to be good indicators of severity of this kinematic behavior. Conse-

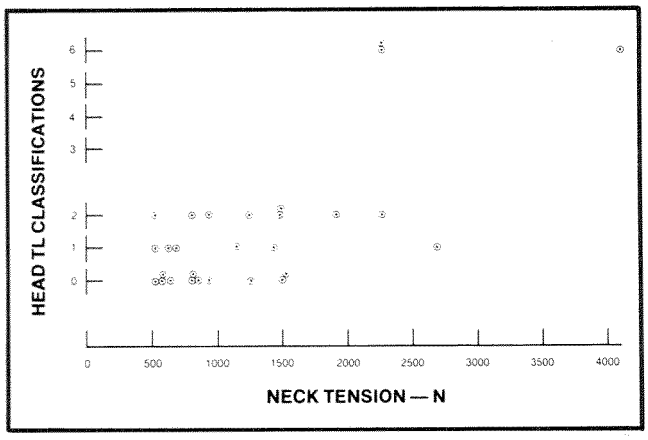


Figure 2. Paired child dummy neck tension values and animal head TL values.

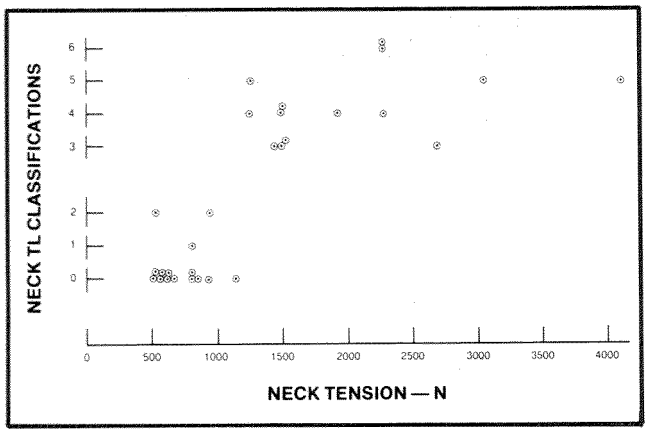


Figure 3. Paired child dummy neck tension values and animal neck TL values.

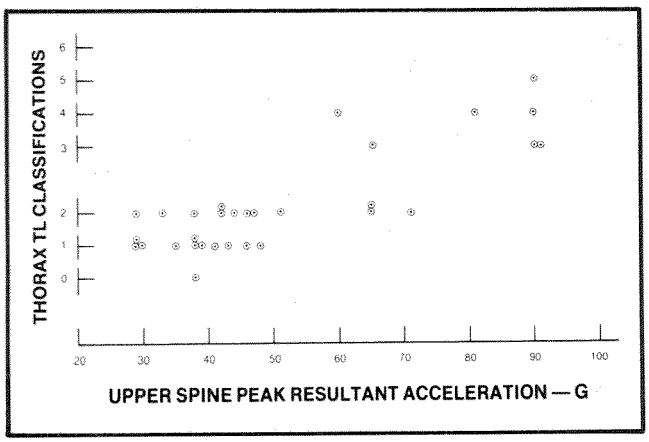


Figure 4. Paired child dummy peak upper-spine resultant acceleration values and animal thoracic TL values.

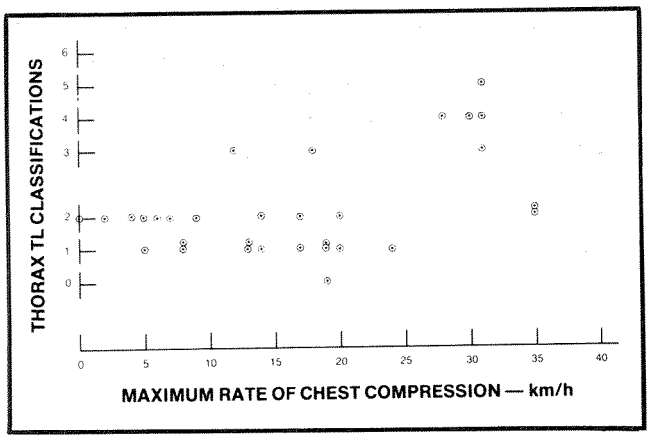


Figure 5. Paired child dummy maximum rate of chest compression values and thoracic TL values.

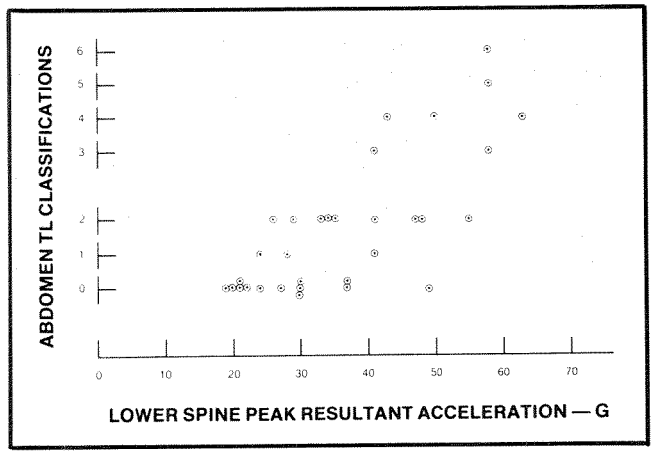


Figure 6. Paired child dummy peak lower-spine resultant acceleration values and animal abdominal TL values.

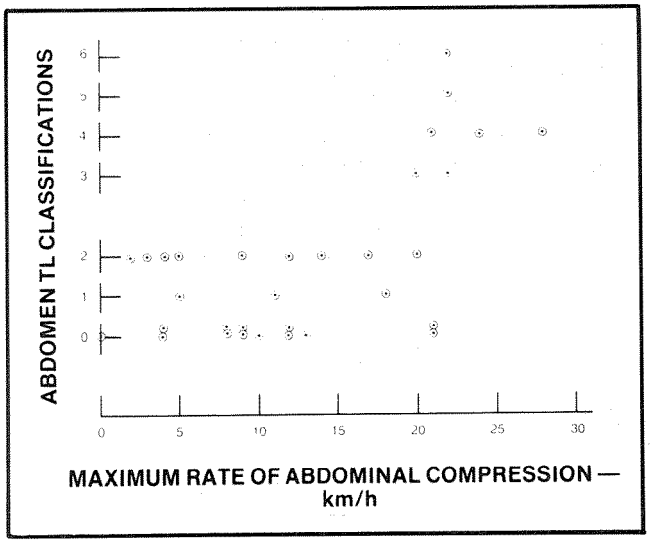


Figure 7. Paired child dummy maximum rate of abdominal compression and animal abdominal TL values.

quently, both child dummy responses were paired with the animal's head TL ratings.

To emphasize that linear relationships do not exist between the integer values assigned to the various injury severity classifications, adjacent TL classifications shown on Figures 1-7 are separated by a space. A larger space is used between the TL = 2 and TL = 3 classifications to distinguish between significant injuries (TL = 3, 4, 5 and 6) and nonsignificant injuries (TL = 0, 1 and 2).

DISCUSSION OF ANIMAL INJURY—CHILD DUMMY RESPONSE ASSOCIATIONS

Extremes of Injury Severity Classifications

The extremes of the range of the child dummy response data for a given body region and TL classification are bounds for the child dummy response value that is associated with 50 percent of the animals experiencing that level of injury severity for the prescribed body region. The lowest child dummy response value of the range is a conservative estimate of the 50 percent value, while the largest value is a nonconservative estimate. The actual 50 percent value will lie somewhere between the extremes and will not be, in general, the mean value of the child dummy response data associated with the given TL classification.

Distribution of Dummy Response Data for a Prescribed TL Classification and Body Region

There are two important features of the distribution of dummy response data for a prescribed TL classification and body region that need to be considered. First, the mean value of the child dummy response data for a given injury severity classification and body region is always greater than the child dummy, 50 percent response value. To understand why the mean value is a nonconservative estimate, the procedure used to select the test conditions must be examined. Test conditions were selected to obtain a broad range of child dummy response data for the body regions of the head, neck, thorax and abdomen. It was conjectured that the selection process would result in exposure environments that would produce a wide spectrum of animal injury types and severities, which it did. The test conditions were not selected to determine what levels of the child dummy response would correspond to the thresholds of the various injury severity classifications for the four body regions of the animal population that was tested. Such an approach would have required conducting multiple tests (6 or greater) for many, many levels of child dummy responses. Hundreds of animals and a similar number of inflatable restraint systems would be needed, both of which were clearly inconsistent with the program time frame and resources. With the approach that was used, it is unlikely that any animal was exposed to the exact test condition needed to produce the levels of injury severities that resulted. For this reason, the measured child dummy response values that were paired with the resulting injury severity ratings are greater than (very seldom equal to) the threshold values for the animal. Consequently, the mean value of the child dummy response data for a given injury severity classification and body region is greater than the 50 percent value.

A second important feature is that the distribution of the child response data within a given injury severity classification for a given body region can be highly dependent on the investigator's choice of test conditions. This feature can be illustrated by the following example.

Assume that all the animals have the same well-defined thresholds (child dummy HIC values of 600, 1000, 1500) for TL = 2, 3 and 4 head injuries. With this assumption, all child dummy HIC values between 600 and 999 will be paired with animal TL's of 2 and all HIC values between 1000 and 1499 would be paired with TL = 3 head injuries. The investigator selects his test matrix so that the child dummy HIC values range from 500 to 2000. If he chooses to conduct most of his tests for the TL = 3 range (1000 to 1499) close to the threshold of 1000, then the average for the TL = 3 classification will be close to 1000. However, if he chooses instead to conduct most of his test for this range close to 1499, then the average will be close to 1499. An even distribution of tests over the range will give an average close to 1250. All three of these mean HIC values are dependent on the investigator's choice of exposure environments and are nonconservative estimates of the child dummy 50 percent value for the threshold of TL = 3 injuries, which in this example is 1000.

Overlap of Ranges of Child Response Data of Adjacent Injury Severity Classifications

If in the preceding example the assumption was made that the animals had different thresholds of dummy HIC values for TL = 3 head injuries, then an overlap in HIC values would exist between the ranges of the TL = 2 and TL = 3 injury severity classifications. Let's assume further that the actual ranges of HIC values for the TL = 2 and 3 classifications are 600 to 1000 and 800 to 1500, respectively. Then, for HIC values within the overlap (800 to 1000), an uncertainty exists as to the injury severity level that a given animal might experience. For HIC values within the overlap, estimates of the percent of animals experiencing TL = 2 and TL = 3 head injuries are needed.

One approach to estimating these percentages is to assume that the thresholds of HIC values for TL = 3 injuries are normally distributed within the overlap. Implicit in this assumption is the requirement that the HIC value corresponding to the mid-point of the overlap is the child dummy 50 percent value. To estimate how the

percent of animals experiencing TL = 3 head injuries varies, all the HIC values within the overlap (both those associated with TL = 2 injuries and TL = 3 injuries) are ranked ordered. These HIC values are assigned median ranking values based on their order numbers (5). The lowest and highest median ranking values and their corresponding HIC values are plotted on normal probability paper. A line drawn through these two points provides estimates of the percent of animals expected to experience TL = 3 head injuries for various child dummy HIC values. The median ranking values of the other HIC values within the overlap are not plotted since their distribution can be biased by the investigator's choice of test conditions.

It is possible that the test conditions and/or animals are chosen so that there is no overlap of the HIC values paired with TL = 2 and TL = 3 head injuries. If such is the case, then the 50 percent HIC value is taken as the average of the highest HIC value corresponding to a TL = 2 head injury and the lowest HIC value corresponding to a TL = 3 head injury. The highest TL = 2 HIC value is assigned the median ranking value of 0.2063 and the lowest TL = 3 HIC value is assigned a value of 0.7937. These are the median ranking values for the first and third order numbers for a sample size of three (5).

Both of these approaches have two shortcomings. The lowest HIC value within the overlap will usually be greater than the threshold HIC value for that animal and the highest HIC value will be less than the threshold HIC value for its corresponding animal. Thus, the median ranking value assigned to the lowest HIC value will be somewhat less than the true median ranking value for that HIC value. The reverse is true for the median ranking value assigned to the highest HIC value. The implications of these shortcomings are that the percent of the animals experiencing TL = 3 head injuries is underestimated for HIC values below the 50 percent value and overestimated for HIC values greater than the 50 percent HIC value. For the case where there is no overlap, the reverse of this implication is true, since the roles of the lowest TL = 3 HIC value and the highest TL = 2 HIC value are interchanged in defining the median ranking values. In both cases, the error in estimating the child dummy 50 percent value depends on how close the median rankings assigned to the extreme HIC values are to their true values.

APPLICATION OF MEDIAN RANKING TECHNIQUE TO ANIMAL INJURY—CHILD DUMMY RESPONSE ASSOCIATIONS

A review of the data shown on Figures 1-7 indicates that in most cases there is considerable overlap between the ranges of child dummy responses for the various injury severity classifications for a given body region. Within these overlaps, one must speak of the percent of animals expected to experience various levels of injury severity for a given value of child dummy response. The median ranking technique discussed previously can be applied to these data if the seven classifications of injury severity can be reduced to two. This can be accomplished by defining two groups: significant injuries (TL = 3, 4, 5 and 6) and nonsignificant injuries (TL = 0, 1 and 2). The results of applying the median ranking technique to the data shown on Figures 1-7 grouped in this manner are given in Figures 8-14, respectively. The percent of animals expected to have nonsignificant injuries for a given body region is 100 percent minus the percent estimated to have significant injuries. The curves of Figures 8-14 should not be construed as showing causative relationships, since the analysis is based on associations made of measured child dummy responses and observed animal injuries. These curves can be used to define a set of child dummy response values corresponding to any prescribed percent of significant animal injuries for the body regions of the head, neck, thorax and abdomen.

RELATIONSHIP BETWEEN OBSERVED ANIMAL INJURIES AND POSSIBLE CHILD INJURIES

The curves shown in Figures 8-14 provide estimates of the probable occurrence of significant animal injuries for various levels of measured child dummy responses. What

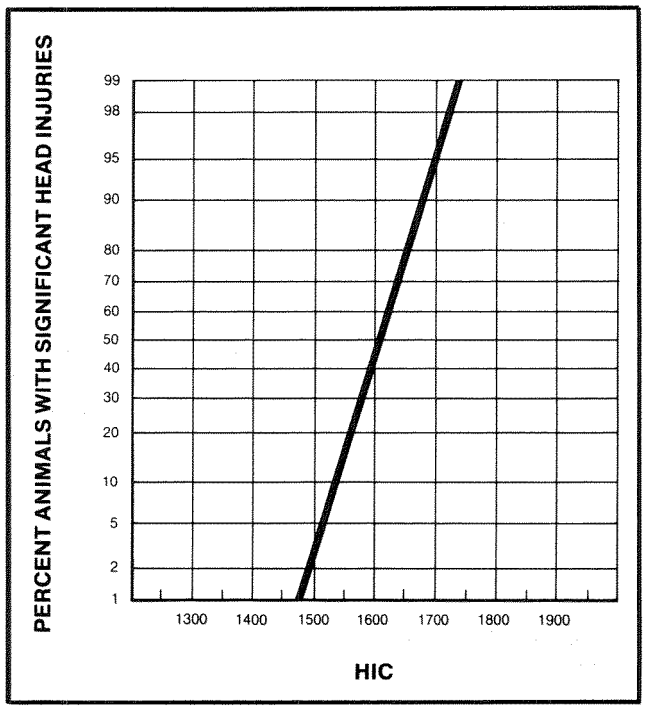


Figure 8. Percent of animals experiencing a significant head injury (TL greater than 2) as a function of child dummy HIC.

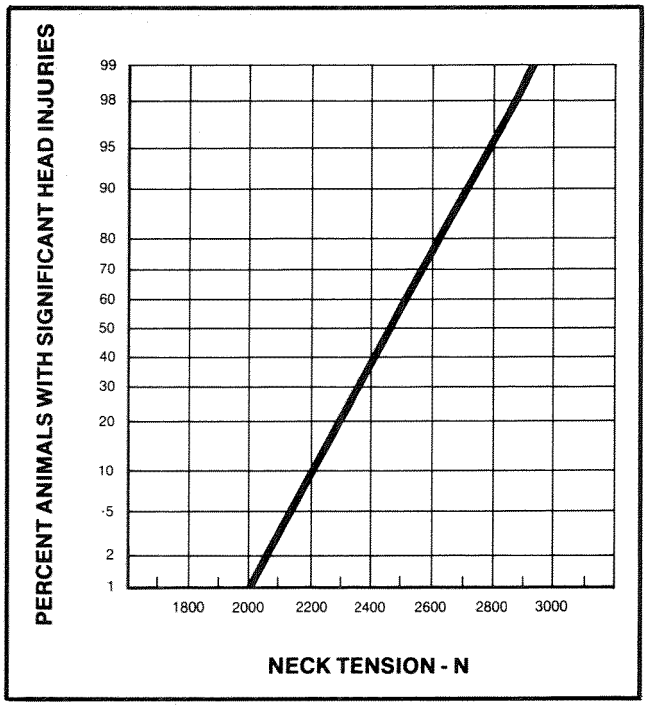


Figure 9. Percent of animals experiencing a significant head injury (TL greater than 2) as a function of child dummy neck tension.

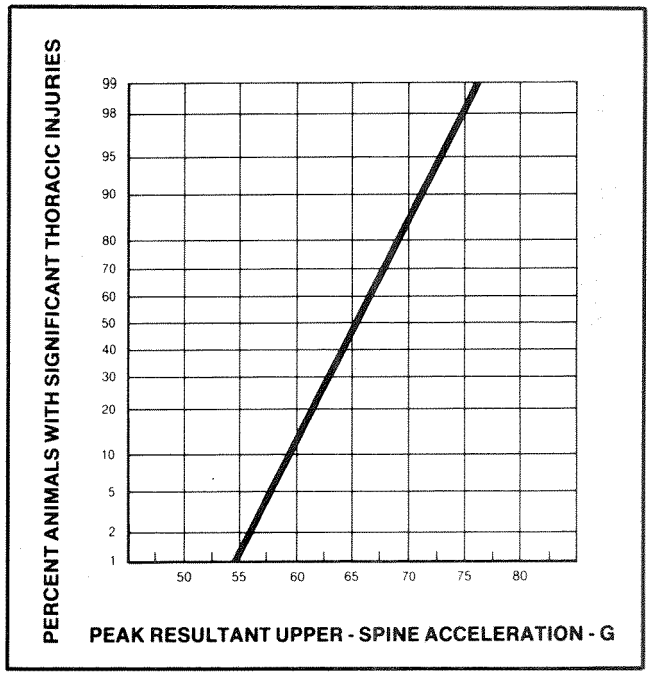


Figure 11. Percent of animals experiencing a significant thoracic injury (TL greater than 2) as a function of child dummy peak upper-spine resultant acceleration.

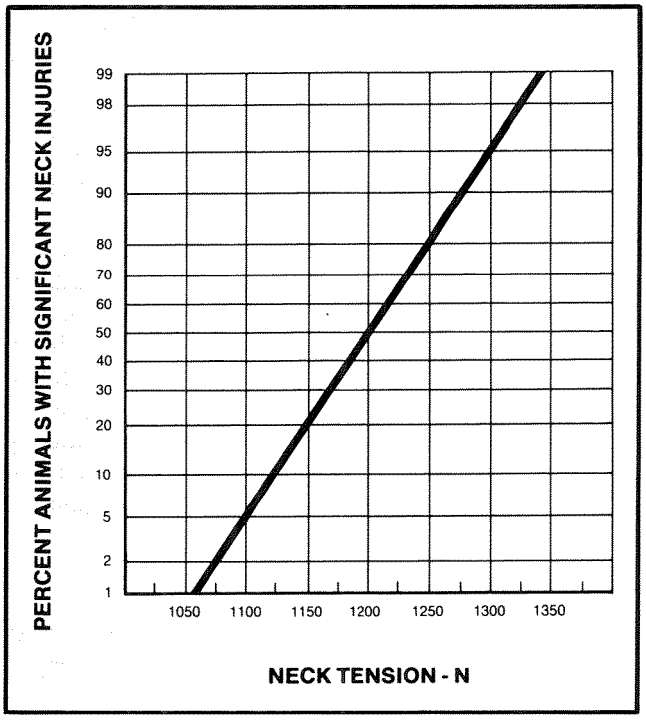


Figure 10. Percent of animals experiencing a significant neck injury (TL greater than 2) as a function of child dummy neck tension.

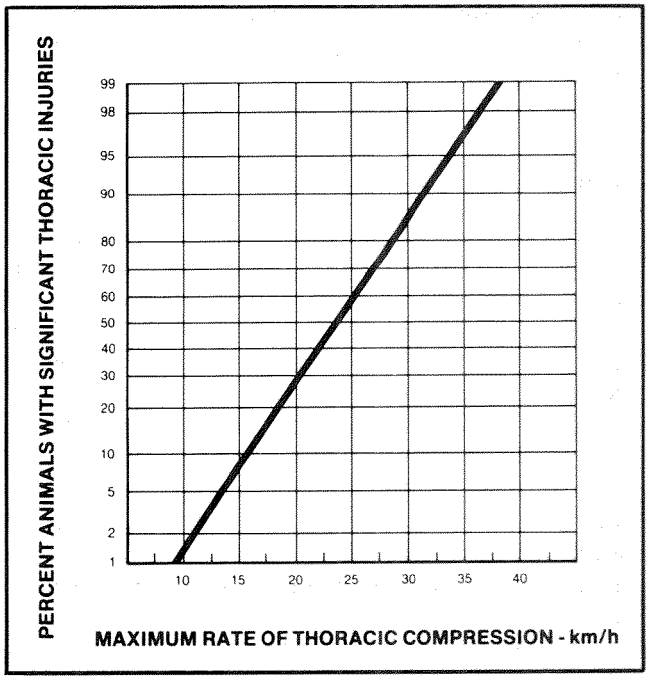


Figure 12. Percent of animals experiencing a significant thoracic injury (TL greater than 2) as a function of child dummy maximum rate of chest compression.

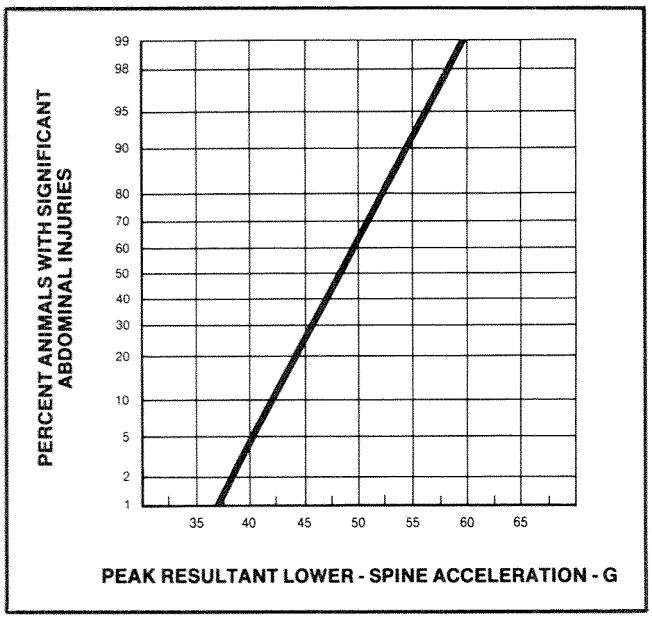


Figure 13. Percent of animals experiencing a significant abdominal injury (TL greater than 2) as a function of child dummy peak lower-spine resultant acceleration.

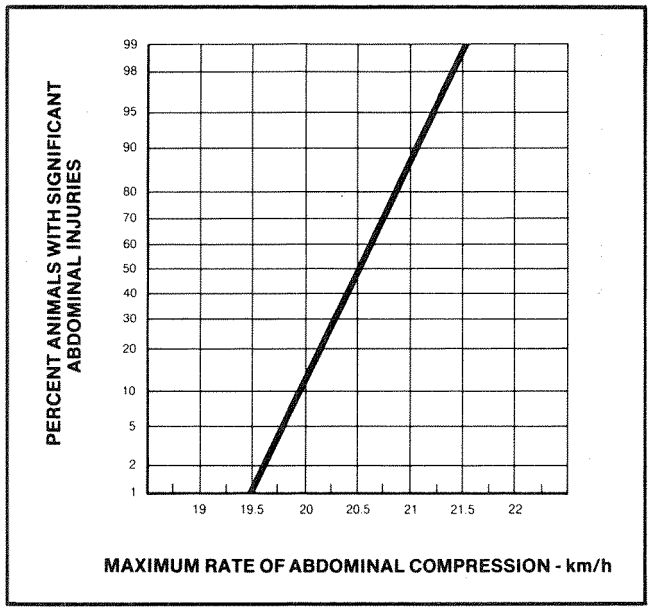


Figure 14. Percent of animals experiencing a significant abdominal injury (TL greater than 2) as a function of child dummy maximum rate of abdominal compression.

is desired are curves giving estimates of the probable occurrence of significant child injuries for various levels of measured child dummy responses. One approach to developing such relationships is to infer the probabilities of significant child injuries from the probable occurrence of animal injuries given by the curves of Figures 8-14. To develop such inferences, a comparison of the geometric, inertial and strength characteristics of the child and the animal must be made.

Animal Species Selection Rationale

The primary considerations used in selecting an animal species for the test program (4) were that its weight and size be comparable to a 3-year-old child, which was the size of the child dummy being used by GM to evaluate various passenger inflatable restraint system concepts. It was reasoned that animal surrogates that had overall geometric and inertial characteristics that were similar to the child would experience similar cushion-collision interaction forces as the child. Three animal species, the chimpanzee, the baboon and the pig, were considered as animal models. Based on comparable size and shape, the chimpanzee was the logical choice. However, chimpanzees could not to be obtained in sufficient quantities to carry out the proposed number of tests. Consequently, only the baboon and the pig were considered as possible child surrogates. While testing was done with both animal species, the majority of the tests were conducted using anesthetized pigs for the following reasons:

1. The pig's thoracic and abdominal breadths compared more favorable to the child's (Table 1). The implication of this consideration is that the thoracic-abdominal cushion interaction would be more comparable to those of the child.
2. The state of physical development of a 15 kg pig was estimated to be quite comparable to a 3-year-old child based on a comparison of human versus pig puberty ages (Table 1). The equivalent child age of the 15 kg pig was estimated to be 4.2 years while that of the baboon was 16.3 years. The implication is that the strength of the anesthetized pig would be similar to that of a child.
3. Based on a limited test program (4) where pigs and baboons were subjected to similar deploying cushion-collision environments, the pig experienced similar, but in some tests, more severe injuries than the baboon. This result is consistent with the previous implication that the physical development of the 15 kg pig is not as advanced as the 15 kg baboon. Using the apparently more injury prone pig would provide a more conservative estimate of the expectation of significant injuries.

Animal Model Deficiencies

There are a number of geometric and response differences between the pig and the baboon, and more importantly between either animal and the child. These differences can influence the interactions between the deploying cushion and the subject, and consequently, affect the resulting injury pattern.

Table 1. Typical size, shape and mass measurements for 15 kg pigs, baboons and children (4).

MEASUREMENT	AVERAGE OF 5 PIGS	AVERAGE OF 4 BABOONS	3-YEAR-OLD MALE CHILD	
			VALUE	REF.*
AGE (YEARS)	0.19	4.3	3	-
EQUIVALENT CHILD AGE (YEARS)**	4.2	16.3	3	-
MASS (kg)	14.9	15.2	14.9	6
SEATED HEIGHT (mm)	746	641	592	6
HEAD-NECK LENGTH (mm)	241	147	226	6
HEAD WIDTH (mm)	111	110	136	6
FORE-AFT HEAD MOTION (DEG)	45	110	105	7
NECK CIRCUMFERENCE (mm)	421	271	243	6
CHEST CIRCUMFERENCE (mm)	529	509	516	6
CHEST BREADTH (mm)	138	110	165	6
CHEST DEPTH TO BREADTH RATIO	1.33	1.44	0.67	6
ABDOMINAL CIRCUMFERENCE AT UMBILICUS (mm)	580	392	486	6
ABDOMINAL BREADTH AT UMBILICUS (mm)	147	125	165	6

NOTES:

* NUMBERS REFER TO PAPERS IN LIST OF REFERENCES.

** EQUIVALENT CHILD AGE = $\frac{\text{HUMAN PUBERTY AGE}}{\text{ANIMAL PUBERTY AGE}}$ × (ANIMAL TEST AGE)

Neither animal's head is geometrically similar to the child's. The pig's head size is comparable to a child's; however, its shape is not due to its snout. The baboon's head is much smaller than a child's, and is characterized by a pronounced muzzle, similar to a dog's head. These characteristics will influence how their heads interact with deploying cushions.

The brain sizes of both animals are much smaller than the child's. Consequently, neither animal is considered a good model for predicting the potential for child brain injury due to direct head impact. However, such impacts were rare events in the test program. The significant head injuries that were produced in the program were massive subdural hemorrhages that appeared to be related to rapid rearward displacement of the animal's head relative to its torso and not to direct head impacts.

For assessing the potential for child neck injuries, the pig has an advantage over the baboon since its head-neck length compares more favorably to the child's. However, both species have a number of major deficiencies as neck injury models. The pig has no chin protuberance for interacting with the deploying cushion since its neck attaches to the rear of its skull resulting in its snout being somewhat aligned with its cervical spine. In contrast, the baboon's neck attaches to the base of the skull similar to the human. However, its long muzzle provides an accentuated, simulated chin protuberance. The fore-aft range of motion of the pig's head-neck structure is much less than the child's, resulting in a smaller degree of rearward motion required to produce a hyperextension neck injury. The baboon can undergo a greater degree of hyperextension than the child. The pig's neck circumference is twice as large as the child's due to its large dorsal neck muscles. However, these muscles had little influence on its head-neck kinematics since the animal was anesthetized. The cervical vertebrae of the pig and child are of similar size.

The pig has a major anthropometric deficiency as a child thoracic injury model in that its chest depth to width ratio is the inverse of the child's (Table 1). Because of this geometric difference, the pig's fore-aft chest stiffness is greater than the child's resulting in greater force levels required to produce compression type injuries to the thoracic organs. This geometric difference could result in the pig underestimating the possibility of the child experiencing thoracic organ injuries due to chest compression. The baboon also has this geometric deficiency.

An in-depth study of the influences of all these various deficiencies is beyond the scope of this paper. A study was undertaken to investigate the influences of the neck deficiencies since significant neck injuries were the most frequent animal injury (Figure 3). The results of that study, when completed, will be the subject of a separate paper.

Interpretations of Measured Child Dummy Responses Relative to Child Injury Potential

The approach used to estimate the possibility of child injuries for GM second-generation, passenger inflatable restraint development program was to assume that a 3-year-old child would experience similar injury types and severities as the anesthetized animals. The curves shown in Figures 8-14 were used to provide a preliminary estimate of the probability of significant child injury based on measured child dummy responses. The final estimates were based on these preliminary estimates, tempered by the knowledge of the various animal model deficiencies discussed previously.

SUMMARY

A technique is given for estimating the potential for significant child injury due to deploying cushion-collision interactions forces based on measurements made with a specially instrumented, child dummy. These estimates should be tempered by the various geometric and response deficiencies noted for the animals that were used as child injury models. This approach proved quite useful in evaluating various concepts of a second-generation, passenger inflatable restraint system that were being developed by GM. The use of this approach should reduce the need for animal testing in any future inflatable restraint development program.

REFERENCES

1. Wolanin, M. J., Mertz, H. J., Nyznyk, R. S., and Vincent, J. H., "Description and Basis of a Three-Year-Old Child Dummy for Evaluating Passenger Inflatable Restraint Concepts", Proceedings of the Ninth International Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, Nov. 1-4, 1982.
2. Patrick, L. M. and Nyquist, G. W., "Airbag Effects on the Out-of-Position Child", SAE 720442, May 1972.
3. Aldman, B., Anderson, A., and Saxmark, O., "Possible Effects of Air Bag Inflation on a Standing Child", Proceedings of the International Meeting on Biomechanics of Trauma in Children, Lyon, France, Sept. 17-19, 1974.
4. Mertz, H. J., Driscoll, G. D., Lenox, J. B., Nyquist, G. W., and Weber, D. A., "Responses of Animals Exposed to Deployment of Various Passenger Inflatable Restraint System Concepts for a Variety of Collision Severities and Animal Positions", Proceedings of the Ninth International Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, Nov. 1-4, 1982.
5. Lipson, C. and Narendra, S. J., *Statistical Design and Analysis of Engineering Experiments*, McGraw-Hill, N.Y., 1973.
6. Snyder, R. G., Schneider, L. W., Owings, C. L., Reynolds, H. M., Golomb, D. H., and Schork, M. A., *Anthropometry of Infants, Children, and Youths to Age 18 for Product Safety Design*, SP 450, SAE, Warrendale, PA, 1977.
7. Diffrient, N., Tilley, A. R., Bradagjy, J. C., "Design Requirements for Infants and Children", *Human Scale (TM) 1/2/3*, MIT Press, Cambridge, 1974.

Clinical and Experimental Studies on Leg Injuries in Car-Pedestrian Accidents

O. BUNKETORP, B. ALDMAN, and L. THORNGREN
Department of Traffic Safety,
Chalmers University of Technology,
Göteborg, Sweden

B. ROMANUS
Department of Orthopaedic Surgery II,
University of Göteborg.

ABSTRACT

Leg injuries in car-pedestrian accidents were analysed and correlated to the speed, the bumper level and the inclination of the car front. The injury mechanisms, not always obvious in these accidents, were studied experimentally with a biomechanical impact system using human leg specimens and a mechanical leg model.

The results from these studies showed a high injury potential of a bumper impacting at or just below the knee level and of a prominent bonnet edge. The experimental studies indicated a possible way to mitigate the injury severity of the impacted lower extremity.

A smooth, compliant, force-limiting and energy-absorbing impact zone with the vertex of the front profile at 35 cm above the ground and a 60 degrees maximum front inclination angle are proposed to lower the risk for serious leg injuries and permanent walking impairment in pedestrians in this type of accident.

INTRODUCTION

The aggressiveness of the vehicle front is an important safety problem in car-pedestrian accidents. Data from real accidents as well as from experimental testing using mechanical or mathematical simulations of the car and the human body have been used to evaluate an optimal car exterior. The bumper and bonnet edge have been shown to be important injury-producing structures (1-15). The majority of the car-pedestrian accidents occur in urban areas and at comparatively low speed. This leads to the assumption that it may well be possible to influence the severity and frequency of pedestrian injuries by rather moderate changes of the front structures of motor cars.

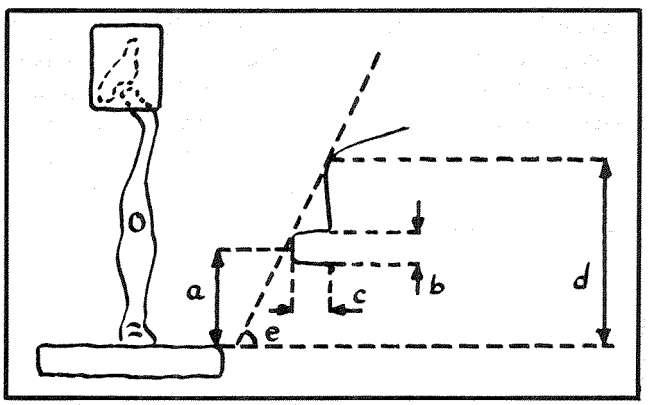
Accident investigations of car-pedestrian collisions have revealed that severe injuries occur in two main areas of the human body: the lower extremity and the head. Of these two types of injuries the head injuries have been considered to be the more important ones to prevent because they are thought to represent a higher risk of having a fatal outcome. The clinical studies referred to in this respect usually describe the short term effects of these injuries as are given by the AIS numbers (16-18). The bumper impacts often cause fractures to the lower extremities. The presence of soft tissue injuries is seldom reported even if this will influence the healing time and final outcome of the injuries. Delayed union of lower leg fractures is known to occur after these injuries.

Leg injuries often prolong the period of hospitalization and rehabilitation because of the difficulties to mobilize

these patients on crutches and different types of knee fixations. The leg injuries may also cause severe social and individual problems. Intraarticular fractures leading to osteoarthrosis are probably more frequent in the knee joint than in the ankle joint and are also more serious than fractures of the tibia diaphysis which usually heal without sequels.

Injuries to the knee joint were seen in only 1.5% in patients injured in car-pedestrian accidents as shown by Weinreich (19). However, knee ligament injuries may occur even at near zero impact velocity and they are easily overlooked during the first period after the accident which may lead to an underestimation of these injuries in accident studies. Intraarticular fractures and extraarticular fractures near the knee joint which influence the joint function in adults and the joint or the epiphyseal growth plates near the knee joint in children may lead to degenerative changes of the joint and permanent impairment. This may also be the result of ligament injuries. Gissane et al. (20) showed that 21% of surviving pedestrian inpatients suffered permanent disability and Baker et al. (21) stressed the importance to create rating systems to classify the injured patient before and after admission and to measure his outcome in all types of accidents. The long-term effects of specific injuries in car-pedestrian accidents remain unknown and have to be studied before final judgments can be made of the aggressiveness of the impact area of the car front.

The injury mechanisms in real car-pedestrian accidents are sometimes obvious: lower leg and knee injuries may be caused by the bumper impact, injuries in the hip and pelvic area by the bonnet edge, and head injuries by the head impact to the bonnet or in the windscreen area. Other details of the impact kinematics are less obvious and this has perpetuated the discussion of how to mitigate the injuries in this type of accident. The first impact of the car influences the kinematics of the body during the later part of the collision and thus also the injuries caused by secondary impacts.



a=bumper level
b=bumper width
c=bumper lead distance
d=bonnet edge height
e=bumper lead angle (front inclination angle)

Figure 1. The experimental set up with a human leg specimen.

The connections between head injuries and the bumper level, the bumper lead angle and the bonnet edge height are not conclusive. Theoretically the car front parameters which determine the body rotation after the primary impact should be the bumper level, the bumper lead angle, and the bonnet edge height. A low mounting of the bumper and a short bumper lead distance, thus, have been recommended to minimize the injuries to the lower leg and knee. On the other hand a low leading edge of the car front may lead to a higher impact velocity of the head against the bonnet. In a mathematical simulation of the body kinematics in a car-pedestrian accident Lestrelin et al. (22) showed a somewhat higher impact velocity of the head if the bumper level was lowered from 50 to 40-35 cm. The same was obtained if the bumper lead angle was diminished. However, the higher risk for head injuries with a lower bumper level and a less steep front inclination has not been verified in any clinical study.

SCOPE

The aim of this paper is to put together the results of the studies undertaken by us so far to correlate the type and severity of leg injuries to the shape and mechanical properties of the vehicle front structures in car-pedestrian accidents. The results refer to adults and are based on a combined clinical and experimental analysis.

METHOD AND MATERIAL

The clinical part of this analysis is based on a retrospective study of 34 adult pedestrians injured by cars and treated at an orthopaedic department in Göteborg, 1975-1976 (23). Information in medical records, interviews with patients and witnesses as well as police reports were used to analyse the accidents and to correlate the injuries to the impact area of the vehicles. Follow-up medical examinations and interviews were made 1-3 years after the accidents. Special interest was focussed on the knee injuries and the walking impairment caused by the impact of the bumper and the car front.

The experimental parts of this research project performed at Chalmers University of Technology were accomplished with a biomechanical leg model system using a human leg specimen and a mechanical leg model impacted by a simulated car front (Fig. 1). The experimental equipment and the test method has been described earlier (24-26).

Two test series were made with human leg specimens. In the first series the specimens were amputated at the mid femur and in the other whole leg specimens including the hip joint were used. One test series was made with the mechanical leg model in which the direct and indirect impact forces in the lower leg and knee could be measured (25).

The injuries produced in these test series were compared with those seen in the real accident study. The possibility to mitigate the leg injuries in this type of accident was estimated.

RESULTS

The descriptions of the different parts of this research program have been presented earlier (23-26). The most important and conclusive results of the studies are synthesized in the following.

The Clinical Study

Injury Distribution and Severity (Table 1). The injuries were multiple in most of the accidents. Half of the injured had two or more fractures. Almost 90% sustained injuries to the lower extremities. In 7 cases (21%) both legs were injured. All head injuries were noted. Minor injuries (AIS = 1) were omitted in the other body regions.

Injuries Related to the Shape of the Car Front. In 33 accidents the injuries to the lower extremity were caused by a direct blow of the vehicle. One pedestrian sustained a knee cap fracture as a result of the fall on the ground after the collision. In another case the victim was overrun by the car after the collision which resulted in several severe injuries. In 28 cases the impact sequence could be reconstructed. In 23 of these the impact was caused by the centre of the car front and in 5 by the front corners.

In these frontal impacts, the bumper level and the bumper lead angle were used as test parameters for injuries in the different body regions. Thus, injuries caused by bumpers below the 40 cm level were compared to injuries caused by bumpers at or above the 40 cm level. In the same way injuries were compared for bumper lead angles below 70° and equal to or above 70°. The bumper level is defined as the "static bumper level," i.e., the distance between the ground to the midpoint of the bumper width when the car is not braking.

Fractures or ligament injuries to the lower extremities were noted in 30 accidents (88%). In 29 of these the injuries were caused by the impact of the car and in 28 accidents injuries were noted at or below the knee level.

Table 1. Injuries in the different body regions.

Body region	Number of patients with injuries in this body region	Percent injured in this region	AIS-range
Head	20	59	1-5
Trunk incl. pelvis	13	38	2-4
Upper extremities	14	41	2-3
Lower extremities	30	88	2-3

The bumper was the most important cause of these injuries. The bonnet edge caused injuries to the thigh and hip. Fractures of the femur diaphysis or the hip were noted in four accidents. In some accidents the bonnet edge may have contributed to the injuries to the knee joint.

Knee condylar fractures or knee ligament injuries were observed if the bumper impacted close to or at the knee level at lower speeds (< 30 km/h). The same type of injuries but more serious ones were seen at higher velocities at the same level of impact. Above 30 km/h very comminuted lower leg fractures also occurred. Impacts by bumpers mounted below 40 cm static level caused low tibia shaft fractures or ankle joint injuries.

Thirteen pedestrians (38%) sustained knee injuries. Seven of these (21%) were intraarticular fractures. If any of these were combined with ligament injuries was not noted in the medical records. In all 7 cases the lateral joint compartment was injured and 5 of these were fractures of the tibial condyle.

In 6 patients (18%) isolated knee ligament injuries were noted including avulsion fractures of the ligament attachments.

The mechanism of the leg injuries caused by the car impact were studied in 27 frontal collisions. The knee injuries (fractures and ligament injuries) related to the static bumper levels and the bumper lead angles are illustrated in Table 2.

Diaphyseal fractures of the tibia and the fibula were seen in 14 accidents (41%). Twelve of these were comminuted and dislocated and 4 were open. The tibia fractures were located 0-13 cm below the static bumper level of the involved car. Severe (AIS = 3) knee injuries were not observed with the bumper level below 40 cm.

Ankle joint injuries were noted in 6 patients (18%). Four of these were fractures. In one of them the fracture was combined with a lower leg fracture on the same side.

Healing Time of Leg Injuries. The healing time in 12 cases that survived with tibia shaft fractures were determined. The variation was 4-34 months. Half of the fractures healed within 8 months. In three of these the impact velocity was below 30 km/h. Fractures of the upper, middle and lower third of the tibia shaft had approximately the same healing time. There was no difference between the healing time of tibia shaft fractures caused

Table 2. Knee injuries (fractures and ligament injuries), static bumper level and bumper lead angle.

Knee injury AIS	Static bumper level < 40 cm	Static bumper level ≥ 40 cm	Bumper lead angle < 70°	Bumper lead angle ≥ 70°
< 2	6	9	1	13
≥ 2	1	11	2	4
$p(\chi^2)$	0.14		> 0.4	

by bumpers above or below 40 cm level. The healing time of the knee and ankle joint injuries were 2-7 months.

Walking Impairment. Four patients who died within one year from the accident as well as 3 patients with injuries only to the upper extremities were excluded from this part of the study. Twenty-two patients with leg injuries were re-examined 1-3 years after the accident when the fractures were healed. Of these 17 had leg injuries caused by car front impacts. The walking impairments of these patients were estimated in relation to their walking capacity before the accident. The following complaints were noted:

A Limited walking range
B Limited staircase climbing
C Limp at walking
D Use of walking aid (stick or crutches)
E Feeling of leg instability.

The patients were divided into two classes, those who complained of 0-2 impairments (I) and those who complained of 3 or more (II). The influence of the bumper level and the impact velocity on the walking impairment is illustrated in Table 3.

Fifteen patients had no complaints from their knee joints. Seven patients had walking impairment caused by knee injuries. In 6 of these the injuries were caused by bumpers at or above the 40 cm level above the ground.

Conclusions. Even if the material is small and the follow-up time is short the following conclusions could be made:

Old pedestrians were more severely injured than younger ones in car-pedestrian accidents.

The main cause of the long time of hospitalization were the leg injuries.

Knee injuries were caused by the bumpers as well as the bonnet edges.

Walking impairment seemed to be correlated to static bumper levels above 40 cm.

The long-term effect of leg injuries in car-pedestrian accidents was not well correlated to the primary injury severity or the impact speed. Further investigations of the long-term effect of leg injuries are needed.

The Experimental Studies

I. The Femur-Amputated Leg Model. During the first part of this project the experimental set up was checked for accuracy and repeatability and a preliminary comparison was made with the injuries seen in the real accidents. Thirty-six experiments were made with a primary leg model using human leg specimens amputated at the femur (24).

Table 3. Walking Impairment, Bumper Level and Impact Velocity.

Impairment Class	Bumper level		Impact velocity	
	<40 cm	≥ 40 cm	<30 km/h	≥ 30 km/h
I	4	4	5	3
II	1	8	3	6
$p(\chi^2)$	0.2		>0.5	

Table 4. Bumper deformation values.

Bumper No.	Type	Impact width cm	Deformation mm	Force kN
A I	Semi-rigid SAAB 99	10	25	1.00
A II	Rigid SAAB 96	3	0	>1.00
A III	Rigid SAAB 96 + 5 cm plastic foam layer	25	45	0.25

A 10 cm wide semi-rigid standard bumper (SAAB 99) was used in 16 experiments and a 3 cm wide rigid standard bumper (SAAB 96) was used in 17. The bumper lead distance was 15 cm. The bumper lead angle was 60 degrees. The bonnet height was 50 cm above the bumper level. A 5 cm layer of plastic foam covered the front. In three experiments one similar layer also covered the rigid bumper and two such layers were used on the front to reduce the bumper lead to zero. The static deformation characteristics of these front structures is presented in Table 4.

The test cart was accelerated to a constant speed before the collision. Its mass was approximately 300 kg. A low (16-17 km/h) or a moderate (23-24 km/h) impact velocity and a low (25 cm) or a high (45 cm) bumper level above the ground were chosen.

Injuries occurred in 31 experiments. In two experiments with legs from people 15 and 16 years of age epiphyseal fractures near the knee were obtained. Some other typical injuries were seen for example: undisplaced malleolar fractures or ankle ligament ruptures associated with a violent tilting of the ankle joint when the leg was hit by the bumper at the lower level and at the lower velocity, comminuted tibia and/or fibula fractures at the impact level when the leg was hit at the lower level and at the higher velocity, ligament ruptures of the knee joint opposite the impact side when the leg was hit at the higher level and at the lower or the higher speed, fractures of the tibial or femoral condyles when the leg was hit by the bumper at the higher level and at the higher velocity. No knee injuries occurred when the leg was hit at the lower level.

The type of injury was not clearly related to the age or sex of the specimens. In three tests in which the smooth and compliant front modification was used (A III) lower bumper forces were recorded, 0.7 kN in all three tests as compared to a mean value of 1.2 kN (0.9-1.7 kN) in the corresponding nine experiments with the two production bumpers. Even if the differences in body weights are taken

Table 5. AIS vs. velocity.

AIS	Velocity (km/h) 17	24	Total
≤2	7	6	13
=3	3	13	16
	10	19	29

$\chi^2 = 3.91$

into account this discrepancy remains. No obvious correlations were noted between the bumper forces, ground friction forces, the accelerations of the foot and leg recorded and the injury ratings in the other experiments, nor did the impact angle seem to matter.

Impact Level, Impact Speed, and Injury Severity. The injury ratings at the two velocities and bumper mounting levels used differed significantly in a X^2-test on the 5% level. This is shown in Tables 5 and 6 for the standard bumper types.

In all three experiments with the smooth and compliant front surface (A III) moderate injuries were noted: undisplaced malleolar fractures and in one case also a partial ligament injury of the knee. All these injuries were given the AIS rating of 2. The difference in AIS rating for this front modification as compared to the production bumpers was not statistically significant when comparing the lower bumper level but it was when comparing both bumper levels.

Conclusions. A bumper impacting at 45 cm level above the ground, which corresponds to the knee level in most adults, caused knee injuries. A bumper impacting at 25 cm level above the ground, which corresponds to the adult mid-tibia level, did not cause knee injuries. At this level the bumper, however, may cause injuries to the lower leg or the ankle joint.

A bumper impacting at the knee level caused severe leg injuries (AIS = 3) more often than a bumper impacting at the mid-tibia level.

The severity of the injuries caused by a rigid metal bumper and a semirigid plastic bumper did not differ significantly. However, by restricting the bumper lead and by making the impact area smooth and compliant the severity rating of the leg injuries was limited to AIS 2 when the impact area was centered to the mid-tibia level and the impact speed was below 25 km/h.

II. The Whole Leg Model. A modified leg model was used in the same type of impact tests between 20 and 30 km/h (25). The leg specimens then also included the hip joint and the lower part of the iliac bone. In most cases the specimens were placed vertically with the knee extended and loaded by a simulated body mass. In some cases the load was reduced to study the influence of the ground reaction forces.

Table 6. AIS vs. bumper level.

AIS	Bumper level (cm) 25	45	Total
≤2	9	4	13
=3	5	11	16
	14	15	29

$\chi^2 = 4.14$

The impact level was 42 or 23 cm above the ground plate, i.e., 2-3 cm below the impact levels used in the earlier tests. A 3 cm wide rigid metal bumper and a specially made 10 cm wide force-limiting bumper was used in these experiments (Fig. 2).

The force-limiting element of this bumper consists of an aluminium tube. This element was mounted between two wooden plates and a 2.5 cm thick polyurethane plastic foam layer covered the front plate. During impact the aluminium tube deformed plastically at a force of about 1 kN. The maximal deformation distance of the tube was 10 cm. The coefficient of restitution of the polyurethane foam layer is 0.4. The mass of the original metal bumper was three times higher than the deformable one. In order to study the influence of the bumper impact separately the bonnet structure was removed in some of the tests.

Nineteen leg specimens were used in 24 experiments. They originated from individuals 47-92 years of age. The influence of the bumper level, the bumper type, the bumper lead angle, and the bonnet edge height was studied.

Rigid Bumper at the 42 cm Level and a Prominent Bonnet Edge. The rigid bumper was used in 5 experiments at the 42 cm level. This corresponds to 6-9 cm below the knee joint. The bumper lead angle was 85 degrees, the bonnet edge height 71 cm, i.e., approximately at the mid-femur level and the impact velocity 20-28 km/h. The specimens were impacted at the anterolateral aspects. In all these cases severe knee injuries were noted. The body mass did not influence the type and severity of the injuries. The injury mechanisms with the bumper and the bonnet edge from one of the experiments in this set up are illustrated in Figure 3.

The probable injury sequence in this case was

1—A transverse fracture below the tibial condyle at

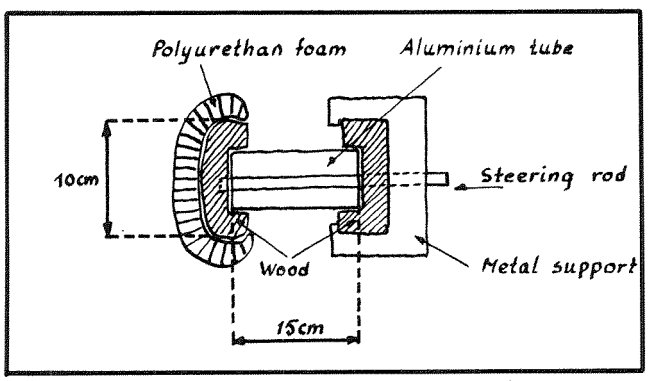


Figure 2. The force-limiting bumper.

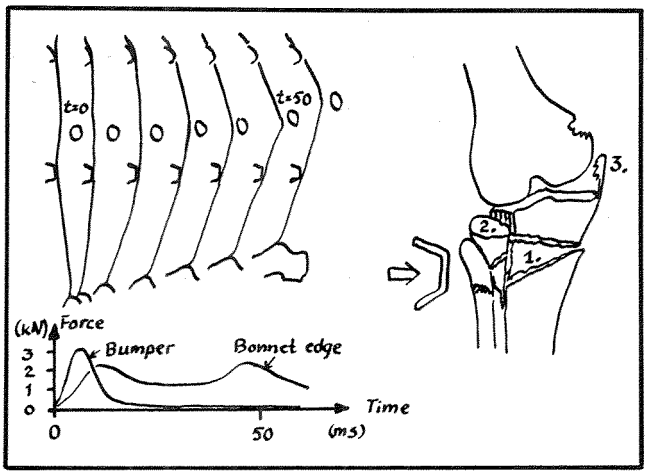


Figure 3. Kinematics and injuries in one of the experiments at 28 km/h with a 42 cm bumper level and a prominent bonnet edge.

the impact level caused by the rigid bumper at 5 ms.

2—A split and depression fracture of the lateral tibial plateau caused by the bumper and/or the bonnet edge at 10 ms

3—An avulsion of the femoral attachment of the medial collateral ligament caused by the bonnet edge at 45 ms.

The injuries 2 and 3 might have occurred in the opposite order but in that case the cruciate ligaments would have been more strained than was seen at the dissection.

Deformable Bumper at 42 cm Level Combined with Less Prominent Bonnet Edge. In 3 experiments the deformable bumper was used at 42 cm level. The bonnet edge height was the same as in the earlier experiments. The bumper lead angle was 60°/75°, i.e., 60 degrees with the tube intact and approximately 75 degrees with the tube compressed. The specimens were loaded with 26 or 45 kg simulated body weight. In these cases somewhat less severe knee injuries were noted compared to the experiments described above. However, the maximum AIS ratings were 3 in all these cases. The injuries in these cases were caused by the bumper but the bonnet edge contributed probably to the outcome.

Deformable Bumper at 23 cm Level Combined with Different Bumper Lead Angles and Bonnet Edge Heights. In 6 experiments the deformable bumper was used at the 23 cm level. The body mass was 45 kg. The bumper lead angle and the bonnet edge height varied. In 2 tests these parameters were 75°/90° and 71 cm, respectively. The knee injuries in these cases were severe (AIS = 3) and caused by the bonnet edge. In 2 other tests a lower bonnet edge (52 cm) and a smaller bumper lead angle (60°/75°) were used. In one of these severe knee injuries occurred. In the other a moderate knee injury was caused. The injury cause in these two cases was shown to be the bonnet edge. In 2 tests the bumper lead angle was 45°/50° and

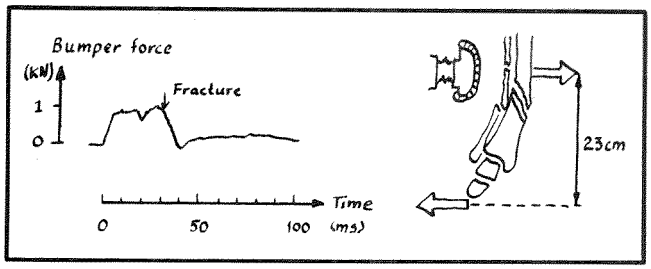


Figure 4. Bumper force and injury in a test with a deformable bumper and a fully loaded leg.

the bumper height 82 cm. No injuries were noted in these cases.

Deformable Bumper at the 23 cm Level and no Bonnet. In 4 experiments the deformable bumper was mounted at 23 cm and the simulated bonnet was removed. The body mass was 71 kg but in one test the load on the platform was reduced to 0.45 kN by lifting the leg. In two of the tests with full load similar types of lower leg fractures were seen. In one other test an undisplaced fracture of the medial malleolus was noted. In the other there was no injury at all. The force-limiting effect of this bumper and the lower leg fracture type is illustrated in Figure 4.

Injuries AIS Related to Bumper Level, Bumper Lead Angle and Bumper Type. For anterolateral impacts the influence of the bumper level, the bumper lead angle and bumper types are illustrated in Table 7.

In three experiments the AIS = 3 injuries were located to the knee joint. They were caused by the bonnet edge and not by the bumper as could been seen on the films. These cases were omitted in this analysis. The 23 cm bumper level caused less severe injuries than the 42 cm level. A deformable bumper and a bumper lead angle below 60°/75° also seemed to cause less severe injuries.

Injuries Related to the Bonnet Edge. The bonnet edge impacted the femur at different levels. The impact tolerance of the femur is greater than that of the lower leg. The highest bonnet edge forces, 4.0 — 7.3 kN, were noted for bonnet edge heights of 71 and 82 cm. Still no injury occurred to the hip or to the femur diaphysis in these tests. In 2 experiments knee injuries were caused during the later part of the impact by the prominent bonnet edge. No injuries were noted with a bumper level of 23 cm and a bumper lead angle of 45°/50°.

Leg Rotation after Impact. The angular velocity of the specimen at 200 ms after impact and the maximal rotation angle were analysed for different bumper levels and bonnet heights. The maximal leg rotation angle caused by the deformable bumper and bonnet edge was compared for the 23 and 42 cm bumper levels. It was greater at the higher bumper level but the difference was not statistically significant. The influence of the bonnet edge height and the bumper lead angle on the leg rotation could not be clearly assessed.

Table 7. Leg injury severity related to bumper level, bumper lead angle, and bumper type.

Injuries max AIS	Bumper level (cm) 23	42	Bumper lead angle (degrees) <60/75	≥60/75	Bumper type Deformable	Rigid
2	3	1	4	2	6	0
3	2	10	2	10	7	5
$P(\chi^2)$	<0.05		<0.15		<0.20	

Conclusions. This improved biological leg model system was found to be able to simulate the kinematics and disclose the injury mechanisms of the lower extremity impacted by a vehicle front in real car-pedestrian accidents.

Fractures of the femur diaphysis and the hip joint were unusual below 30 km/h impact velocity.

High ground friction increased the fracture risk during the simulated stance phase of walking when the leg was impacted at lower bumper levels. The fracture tolerance limit may be below 1 kN in these cases.

A bumper located at or just below the knee level and a prominent bonnet edge were both correlated with increased risk of knee injuries.

A force limiting and energy-absorbing bumper impacting at the lower half of the tibia and a bumper lead angle below 60 degrees reduced the risk of knee injuries.

Lowering of the impact level from 42 to 23 cm reduced the severity of the leg injuries and did not increase the leg rotation after impact.

III. The Mechanical Leg Model. A mechanical model of the adult human leg and knee was constructed (Figs. 5a and b). The description of this model and of the results from the tests with the model has been published earlier (25). The following is a summary of those results.

The following bumper types were used:

B I Metal bumper; no padding; 3 cm impact width

B II Metal bumper; 5 cm polyurethane padding; 5 cm impact width

B III Metal bumper; 10 cm polyurethane padding; 5 cm impact width

The mean bumper forces for different impact levels and paddings at 12 km/h are illustrated in Figure 6.

The peak "ligament" forces for pure bending and for varying impact levels and paddings at 12 km/h are illustrated in Figure 7.

The knee distortion angles for varying impact levels and paddings are illustrated in Figure 8.

The leg angular velocities after impact for various impact levels and paddings at 12 km/h are shown in Figure 9.

Conclusions. The direct impact forces caused by the bumper-leg contact had a maximum when the impact was made near the center of gravity of the lower leg.

The knee reaction forces had a minimum when the impact occurred near the center of gravity of the lower leg.

The knee ligament forces had a maximum for impacts at the knee level.

A padding on a rigid bumper reduced the direct impact bumper force but not the bending forces in the knee.

DISCUSSION

Injury Mechanisms and Clinical Relevance

Impacts on the lower extremity may cause injuries to the ankle joint, the lower leg, the knee, the thigh or the hip. Judging the injury potential of a car front one has to take into account the vulnerability of the impacted parts of the human body as well as the outcome of different types of injuries. Most fractures of the diaphyseal parts of the femur and lower leg heal without permanent impairment although in some cases delayed union and pseudarthrosis occur.

Intraarticular fractures or juxtaarticular fractures or ligament injuries interfering with the joint function should be prevented especially in the knee as these injuries are more difficult to treat and may lead to impaired joint function and osteoarthroses.

The injury mechanisms in real accidents are difficult to determine. In many cases similar injuries were produced in the experiments and a combined analysis of the results from these parts has made it possible to evaluate the injury potential of different car front geometries.

Ankle Joint. Malleolar fractures and ligament injuries of the ankle joint are usually caused by bumper impacts

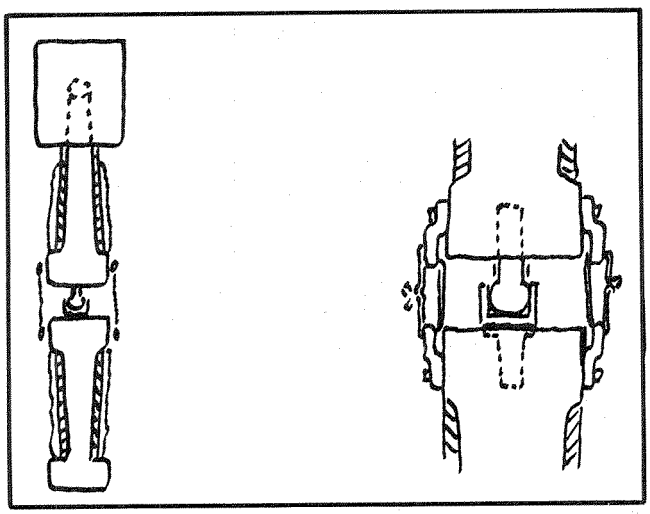


Figure 5a. The whole leg. Figure 5b. The knee joint

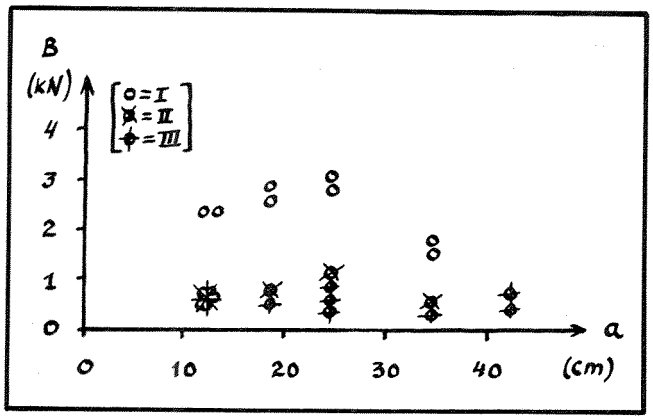


Figure 6. Mean bumper forces B for different impact levels a and paddings at 12 km/h.

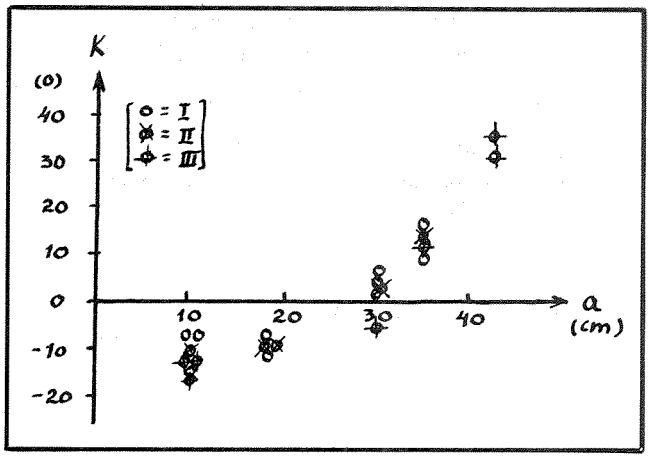


Figure 8. The knee distortion angles K for varying impact levels a and paddings at 12 km/h.

at mid-tibia level. The injury mechanisms are probably a combined action of the shearing force of the distal part of the tibia and the inertia force of the accelerating foot. The severity of these injuries in the experimental investigations were all moderate (AIS = 2) and the fractures should be easily stabilized with a lower leg cast in most real cases.

Lower Leg. The lower leg injuries mostly caused by bumper impacts are soft tissue injuries and fractures at the impact level. A rigid and narrow impact surface concentrates the blow on the leg to a shorter time and a smaller area and what could be called a "high impact speed" fracture may occur. The skin and muscular injuries adjacent to a lower leg fracture are significant and the healing time is longer for this type of injury compared to a "low impact speed" fracture (27). The results obtained in the first experimental study indicated 15 km/h as a lower speed limit below which serious injuries (AIS = 3) would not occur if the bumper impacted at mid-tibia level. The lowest speed for avoiding severe injuries at other impact levels could not be assessed.

Knee. Knee injuries are usually caused by the bumper and sometimes by a prominent bonnet edge. They are seen even at low velocities (< 15 km/h) if the bumper impacts near the knee level. Knee injuries are caused by direct or indirect forces. Hypothetically the impact reaction forces will increase with increased ground friction. This could not be verified with the bumper impacting near the knee level. In this case there was a bending of the leg around the bumper. Although the body mass loaded the leg the impact velocity was high enough to lift the foot from the ground very early in the impact sequence. The conclusion is that the ground friction could have little influence upon the occurrence of injuries compared to the inertia of the leg if the leg is hit at the knee level at above 15 km/h impact speed.

A lower bending stiffness of the leg in the impact direction at the knee level will reduce the bumper impact force and the knee shear force. If the extended leg is hit from the anterior side not far below the knee level the posterior capsule and the posterior cruciate ligament of the knee are most heavily loaded (28). If the lower leg is

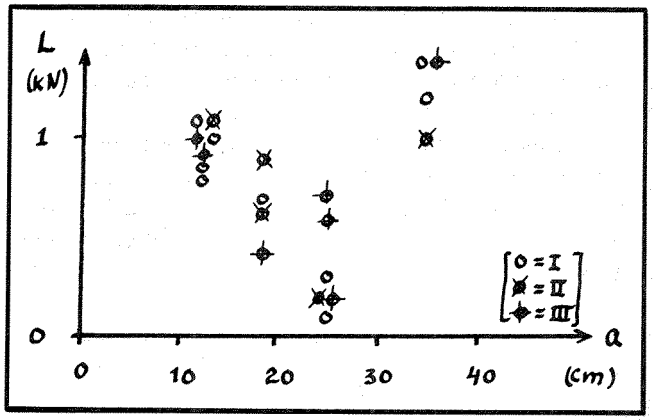


Figure 7. Peak knee ligament forces L for varying impact levels a and paddings at 12 km/h.

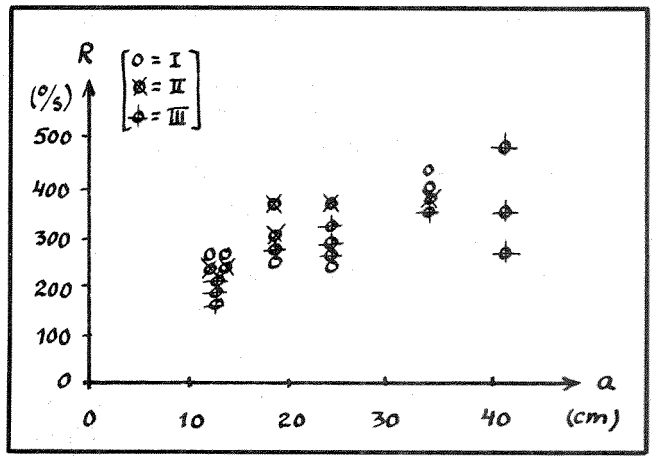


Figure 9. Leg angular velocities R after impact for varying impact levels a and paddings at 12 km/h.

hit in the opposite direction the anterior cruciate ligament is maximally strained. For intermediate impact directions mixed ligamentous and menisceal injuries are possible (28).

The knee joint surface compression force also depends on the parameters mentioned above. A flexed knee seems to be more vulnerable to compression forces as compared to an extended knee according to a biomechanical study by Hirsch and Sullivan (30). Blow fractures of the tibial or femoral condyles combined with injuries in the knee joint caused by bending, shearing and compressive forces are severe as they may lead to permanent instability and osteoarthrosis.

Thigh and Hip. Injuries to the thigh and hip were noted in 4 cases (12%) in the clinical study but not in the experimental one. Fractures of the proximal part of the femur and hip are frequently caused by a fall to the ground in adults. The injury mechanisms may be different in car-pedestrian accidents. The impact velocity must probably exceed 30 km/h for these injuries to occur.

Ground Friction. The ground friction force is important at low impact speeds. Severe ligament ruptures or condyle compression fractures can easily be produced even near zero impact velocities if the force is applicated at the knee level and the foot is pressed against the ground. The friction force may also be important if the impact occurs at mid-tibia level due to the smaller distance between the impact and friction force in this case and to the higher bending stiffness of the leg at this level.

Theoretical Analysis

A theoretical analysis has been made of the bumper-leg impact sequence (31). In this analysis a compound pendulum model was used. The mass and dimensions of this pendulum correspond to an adult human leg. The model was based on the results from the earlier experiments on human leg specimens. The relative values of the mean bumper force at the impact point and the ligament force in the knee joint and the sum of these forces calculated on the basis of this model are illustrated in Figure 10.

The knee reaction forces can be considered as a combination of a shear force component and a bending force couple consisting of a ligament tension force and a joint surface compression force. An axial rotation force and an axial tensile force of the ligaments can also appear as a result of the impact. The total ligament force approximately equals the bending force plus the axial tensile and rotational forces. The axial tensile force will lower the surface compression force.

This theoretical analysis indicates the possibility of minimizing the reaction forces in certain parts of the lower extremity during lateral impacts by choosing suitable impact level. The bending force at the knee joint level of this model has a well-defined minimum when the impact

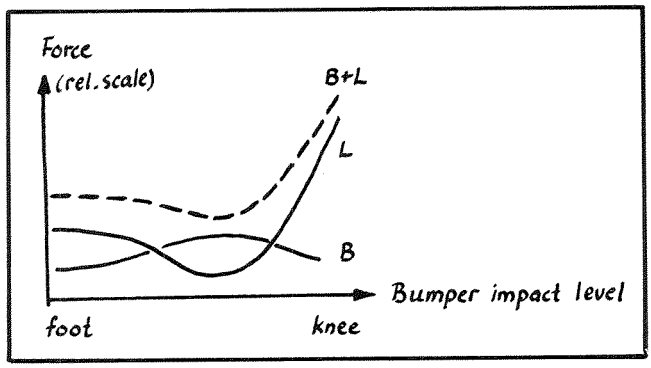


Figure 10. Relative values of the mean bumper force B, the mean ligament force L and the sum of these forces for various impact levels.

occurs near the center of gravity of the lower leg. On the other hand the direct impact force would be higher at this level than at the knee joint level. The sum of the direct impact force and the knee reaction forces probably has a minimum value somewhere between the mid-tibia and the knee joint level. This minimum will be just above the center of gravity of the lower leg.

Proposals for Injury Mitigation in Car-Pedestrian Accidents

The bumper and the bonnet edge are both correlated with severe injuries to the lower extremity in adults as has been shown in these studies. The car front design should be determined by protection criteria against serious injuries at the time of accident as well as against injuries causing permanent impairment. A static bumper level above 40 cm and a bumper lead angle greater than 60 degrees should be avoided. An optimal impact level between 25 and 30 cm for minimal knee and lower leg injuries was suggested in the theoretical analysis of leg impacts and has been shown to lower the risk for severe injuries in the lower extremity compared to a bumper impacting at the knee level. The static bumper level was 0 — 13 cm above the fracture centres in the clinical study. Thus, the optimal static bumper level should be 35 cm for adult pedestrians. This is in good agreement with Stürtz (18).

The impact force can be sufficiently reduced by incorporating deformable material in the impact area. However, this does not significantly lower the risk for knee injuries if the impact is at the knee level. Besides, a higher angular velocity of the body rotation after the primary impact may follow as well, if the elasticity of the impact area is high. An increased risk for head injuries has been feared if the bumper level is lowered (22). However, in the mechanical leg model study an increased leg rotational velocity has not been verified for the 34 cm impact level compared to the 42 cm level. Quite the contrary at impact

levels below 34 cm the angular velocity of the leg seems to diminish. This was also noted in the other test series. A lower bumper level was not correlated with a higher incidence of head impacts in the clinical study either. The body rotation after the primary impact to the car front is probably not governed by the bumper level as much as by the bumper lead distance and the bonnet edge height. Further investigations are needed to answer these questions. There is also a high risk of head and trunk injuries in children impacted by the bonnet edge and thus this parameter should not primarily be evaluated out of leg injury protection criteria in adults only.

Based on the results in these investigations and on the studies presented by Ashton and Mackay (32) and by Pritz (33) the principles for injury mitigating in car-pedestrian accidents are illustrated in Figure 11.

In the model a "pedestrian bumper" with a smooth and soft impact area is mounted on a force-limiting element which can deform plastically below 1 kN. The bonnet edge is not prominent and made deformable for loads below the injury tolerance limit of the body parts impacted by this element, that is the femur and pelvis of adults and the head and trunk of children.

SUMMARY AND FINAL CONCLUSIONS

The results from these clinical and experimental studies are in good accordance with each other. The number of cases in the clinical study is small but the conclusions should be quite reliable as they are not contradicted by any results in the experimental parts.

Based on these studies the following conclusions and recommendations are made:

1) Old pedestrians are more severely hurt than younger ones in car-pedestrian accidents.
2) Leg injuries are the main cause of the long time of hospitalization for adults in car-pedestrian accidents.
3) Fractures of the femur diaphysis or the hip joint are unusual below 30 km/h impact velocity.
4) The bumper is the main cause of injuries to the ankle joint, the lower leg, and the knee in adult pedestrians.
5) Also a prominent bonnet edge may cause knee injuries.
6) A bumper impact at or just below the knee level is correlated with a high risk of serious knee injuries.
7) High ground friction increase the fracture risk during the stance phase of walking if the leg is impacted at lower levels. The fracture tolerance limit may be below 1 kN in these cases.
8) A force-limiting and energy-absorbing bumper impacting at the lower half of the tibia and a bumper lead angle below 60 degrees will reduce the injury severity of the lower extremity in car-pedestrian accidents.
9) Lowering the static bumper level from 45 cm to 35 cm above the ground will reduce the severity of the leg injuries in adults in car-pedestrian accidents.
10) The biomechanical leg model system which has been developed and used in this research program can simulate the kinematics and disclose the injury mechanisms of the bumper and bonnet edge impacts on the lower extremity in car-pedestrian accidents. The equipment can be used as an instrument for rating car front aggressiveness in this type of accidents.

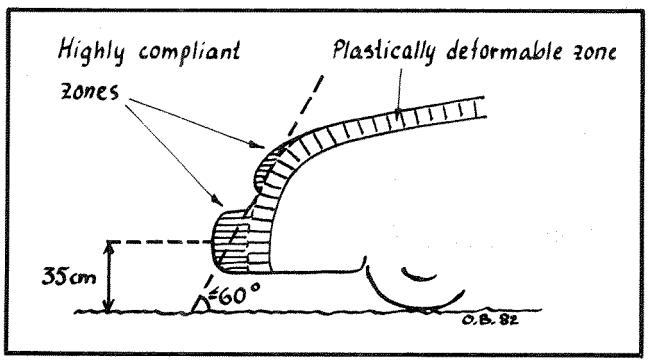


Figure 11. Pedestrian adapted car front.

REFERENCES

1. Fisher, A. J., Hall, R. (1972): The influence of car frontal design on pedestrian accident trauma. Accid. Anal & Prev 4: 47-58.
2. McLean, A. J. (1972): Car shape and pedestrian injury. Proc of the National Road Safety Symposium. Canberra, March 1972.
3. Kramer, M., Burow, K., Heger, A. (1973): Fracture mechanism of lower legs under impact load. Proc of the 17th Stapp Car Crash Conference, Oklahoma, November 1973, pp 81-100.
4. Schneider, H., Beier, G. (1974): Experiment and accident: Comparison of Dummy Test Results and Real Pedestrian Accidents. Proc of the 18th Stapp Car Crash Conf. Ann Arbor, December 1974. pp 26-29.
5. Appel, H., Stürtz, G., Gotzen, L. (1975): Influence of impact speed and vehicle parameter on injuries of children and adults in pedestrian accidents. Proc of the 2nd IRCOBI Conference on the Biomechanics of Serious Trauma, Birmingham, September 1975. pp 83-100.
6. Ashton, S. J., Pedder, J. B., Mackay, G. M. (1976): A review of riders and pedestrians in traffic collisions. Proc of the IRCOBI-meeting on Biomechanics of Injury to Pedestrians, Cyclists and Motorcyclists. Amsterdam, September 1976. pp 129-162.
7. Bacon, D. G. C., Wilson, M. R. (1976): Bumper characteristics for improved pedestrian safety. Proc of the 20th Stapp Car Crash Conf., Michigan, October 1976. pp 389-428.

8. Krieger, K. W., Padgaonkar, A. J., King, A. I. (1976): Full scale experimental simulation of pedestrian-vehicle impacts. Proc of the 20th Stapp Car Crash Conf., Michigan, October 1976. pp 429-464.
9. Kramer, M. (1977): Bestimmungen der äquivalenten Verletzungsschwere in experimentellen Fussgänger-Fahrzeug-Unfällen. Vortschrittberichte der VDI Zeitschriften, Reihe 17, Nr 3, Mai 1977.
10. Weiss, Jr., E., Pritz, H. B., Hassler, C. R. (1977): Experimental automobile-pedestrian injuries. The Journal of Trauma. Vol 17, No 11, 1977. pp 823-828.
11. Padgaonkar, A. J., Krieger, K. W., King, A. I. (1977): A three-dimensional mathematical simulation of pedestrian-vehicle impact with experimental verification. J of Biomechanical Engineering, May 1977.
12. Twigg, D. W., Tocher, J. L., Eppinger, R. H. (1977): Optimal design of automobiles for pedestrian protection. Society of Automotive Engineers, 770094.
13. Ashton, S. J., Pedder, J. B., Mackay, G. M. (1977): Pedestrian leg injuries, the bumper and other front structures. Proc of the 1977 IRCOBI Conference on Impact Trauma, Berlin, Sept., 1977, pp 33-51.
14. Kühnel, A., Rau, H. (1978): The fidelity of dummies in pedestrian collisions. Proc of the 3rd IRCOBI meeting on the Simulation and Reconstruction of Impacts in Collisions. Lyon, September 1978. pp 183-194.
15. Lucchini, E., Weissner, R. (1978): Influence of bumper adjustment on the kinematics of an impacted pedestrian. Proc of the 3rd IRCOBI meeting on the Simulation and Reconstruction of Impacts in Collisions. Lyon, September 1978. pp 172-182.
16. Gotzen, L., Flory, P. J., Otte, D. (1980): Der Fussgängerunfall-Seine Verletzungssituation und Kollisionsmechanik. Unfallheilkunde Vol 83, pp 306-314.
17. Langwieder, K., Danner, M., Wachter, W., Hummel, Th. (1980): Patterns of multi-traumatisation in pedestrian accidents in relation to injury combination and car shape. Eighth International Technical Conference on Experimental Safety Vehicles (ESV), Wolfsburg, October 1980.
18. Stürtz, G. (1981): Das Kind in Verkehrsunfall: Biomechanik, Anforderungen an die äussere und innere Sicherheit von Kraftwagen. VDI-Verlag, Düsseldorf.
19. Weinreich, M. (1979): Der Verkehrsunfall des Fussgängers. Unfallheilkunde Vol 135.
20. Gissane, W., Bull, J., Roberts, B. (1970): Sequele of road injuries. Injury Vol 1, No 3, pp 195-203.
21. Baker, S. P., O'Neill, B., Haddon, W., Long, W. B. (1974): The injury severity score: A method for describing patients with multiple injuries and evaluating emergency care. The Journal of Trauma Vol 14, No 3. pp 187-196.
22. Lestrelin, D., Brun-Cassan, F., Fayon, A., Tarrière, C., Castan, F. (1980): "Prakimod": Mathematical simulation of accident victims. Validation and application to car-pedestrian collisions. Presented at the 8th ESV-Conference, Wolfsburg, October 1980.
23. Bunketorp, O., Romanus, B. (1981): Clinical studies on leg injuries in car-pedestrian accidents. Proc of the 1981 IRCOBI Conference on the Biomechanics of Impacts, Salon de Provence, September 1981. pp 235-242.
24. Aldman, B., Lundell, B., Thorngren, L., Bunketorp, O., Romanus, B. (1979): Physical simulation of human leg-bumper impacts. Proc of the 1979 IRCOBI Conference on the Biomechanics of Trauma, Göteborg September 1979, pp 232-242.
25. Aldman, B., Thorngren, L., Bunketorp, O., Romanus, B. (1980): An Experimental Model for the Study of Lower Leg and Knee Injuries in Car-Pedestrian Accidents. Proc of the 1980 IRCOBI Conference on the Biomechanics of Impacts, Birmingham, September 1980. pp 180-193.
26. Bunketorp, O., Aldman, B., Jonson, R., Romanus, B., Roos, B., Thorngren, L. (1981): Experimental studies on leg injuries in car-pedestrian accidents. Proc of the 1981 IRCOBI Conference, Salon de Provence, September 1981. pp 243-255.
27. Bauer, G. C. H., Edwards, P. (1965): Fractures of the shaft of the tibia. Acta Orthopaedica Scandinavica 36, 1965. pp 95-103.
28. Kennedy, J. C., Grainger, R. W., (1967): The posterior cruciate ligament. The Journal of Trauma, Vol 7, No 3. pp 367-377.
29. Kennedy, J. C., Weinberg, H. W., Wilson, A. S. (1974): The anatomy and function of the anterior cruciate ligament. The Journal of Bone and Joint Surgery. Vol 56-A, No 2, March 1974.
30. Hirsch, G., Sullivan, L. (1965): Experimental knee joint fractures. Acta Orthopaedica Scandinavica 36, 1965. pp 391-399.
31. Bunketorp, O. (1979): Theoretical studies on leg injuries in car-pedestrian accidents. (Unpublished)
32. Ashton, S. J., Mackay, G. M. (1979): Car design for pedestrian injury minimization. 7th Int Techn Conference on Experimental Safety Vehicle, Paris, June 1979. pp 630-640.
33. Pritz, H. B. (1979): Vehicle design for pedestrian protection. 7th Int Technical Conf on Experimental Safety Vehicles. Paris, June 5-8, 1979.

ACKNOWLEDGEMENTS

The clinical studies of this project have been supported by grants by

University of Göteborg
Skandia
Volvo
Förenade Liv
National Association for Victims of Traffic and Poliomyelitis.

The experimental parts of the project were accomplished under a contract entered with the Commission of the European Communities and the Swedish Transport Research Delegation.

Technical Session No. 3

Side Impact Protection

James Hackney, Chairman, United States

Factors Influencing Structural Deformations and Passenger Loads During Lateral Collisions—Results of a Test Series—

RAINER HOEFS
Dr. Ing. h.c.F. Porsche AG
Research & Development Center

ABSTRACT

Side collisions accounting for approximately 10 to 15% of all passenger car accidents and for about 20% of the fatally injured passenger car occupants, play an important part in the overall accident events.

The specific improvement of self protection and partner protection under consideration of overall economic criteria such as cost/benefit factors, requires that the quantitative influence of certain essential parameters on the deformation properties of the vehicle structure and on the occupants' injury severity be determined from accident analyses and corresponding tests.

According to pertinent literature, such essential parameters are the collision speed, the mass ratio of the colliding vehicles as well as the structural stiffnesses (including padding) of the impacting and impacted vehicles.

A test series was performed with the stiffness of the impacted car being constant while one of the other parameters each per test was varied. This is the most obvious difference as compared with other test series, where different mass ratios automatically for example mean also different front end stiffnesses.

The results of these tests are presented and interpreted in the present paper.

INTRODUCTION

According to accident statistics prepared in the FRG, in 1980, 6440 (= 49%) of the killed and 73170 (= 49%) of the severly injured road users were passenger car occupants (1). Of these 6440 occupants, approximately 40% died in frontal collisions, while about 32% were killed in side impacts. As far as the severely injured persons are concerned, frontal collisions account for about 30% and side impacts for almost 50% of the cases.

With view to frontal collision, current knowledge of passenger protection seems to be mostly sufficient and well founded due to extensive research (2, 3, 4, 5, 6). In the area of side impacts, however, there are a couple of problems which still need further investigation. This is mainly true for the influence of the mass and stiffness of the impacting car on the loads acting upon the occupants of the impacted vehicle, which is not yet sufficiently known. It is in this area that basic test data must be provided to serve as a basis and support for the discussion on "compatibility," respectively protection of other road users.

TEST PROCEDURE

The level of the loads acting upon the occupants of the impacted vehicle are particularly influenced by the collision speed, the masses of the vehicles involved and the stiffness of structures and paddings (7, 8). In the present test series only one of the parameters of mass, front structure stiffness of the impacting car, and impact speed was varied per test, while the side structure stiffness of the impacted vehicle remained unchanged throughout the entire test series.

TEST VEHICLES

The test series was performed using a Porsche 924, whose side and front structures as well as the bumper arrangement were European standard. Former publications have already confirmed the transferability of test results obtained with wedge-shaped vehicle fronts to pontoon-shaped configurations (9).

The modifications aimed at weakening the vehicle front structure are shown in Figure 1. They consist in cutting up the front longitudinal member over a length of approximately 400 mm, in reducing the bumper cross section, and in softening the bumper mounts.

TEST DUMMIES AND RESTRAINT SYSTEMS

In both, the impacting and the impacted vehicle, HII Part 572 dummies were used on the drivers' and front

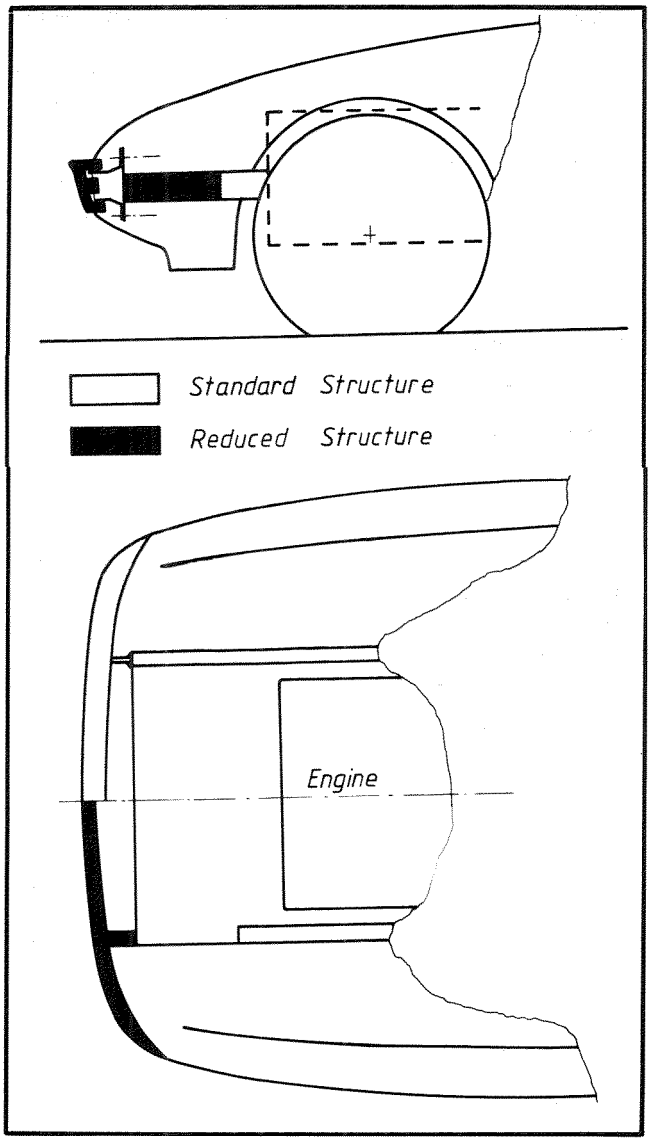


Figure 1. Measures for reduction of front structure stiffness.

passengers' seats and fastened by means of standard automatic three-point belts.

The use of HII dummies in the impacted vehicle was critical but justified by the fact, that they allowed comparison with other investigations. Anyway, no HSRI or APR-Side-Impact dummies were available at the period of testing.

A research project under way today is expected to furnish interpretation aids with view to real-life traffic accidents (10).

TEST MATRIX

Figure 2 shows the parameter combinations investigated in the course of 7 side impact tests. The basis is provided by tests with standard cars (European standard version) of identical masses performed at 30, 40, and 50 km/h.

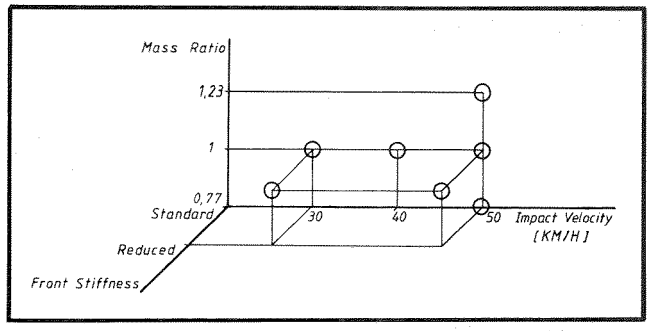


Figure 2. Parameter combinations tested.

The influence of different mass ratios was examined at an impact speed of 50 km/h, while the effects of the about 50% lower front stiffness on the occupants of the impacted car were determined at 30 and 50 km/h.

The 90° side impact was arranged in such a way that the centerline of the impacting vehicle hit the SR-point of the standing car.

MEASURING AND EVALUATION PROCEDURE

Dummy loads

The head, chest, and pelvis accelerations of the dummies in the impacted car was triaxially recorded.

For evaluation purposes, the resulting acceleration figures of head, chest, and pelvis, i.e., maximum acceleration and 3 ms acceleration were determined. From these values the HIC of the head and the SI values for chest and pelvis were derived.

The dummy loads in the impacting car were not measured, since they are known to be uncritical.

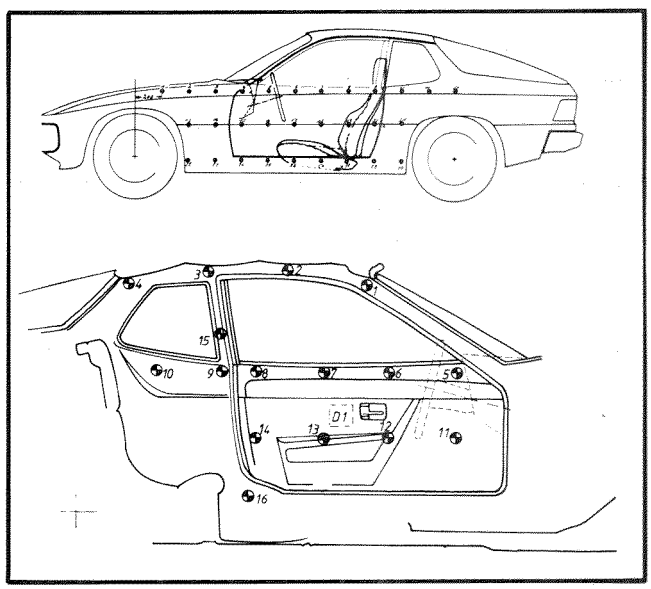


Figure 3. Measuring points for determining outside and inside vehicle deformation.

Vehicle Values

Prior to the test, the side of the car to be hit was measured inside and outside in accordance with a given screen (Figure 3). During the test, the accelerations at the center tunnel, the A and B pillars, and the door sill of the opposite side were recorded in transverse direction. The deformation time of the side structure was measured by means of a distance potentiometer installed between the two inner door panels.

In the impacting vehicle, the deceleration at the tunnel as well as the overall statical deformation were determined.

Energy Calculations

Using the impact kinematics, the impact number κ (1) and the deformation energies of both vehicles (2) were determined from the measured values:

$$\kappa = \frac{v_2' - v_1'}{v_1 - v_2} \qquad (1)$$

$$E_{DEF} = \frac{m_1 \cdot m_2}{2(m_1 + m_2)} \cdot v_1(1 - \kappa^2) \qquad (2)$$

Equation (2) does not show the distribution of the deformation energy to the front and side structures. In order to precisely define the deformation energy absorbed by the side structure, the following approach was chosen: The forces causing a deformation of the vehicle front in a 0° wall impact are identical with those forces causing a commensurate frontal deformation during a side collision. So, the energy/deformation characteristics of the wall impact can be transferred to the side collision.

Thus the deformation energy of the impacting car is calculated by determining the amount of energy required for the measured maximum frontal deformation (Figure 4).

With this approach, the deformation energy of the vehicle side structure is obtained from:

$$E_{SIDE} = E_{DEF} - E_{FRONT} \qquad (3)$$

Table 1. Dummy loads in a 0° wall impact, impact velocity 50 km/h.

		Standard Front structure stiffness		Reduced Front structure stiffness	
		driver	passen-ger	driver	passen-ger
A 3ms head	(g)	61	66	93	90
HIC		357	821	1073	1100
A 3ms chest	(g)	36	50	54	43
A 3ms pelvis	(g)	46	52	59	56
F max femur	(kn)	1.7	1.2	3.5	3.3

RESULTS OF 0° WALL IMPACTS

The wall impact tests were meant to determine the force-deformation characteristic and energy absorption obtained by the front structure modification on the one hand and to examine the influence of the weakened structure on the dummy load on the other. The basic test was a 0° wall impact performed with a standard Porsche 924 at an impact speed of 50.2 km/h. The dummies were restrained with automatic three-point belts.

DUMMY LOADS

As had been expected, the dummy loads in the car with reduced front stiffness are higher than in the series vehicle, but except for the head load none of the values exceeds the limits for the frontal impact (Table 1). The HIC of 1073 (driver) and 1100 (front passenger) is slightly higher than the limit value, though lower than HIC 1500 which is nowadays in discussion (11) as a tolerable level.

VEHICLE FRONT STRUCTURE

The change of the passenger compartment deceleration as a consequence of the above-mentioned measures can be seen in Figure 5. The deceleration up to a deformation time of approximately 30 ms is lower than in the basic

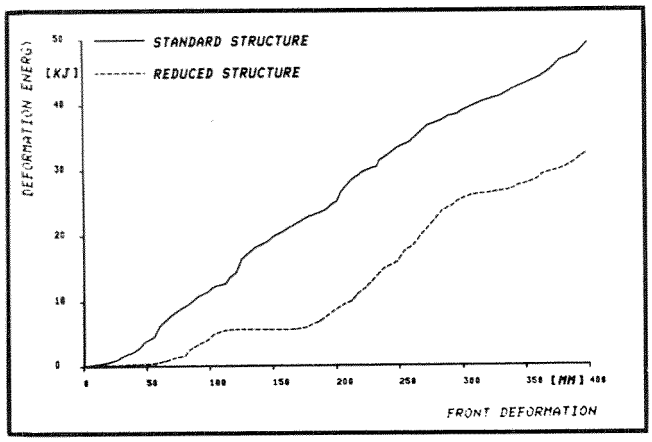


Figure 4. Deformation energy versus deflection in a 0° wall impact, impact velocity 50 km/h.

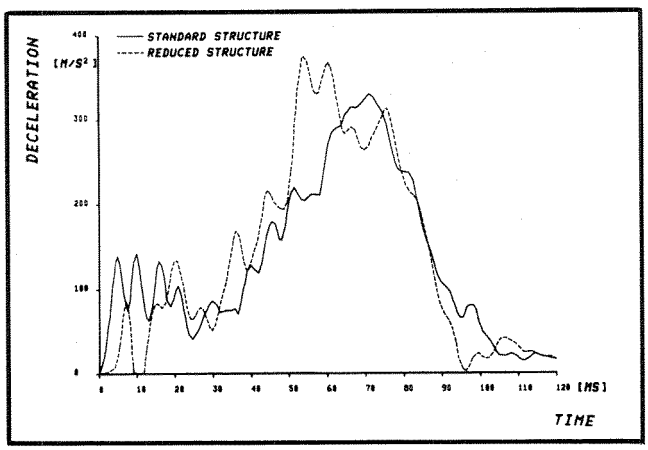


Figure 5. Deceleration of passenger compartment versus time in a 0° wall impact, impact velocity 50 km/h.

test, whereas the maximum value of 374 ms^{-2} is 13% higher than the basic test value and occurs about 15 ms earlier. The energy-deformation characteristic calculated from this curve is given in Figure 6. The area of frontal energy absorption which is of special interest in the case of side impacts (up to deformation distances of 400 mm), clearly shows, that, as compared with the standard vehicle, about twice the deformation distance is available for identical energy absorptions. This means that the initial force level is reduced by approximately 50%.

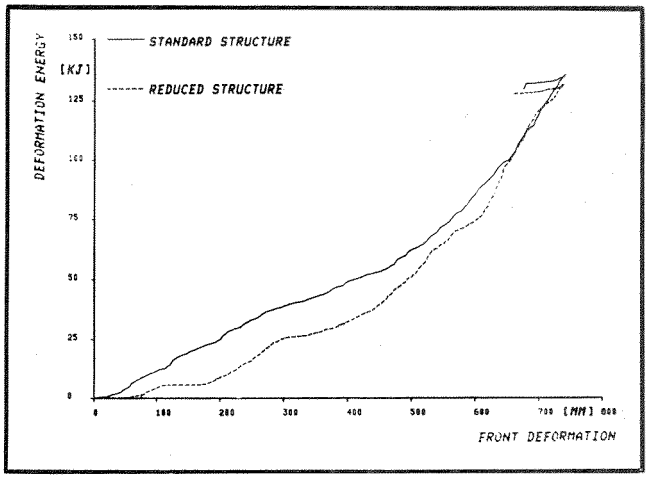


Figure 6. Deformation energy versus deflection in a 0° wall impact, impact velocity 50 km/h.

RESULTS OF SIDE COLLISIONS

Table 2 summarizes the most important vehicle and dummy data. The following evaluation only deals with the measured values of the dummy sitting at the impacted

Table 2. Car and dummy results in side impact tests.

Impacting car							
V0 (km/h)	32.9	40.67	53.1	49.38	32.96	50.34	50.7
M1 (kg)	1368	1379	1381	1063	1382	1380	1710
Max. defor (mm)	82	132	165	150	230	390	220
Deform. energy							
Front (nm)	10000	17300	21500	20000	13000	32000	30000
Remarks	—	—	—	—	Reduced structure	Reduced structure	—
Impacted car							
M2 (kg)	1365	1375	1374	1383	1373	1382	1390
Max. deform.							
Outside (mm)	264	397	403	321	229	305	408
Inside (mm)	188	284	268	254	157	219	271
Deform. energy							
Side (nm)	18368	26310	52885	35707	15063	34010	43951
Kin. Ener. (nm)	57127	87999	150227	100000	57923	134918	169591
Mue (M1/M2)	1.00	1.00	1.01	0.77	1.01	1.00	1.23
Dummy							
Impacted side	H II	H II	H II	H II	H II	H II	H II
A head max	19	34	49	38	18	31	25
A head 3ms	19	33	43	37	17	30	24
HIC	19	150	298	180	32	106	66
A chest max	23	60	82	57	26	35	38
A chest 3ms	23	49	63	41	22	32	33
SI	48	203	468	239	44	124	115
A pelvis max	39	68	98	93	17	31	109
A pelvis 3ms	35	62	88	76	17	27	91
SI	106	456	909	549	23	96	633
Dummy							
Opposite side	H II	H II	H II	H II	H II	H II	H II
A head max	13	24	34	19	13	110*	32
A head 3ms	13	24	32	19	13	39*	29
HIC	22	23	107	35	15	178*	97
A chest max	11	53	66	29	14	46	47
A chest 3ms	11	41	54	24	11	34	42
SI	10	102	886	47	9	68	116
A pelvis max	11	18	27	18	8	25	19
A pelvis 3ms	11	18	26	18	8	24	19
SI	15	35	80	39	10	59	52

*Contact driver-passenger.

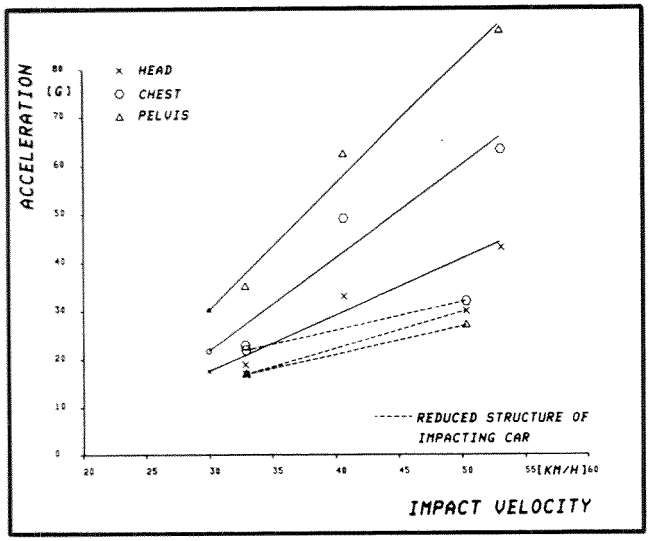


Figure 7. Results (3 ms values) of dummy accelerations (impacted side) versus impact velocity.

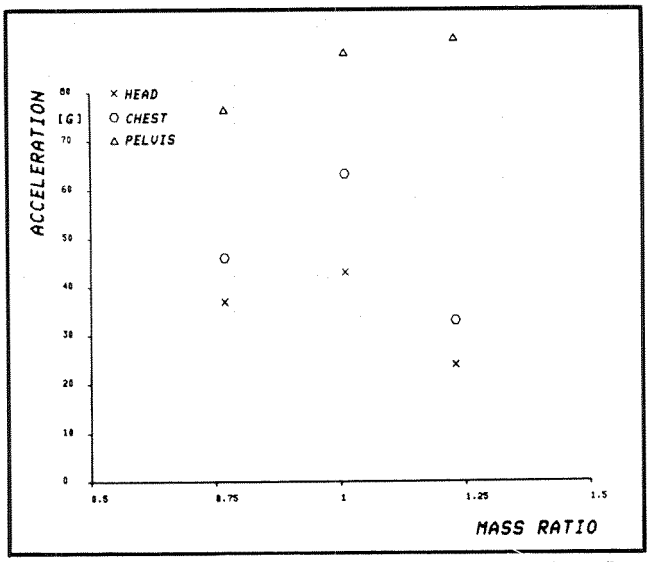


Figure 8. Result (3 ms values) of dummy accelerations (impacted side) versus mass ratio.

side. The loads acting on the dummy at the opposite side are generally low since there is no direct force transmission through body components, provided that there is no contact between the driver and the front passenger. In the present context, these values can therefore be neglected.

DUMMY LOADS

Tests performed with standard vehicles, having a mass ratio of $\mu = 1$, show similar results as the HII dummy tests: the pelvis is more heavily loaded than the thorax, which in turn undergoes stronger loads than the head. This order is the same for the three test speeds (Figure 7).

In those tests, where the front stiffness of the impacting car is reduced, so little difference between the head, chest, and pelvis figures was found, that it would not be reasonable to try and stipulate an order.

At an impact speed of 33 km/h, only the pelvis load is clearly reduced, with the 3 ms-value being lowered from 35 g to 17 g.

At a collision speed of 50 km/h, the dummy load reduction is more pronounced: the chest loads are halved to 32 g, while the pelvis loads are reduced by more than two thirds to 27 g.

The mass influence was examined in three tests performed with standard vehicles at a speed of $v_o = 50$ km/h (Figure 8). It is noticed that the pelvis values only increase with mass ratio "μ", while the chest and head values are lowest when "μ" reaches its maximum. Since this result does not seem to be plausible, it must be conservatively interpreted in saying that apparently the dummy loads do not depend on the mass ratio of the "μ" examined herein. This statement confirms results obtained by other authors (e.g. (7)).

Figure 9 shows effects of the frontal stiffness on dummy accelerations for various deformation energy levels of the vehicle side structure. With identical side deformation energy and reduced frontal stiffness, the head and chest accelerations are slightly reduced while the pelvis acceleration decreases considerably.

If the impacting vehicle has a standard frontal stiffness, the dummy values in the impacted car increase steeply versus the deformation energy of the impacting car (Figure 10). This increase is less pronounced if the frontal stiffness of the impacting car is reduced. This is to be attributed to the change in the energy distribution between

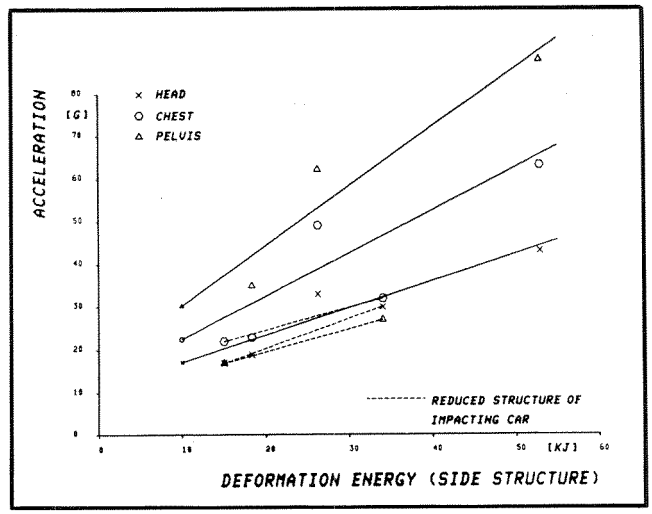


Figure 9. Results (3 ms values) of dummy accelerations (impacted side) versus deformation energy of side structure.

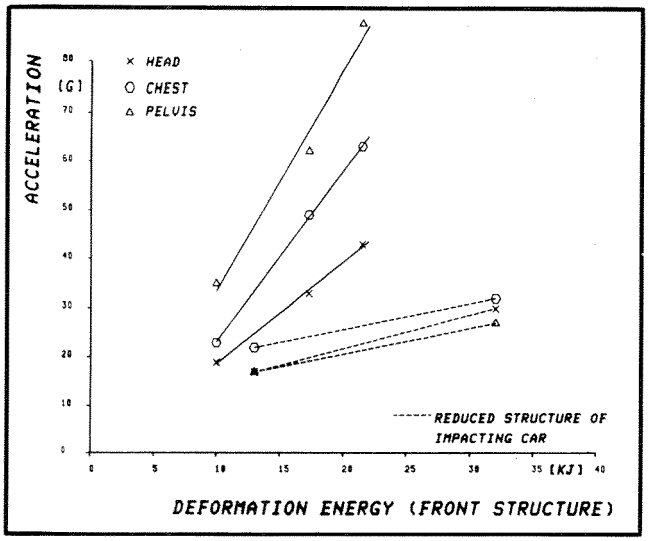


Figure 10. Results (3 ms values) of dummy accelerations (impacted side) versus deformation energy of front structure.

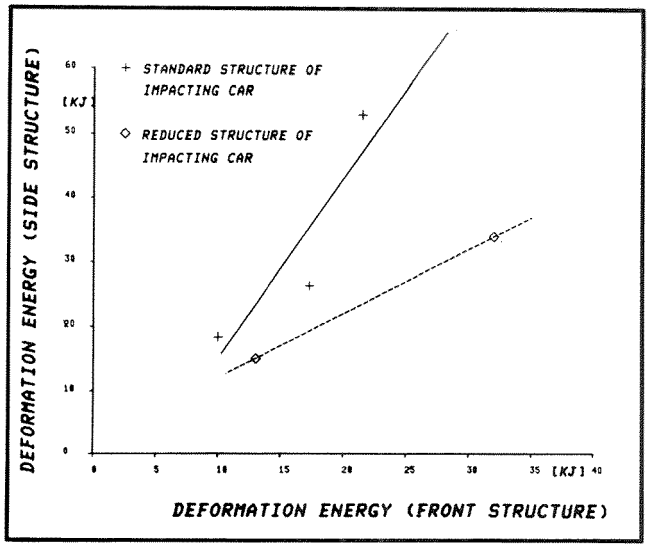


Figure 12. Deformation energy of side structure versus deformation energy of front structure.

the impacting and impacted vehicles: Instead of the original 35%, the impacting car with reduced frontal stiffness now absorbs about 47% of the total deformation energy in frontal deformation. This means that the deformation energy of the vehicle side is reduced by the same amount, resulting in lower dummy loads.

VEHICLE SIDE STRUCTURE

The evaluation of the vehicle side structure is based on the maximum side deformation distances, the deformation energies, and the deformation times. It is noticed that the lateral deformations show a linear increase with increasing energy absorption (Figure 11).

For standard vehicle combinations the deformation energies split up into ⅓ absorbed by the impacting car and ⅔ absorbed by the vehicle hit. By weakening the front structure the deformation energies generated at the given test speeds were almost evenly distributed to both cars (Figure 12).

At the same time, also the deformation time response changed (Figures 13, 14): approximately 30 ms after the impact, the intrusion of the inner door side is interrupted for 15 to 30 ms, the period during which the dummies hit the door. By structural modifications of the impacting car the impact velocity $\Delta v_{\text{passenger-door}}$ could be substantially reduced (Figures 15, 16).

CONCLUSIONS

According to the results of the present test series the loads acting on the dummies in the impacted vehicle can

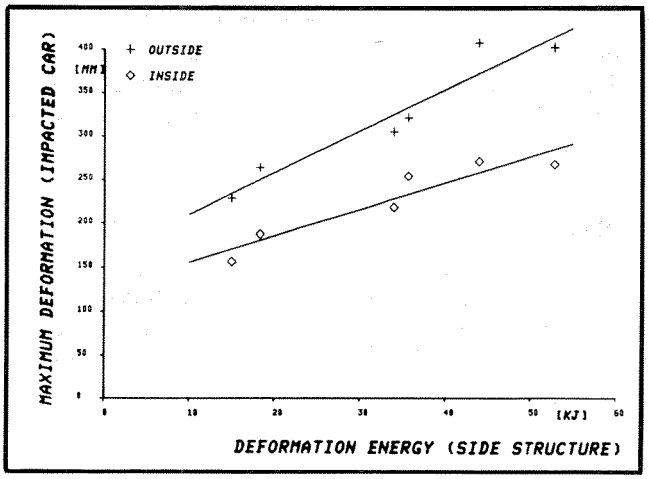


Figure 11. Maximum deformation of the impacted car versus deformation energy of the side structure.

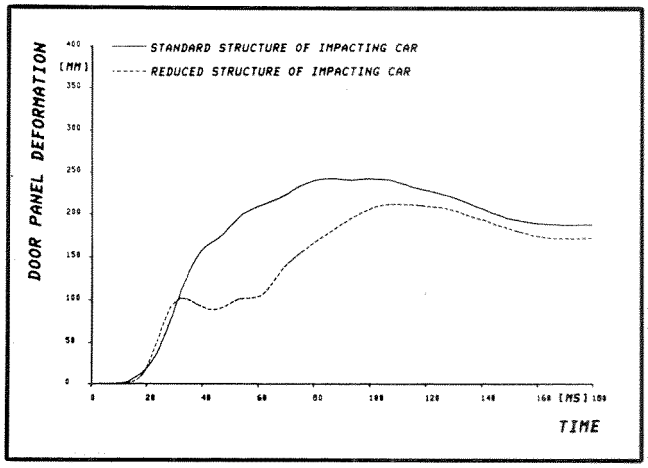


Figure 13. Deformation of inner door panel versus time, impact velocity ~ 33 km/h.

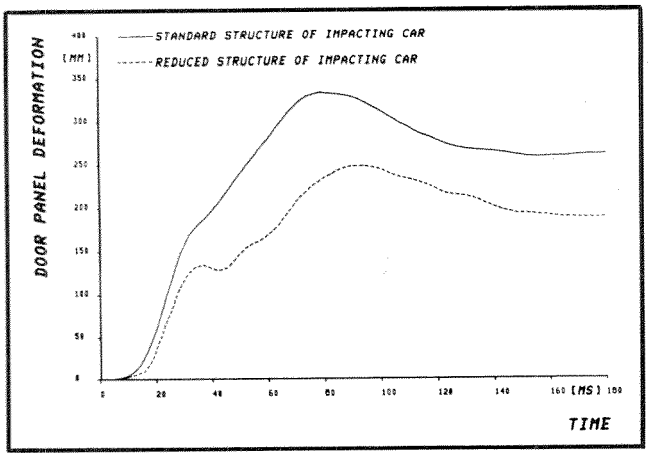


Figure 14. Deformation of inner door panel versus time, impact velocity ~ 50 km/h.

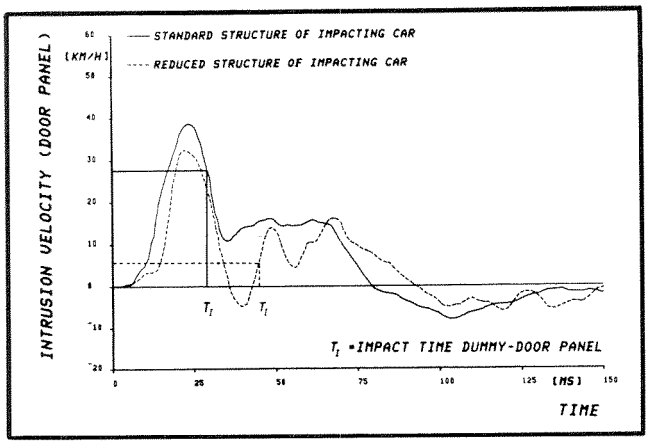


Figure 16. Intrusion velocity of inner door panel versus time, impact velocity ~ 50 km/h.

be distinctly reduced by weakening the frontal structure of the impacting car. Additional potential for further reducing the passenger loads is offered by improvements of the side structure and installation of energy-absorbing paddings inside the impacted car, which were not taken into consideration in the present tests.

In the tested range, the mass ratio apparently has no clearly definable influence on the dummy values. The mass ratio range chosen for the present tests considers the real-life mass differences between vehicles of the same type, which are attributable to different payloads.

The dummy values measured in the 0° wall impact suggest that the occupants of a vehicle with weakened front structure are more heavily loaded than in a standard car, but the evaluation of a possible resulting increase in injury severity is highly difficult, since it is impossible to foretell whether, parallel to the stated increase of the dummy values, the injury severity in real accidents will also go up by one or even more AIS codes (12).

Technical devices suited to lower the loads on vehicle passengers during frontal collisions, such as belt retractors

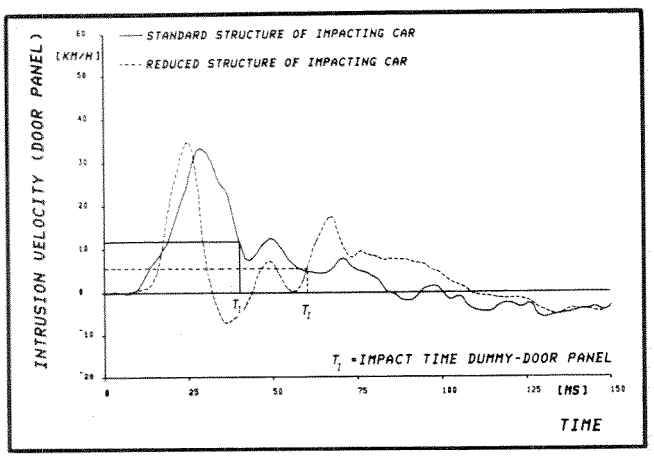


Figure 15. Intrusion velocity of inner door panel versus time, impact velocity ~ 33 km/h.

for example, are sufficiently known as being efficient and feasible (13, 14), so that an increase of the individual passenger risk during a frontal collision can be avoided by appropriate combination of structural measures and restraint systems.

The requirement for improved protection of other road users could be met by modifying existing safety regulations, i.e., for example by reconsidering the wall impact speed which serves to confirm the occupant protection during frontal collisions in dependence on the vehicle mass. The speed limit of less than 30 mph or 50 km/h respectively for upper class vehicles indeed increases the injury risk, depending on the respective vehicle structure.

On the other hand the demand to design vehicle structures, restraint systems, seats, and paddings in such a way that sufficient occupant protection be ensured during collisions at 35 mph or more against a rigid wall is in contradiction to the above requirement for increased partner protection. Time has come to stipulate priorities with view to these contradictory requirements, while taking into consideration necessary marginal conditions and criteria, such as ethical restrictions (no increase of the injury risk in frontal collisions), cost-benefit aspects, etc.

In doing so, the actual safety level reached should be maintained, i.e., restrained passengers should survive frontal collisions with vehicle velocity change of $\Delta v \sim 50$ km/h uninjured or only slightly injured.

SUMMARY

In the side impact tests the parameters of impact speed, structural stiffness of the vehicle front, and mass ratio where combined in such a way that only one parameter each was changed per test, while the others remained constant.

When interpreting the dummy loads it must be kept in mind that the tendency shown in the results can be considered as being confirmed, but that they cannot be

transferred to the injury severity in real accidents as long as there is no sufficiently precise correlation between dummies and human beings.

Head, chest, and pelvis acceleration increase with the impact speed, the pelvis showing the greatest acceleration values, followed by the head and the thorax, the latter displaying the lowest acceleration.

By reducing the initial frontal stiffness of the impacting car for deformation distances of up to 400 mm (which are of particular interest for side collisions) by approximately 50%, all measured dummy accelerations could be considerably lowered. This is to be attributed to a change in the deformation distance time response on the one hand to the increased energy absorption by the vehicle front in combination with lower energy absorption of the side structure on the other.

There are no indications for a relationship between the dummy loads in the impacted car and the mass of the impacting vehicle in the range of $0{,}77 < \mu < 1{,}23$.

Due to the weakened front structure, a frontal wall impact at 50 km/h will produce somewhat higher loads on the vehicle occupants, though the chest and pelvis values will be lower than the actually applied limits.

The HIC values are clearly lower than the limit of 1500, which is nowadays in discussion.

For further investigation of the conflicting objectives of improved partner protection on the one hand and enhanced self-protection on the other, uniform generally acknowledged marginal conditions and criteria must be stipulated. But the actually achieved safety level of our vehicles must remain unaffected.

REFERENCES

1. Statisches Bundesamt Wiesbaden, Straβenverkehrsunfälle 1980.
2. "Belastbarkeitsgrenzen des angegurteten Fahrzeuginsassen bei der Frontalkollision", FAT—Schriftenreihe Nr. 15.
3. Langwieder, K.: "Reduzierung von Verletzungen und Änderungen des Verletzungsbildes durch Anlegen der Sicherheitsgurte", Unfall—und Sicherheitsforschung Straβenverkehr, Heft 10, 1977. Herausgegeben im Auftrag des Bundesministers für Verkehr von der Bundesanstalt für Straβenwesen.
4. Scholz, H. J.: "Die Entwicklung des produktionsreifen Mercedes Benz Airbag-Systems für den Einsatz in den USA", VIII. ESV-Konferenz, Wolfsburg 1980.
5. Alfa Romeo: "Non symmetrical front impact against barrier—analysis of the behaviour of the different car models and consequences to the occupants", VI th ESV—Conference, Washington 1976.
6. Seiffert, U. W.: "Entwicklungsmöglichkeiten für Rückhaltesysteme", Unfall—und Sicherheitsforschung Straβenverkehr, Heft 10, 1977. Herausgegeben im Auftrag des Bundesministers für Verkehr von der Bundesanstalt für Straβenwesen.
7. Ventre, P.; Provensal, J.; Stcherbatcheff, G.: "Development of Protection Systems for Lateral Impacts", SAE—Paper 790710.
8. Seiffert, U. W.: "Lateral Impact—Considerations for Vehicle Development", SAE—Paper 790709.
9. Bez, U.; Hoefs, R.; Stahl, H. W.: "The V-Shaped Vehicle Front—Its Influence on the Injury Severity in Pedestrian Accidents and Side Collisions", 7th ESV—Conference, Paris 1979
10. FAT: "Side Impact—A comparison between HSRI, APROD and Hybrid II Dummy, and Cadavers", 9th ESV Conference, Kyoto 1982.
11. Walfisch, G.; Fayon, A.; Tarriére, C.; Chamouard, F.; Guillon, F.; Got, C.; Patel, A.; Hureau, H.: "Human Head Tolerance to Impact: Influence of the Jerk on the Occurence of Brain Injuries", 6th IRCOBI Conference; Salon-de-Provence 1981.
12. American Association for Automotive Medicine: "The Abbreviated Injury Scale", 1980 Revision.
13. Walsh, M. J.; Kelleher, B. J.: "Development of a Preloaded, Force-Limited Passive Belt System for Small Cars", SAE-Paper 800300.
14. Weissner, R.: "A Comparison of Advanced Belt Systems Regarding their Effectiveness", SAE-Paper 780414.

Structures Improved Side Impact Protection In Europe

EEVC Working Group

European Experimental Vehicles Committee

Review the available accident data in Europe concerning side impact collisions involving passenger cars and make recommendations for a suitable test procedure and standards for reducing injuries to vehicle occupants in such accidents. It will consider the validity of the USA proposals for side impact collision tests as a mean of reducing injuries involving European cars.

CHAPTER 1: INTRODUCTION: THE NEED FOR A STANDARD SIDE IMPACT TEST

The work of the WG 6 "Structures" can be looked at as continuation of the WG 5 "Impact Test Procedures" which dealt with frontal, side and rear collision and rollover.

The main points of WG 5 were:

—The Group proposes a test with a stationary case car struck by movable barrier under an angle of 90°.
—The barrier should be deformable for the long-term solution but no further details could be given at that time because of missing research results.
—For the short-term solution no concrete test procedures (i.e., with the same type of car) could be adopted either because of some basic disadvantages of each of those proposals.

Concerning side collision a lot of questions remained open.

The frequency of side impact accidents comes second to the frequency of frontal impact accidents, and according to our present knowledge of accident statistics, it is the vehicle-to-vehicle collision which has the greatest statistical significance of all accidents involving side impact (1, 2).

According to various studies, side impacts involving a collision with a private car represent 15 to 20% of private car accidents (2, 3, 4). This percentage varies according to the country, but also according to the definition of side impacts, one is given for instance in (5).

Side impact accidents are more serious than accidents which occur according to the other configurations: in 4 European countries (West Germany, France, Italy and the United Kingdom), 21,6% to 31,2% of serious or fatal car accidents are side impact accidents (6) and the occupants most seriously injured are those seated at the side on which the impact occurs (5). Lastly, during recent years, protection improvement has concerned essentially frontal impact which suggests a deeper study of the side impact, as the means of protection (i.e., seat belts) proposed for frontal impact have little effect in side impact; their principal contribution in this type of impact is to prevent ejection and a restaint to some extent to the offside occupant (2). These particulars are sufficient to justify the principle of systematic studies of side impacts and protection from injury.

CHAPTER 2: CRASH CONFIGURATIONS AND CONSEQUENCES OF SIDE IMPACT ACCIDENTS

Different studies have been made from analysis of real accidents, describing the conditions of impact and the typology of injuries from side impact accidents.

In (7) is given an overlook over the situation of all collision types divided in 12 main groups. If they are judged by criteria from several authors (8, 9) the rectangular side collision ranks third behind two frontal collision types.

On the basis of an accident survey conducted in France (10), it appears that the most frequent and the most serious side impact accidents correspond to a point of maximum intrusion close to the projection of the H point of the vehicle collided with, as indicated in Figure 1. The same document indicated that over half of serious or fatal accidents occur according to an angle of between 55° and 85° of the colliding car in relation to the collided car.

Many details of the types of damage to car sides and of how occupants are injured are given in a United Kingdom study (11) and a more detailed analysis of these

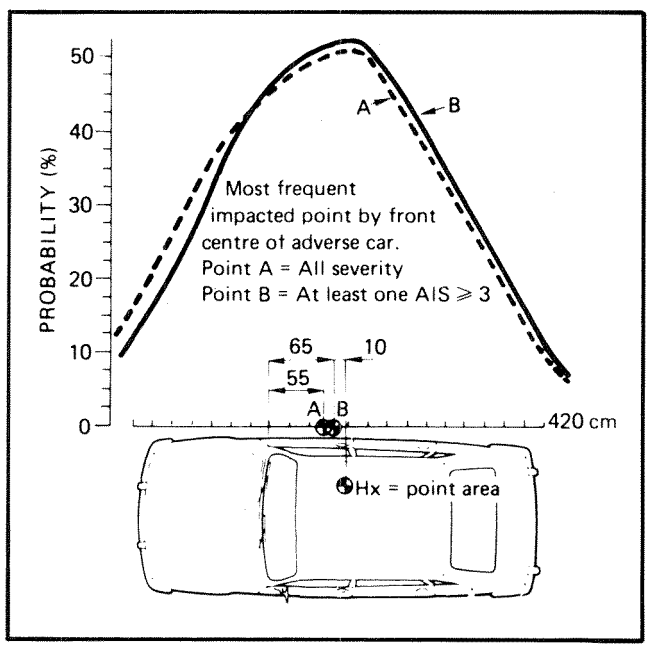


Figure 1. Location of impacted area in side impact (10).

accidents is now being carried out. For example it shows that in 62% of all side impact accidents and in all fatal cases, the front door of the car run into is directly implicated by the impact.

This study of right hand drive cars also shows that the most frequent clock direction is 2 o'clock for overall side impacts and 9 o'clock for fatal accidents. This study also shows that more than three-quarters of fatal accidents occur according to hour directions between 2 o'clock and 4 o'clock and between 8 o'clock and 10 o'clock, as indicated in Figure 2. It should be noted that the example of this study has been rectified to be statistically representative of the English situation. A study carried out in The Netherlands on more than 8,000 accidents (12) confirms the preceeding results, in particular in respect of the damaged side zones of the vehicle in question.

In (1) it is said, that a side impact in the passenger cell area involves a far greater injury risk than in other configurations and that a greater safety benefit can be expected from a test requirement which is intended to optimise the deformation behaviour of the side structure in the area of the passenger cell.

Figure 3 shows a statistically representative collision configuration including vehicle speeds and masses (2, 10, 13, 14). The angle of approach is 90 degrees and the longitudinal centre plane of the colliding vehicle contacts

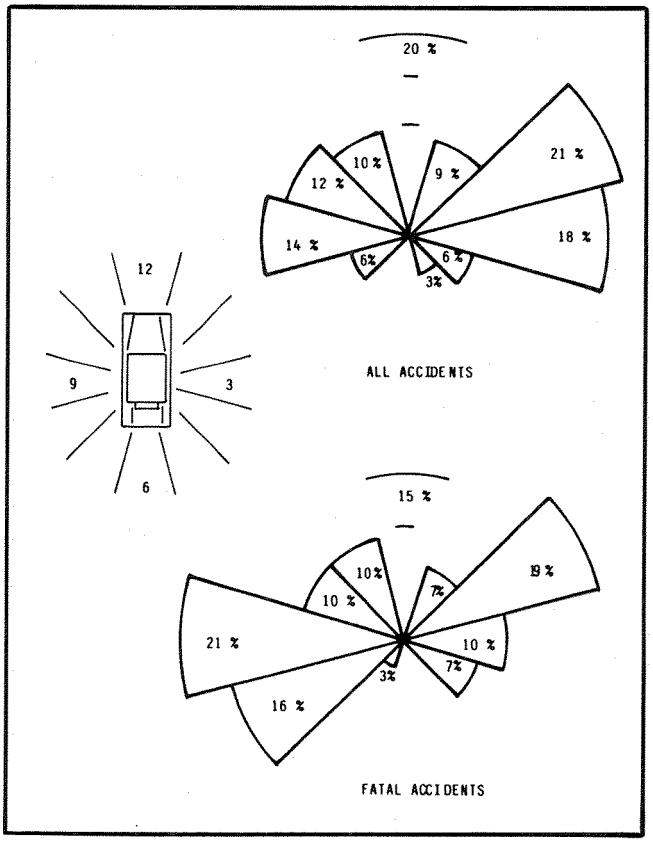


Figure 2. Frequency of impact direction in side impact accidents (11).

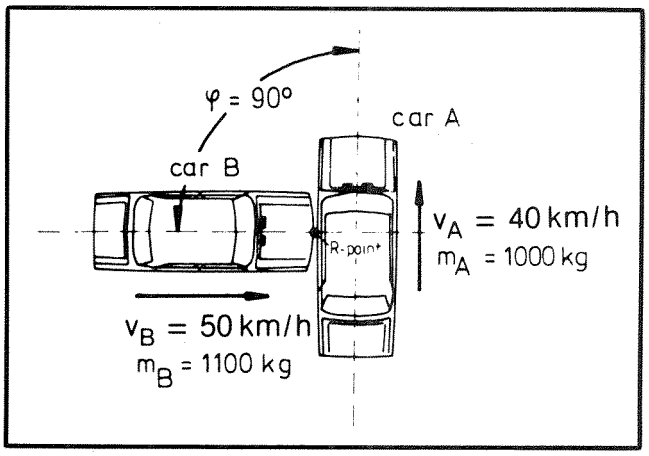


Figure 3. Cumulative percent for curb weight (1).

the other vehicle at the latter's R-point projected into the outer body surface. The speed of the colliding vehicle is 50 km/h, and that of the other vehicle 40 km/h. This gives a relative collision speed of 65 km/h, corresponding to the 90th percentile point of the distribution function (15). The colliding vehicle has a mass of 1100 kg corresponding to the maximum of the distribution density.

In this percent frequency distribution the shifting of emphasis of the maximum collision frequency and, in particular, the far higher percentage of lorries involved in collisions with injuries such as severity AIS 3 become evident.

Some 75 percent of all vehicles involved in side collisions were impacted at a speed of less than 45 km/h, and 95 percent of all collision speeds lie within the range up to 60 km/h; the maximum relative speeds in unfavourable circumstances can be deduced from this.

Here, one must, however, take into account the fact that real-life speed variations are far less and that in collisions at intersections (18) only 40 to 45 percent of the kinetic initial energy is transformed into deformation energy, the remainder being consumed in post-crash

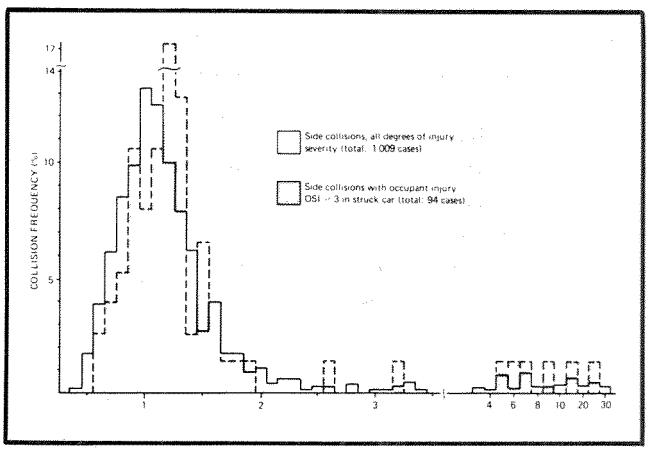


Figure 4. Collision frequency and mass ratio in car/car and car/truck side collisions.

mouvement. On the basis of these data, it can be assumed that a test speed of 50 to 60 km/h in lateral collisions will embrace at least 90 percent of all real-life collisions (5).

In this sample of Cesari (13) the average overall severity index is 2,9 for the side impact and only 2,3 for the frontal impact.

As a consequence of the high degree of injuries, however, 28% of all fatally injured, 20% of all seriously injured (as from AIS 3), and 27% of all injured (as from AIS 1) occupants in car/vehicle accidents are to be found in cars with a side impact (14, 5).

The occupants the most seriously and most frequently injured in side impact accidents are those seated at the side where the impact occurs and severe injuries to impact-side occupants (severity degree AIS 3) are recorded in cases of head injuries (1,5 times), chest injuries (3,5 times) abdominal injuries (5 times) as often as to opposite-side occupants (5).

The study carried out in the United Kingdom (4) shows that in the case of the injured among whom at least one injury has an "AIS" 3, the head, the thorax, the abdomen, and the pelvis, are the parts of the body most frequently injured, and in the case of the most seriously injured (AIS 4, 5, 6), abdominal and thoracic injuries are more frequent than cephalic injuries.

Certain injuries are more frequent in side impact accidents in comparison with the other accident configurations and this is particularly true for pelvic and thoracic injuries (2, 10, 15).

CHAPTER 3: INJURY MECHANISMS IN SIDE IMPACT

Contrary to frontal impact where it has been established that the velocity change of the involved car is the main parameter which fixes the force of the impact, this parameter has only a very secondary effect in side impact accidents.

The parameter which is most directly linked to the severity of side impact accidents is the speed of the vertical surface of the vehicle which is run into, at the moment of contact with its occupant (19, 20).

The front structure of the modern passenger car is capable of absorbing about 2 or 5 times as much energy as the side structure (1). In a side collision with contact in the area of the passenger cell the occupant sitting on the side of impact will be struck by the side structure intruding into the passengers compartment while still in his original seating position, and will be accelerated toward the opposite side of the vehicle before the speed of the vehicle itself begins to change to any appreciable extent. In terms of the loadings imposed upon the occupants, therefore, the motion of the vehicle itself is of merely secondary importance. The decisive factor is actually the large relative motion between the side structure and the vehicle, in other words the rate of intrusion.

It should be noted that in this situation, due to intrusion, this vertical surface speed is much greater than the speed variation of non-deformed structures on the vehicle collided with, as may be seen in Figure 5.

From this fact, in order to improve safety in side impact, on the one hand, the speed of contact of the occupant/surface should be decreased, either by increasing the resistance of the side body of vehicle, or if necessary, by reducing the rigidity of the front of vehicles in frontal impact. These modifications should be completed by installing padding on the inside of the side panel so as to improve the distribution of the impact on the human body and to reduce the pressure.

CHAPTER 4: THE PROBLEM OF COMPATIBILITY IN SIDE IMPACT

The principal mechanism at the origin of injuries in side impact accidents being the speed of the surface, and this being a function of the relative rigidity of the front of the striking car and the side of the struck car, protection in side impact is subject to compatibility between the lateral and frontal structures of vehicles on the roads.

The interaction between the striking car and the struck car occurs essentially, on the one hand between the front bumper and the side sills on the lower part of the body, and on the other hand, between the front wings and the A and B pillars and the doors. In order that the com-

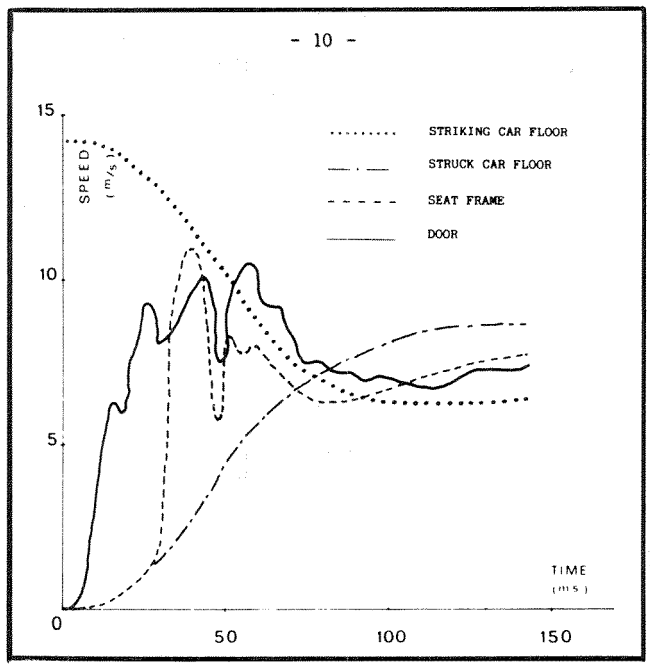


Figure 5. Velocity change in side impact in a 50 km/h test (20).

patibility be assured, the sills should be more rigid than the bumper, and the pillars be more rigid than the wings.

To take into account the fact that the trajectory of the striking car is rarely orthogonal to the struck car, the doors also should be sufficiently resistant to be compatible with the force created by the wings of the colliding car (21).

Concerning the reached status of compatibility there can be referred to a project financed by the German Ministry of Research and Technology. In (7) there are reports on the results of collision tests with a modified Audi 100 into a modified VW Golf (collision angle 90°, collision speed 50 km/h, mass ratio 1,42 for the modified status). It is shown that the loadings of dummies (resultant acceleration, HIC, SI, etc. . . .) can be kept very far below the critical values. The main modifications were: reinforcement of compartments (door guard beam at bumper height, modification of B pillar, door padding inside with foam and steel). Compatibility of the deformation forces on the front and side structures was achieved. Furthermore the frontal safety of the modified cars was increased also and the modifications, which did not increase the cars' weight, has a calculated cost/benefit ratio of about 1.

In addition to the design compatibility, the question of the influence of the relation between the masses of the two vehicles in the collision should be posed.

A study has shown that increasing the weight of the striking car has small impact on dummy loadings (22), whereas a study in progress in Germany (23) shows that when VW Golf is struck by a 123 Mercedes, the intrusion is clearly higher than when it is hit by another VW Golf. The maximal intrusion is increased of about 50%, but in this case there is at the same time modifications of the striking car weight and the striking car architecture.

An American study (24) also showed that the weight of the colliding car influenced the seriousness of the injuries.

FIAT Company has started 10 years ago studies in the field of compatibility inside impact. These studies have resulted in the elaboration of a testing method, and in design of a barrier in the aim of making and quantified evaluation of the compatibility. This barrier is described in paragraph 6.1 of this report.

CHAPTER 5: TEST METHODS FOR SIDE IMPACT SAFETY ASSESSMENT

Different test methods have been proposed to evaluate the protection of the occupants in side impact, and these may be classified in two categories: full-scale tests and tests of components.

The combined efficacy of padding and structure reinforcement can be established from full-scale tests on cars. A complete vehicle containing dummies is used, this vehicle being generally run into by a mobile barrier representing the colliding car. The dummies should be built so that the criteria of specific injuries can be recorded. Work on the design of dummies which is being sponsored by the EEC, and which is on the point of being completed, provides for the possibility of using more lifelike dummies for full-scale tests, than are currently available. A proposal have been made several times to use sub-system as an alternative to whole-vehicle tests. These tests should contain on the one hand, an exterior loading (either static or dynamic) of the structure, on the other hand, loading on the padding with shapes representing the different parts of the body liable to be in contact with these paddings. This method is certainly simpler than whole-vehicle tests, but has the inconvenience of evaluating separately the two types of features likely to influence the protection in side impact, without discovering their cumulative effect and thus the total protection offered.

The members of the EEVC Working Group 6 considered that full-scale tests were preferable to component tests in order to be the basis of future regulations concerning protection in side impact. However, component tests will probably be necessary in order to complete the verification in zones where the dummy had no contact during the test, but where contact could occur during other types of real accidents.

The whole-vehicle impact test could be a car/car impact; however this solution has the inconvenience of only allowing the safety offered to be verified when the vehicle in question is run into by the one chosen car model, usually an identical one, which is not a frequent occurrence.

Moreover, this solution should be to the advantage of some cars and penalize some others. On account of this, the group abandoned this solution.

The other possibility for whole-vehicle tests is to use a mobile barrier. This barrier could either be completely rigid, or have a deformable front surface. The advantages of rigid barrier are particularly the low cost of the tests and their repeatability. However, being totally undeformable, they do not absorb energy during impact, and thus do not permit the mechanism of deformation of the struck car to be reproduced accurately.

Especially it is the door velocity change which is the main factor linked to the severity of injuries sustained by nearside car occupants.

Mobile deformable barrier should have more realistic behaviour than rigid ones for representing the car/car impact. There are two sorts of mobile deformable barrier:

A—a barrier which simulates the average characteristics of a vehicle population. Its front surface is constituted of deformable elements of different rigidity representing the stiffness of the principal frontal elements of a vehicle. The barrier serves to reproduce a typical impact and the results are noted either on the dummies which occupy the struck car and these are compared with

the protection criteria or on the struck car structures in terms of panel velocity change and of intrusion.

B—a more complex barrier which does not simulate a car front, but constitutes an appliance for noting local rigidities (force and deformation) at every moment on every zone of the collided car (the front face contains a large number of identical elements). In agreement tests, the results are recorded either on the barrier or on the struck car; in compatibility tests the results should be judged in comparison with those of other vehicles, with the help of a mathematical model.

The favorable and unfavorable features in the two solutions are:

Solution A: is simpler and less expensive in terms of both development and use.

The more the characteristics of the tested car depart from those simulated by the barrier, the less reliable the compliance judgment is.

Following the evaluation of the vehicles on the road, this barrier needs to be modified.

It allows compatibility to be only indirectly evaluated, not quantitatively.

Solution B: is more complex and expensive to develop and use.

It is independent of the characteristics of the car against which it is used and is always stable, not being affected by the evolution of the vehicles on the road.

It allows compliance tests, research tests, as well as quantitative evaluation of compatibility on a car with respect to each tested model.

The members of the group thought that the second solution should be very interesting in the study field, but that the first solution was more appropriate for regulatory tests.

CHAPTER 6: DESCRIPTION OF EXISTING DEFORMABLE BARRIERS

Various studies on the development of deformable mobile barriers have been carried out recently. These are principally the FIAT, NHTSA, CCMC, TRRL and UTAC barriers.

1) The Fiat Barrier (25)

This barrier has a flat front surface incorporating 36 honeycombed parallelepipeds, each fixed to a load cell. Figure 6 shows this barrier and it can be noted that its dimensions are inspired from the flat USA type barrier. This barrier is destined to be used in frontal impacts as well as in side impacts. A complex mathematical program is necessary to evaluate the compatibility with other vehicles that the results allow the data relative to the force and crush caused by the impact to be analysed. It is possible to reduce the front width from 1830 to 1600 mm

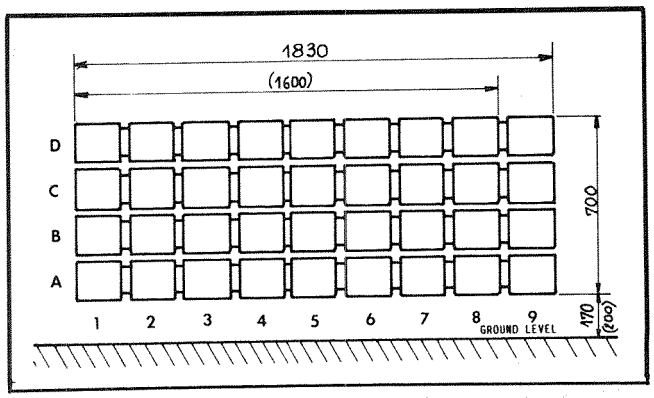


Figure 6. FIAT barrier front face (25).

by removing a module column, and to modify the ground clearance from 170 to 200 mm.

2) The NHTSA Barrier (26)

In 1977, NHTSA completed a research programme concerning the protection of automobile occupants. This programme resulted in the construction and the validation of a deformable mobile barrier shown in Figure 7. The characteristics of this barrier are derived from the masses and the dimensions of vehicles registered in 1978 in the USA, which explains the values greater than those existing in Europe.

During the study, the construction of the barrier evolved from a complex solution in the shape and number of elements, to arrive at a much more simple construction with simulation of a front bumper. The test procedure proposed by NHTSA has a crab-like displacement.

3) The CCMC Barrier (27)

CCMC determined the characteristics of a mobile deformable barrier from the characteristics of vehicles sold in 1976, in 12 European countries. This resulted in a barrier of 950 kg whose dimensions and frontal charac-

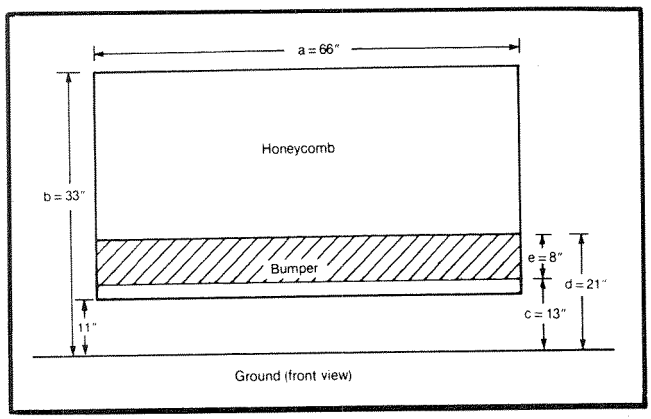


Figure 7. NHTSA barrier front face (26).

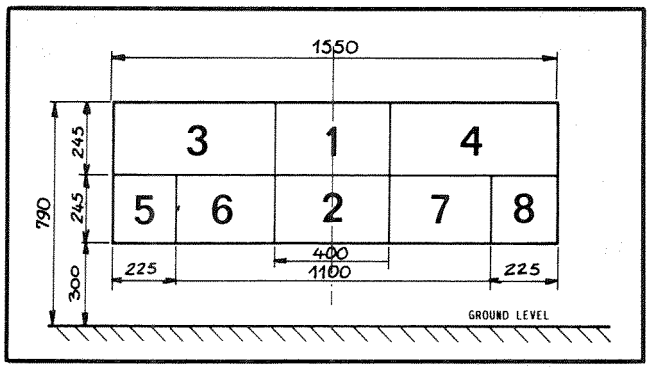


Figure 8. CCMC barrier front face (27).

teristics are shown in Figure 8. It should be noted that this barrier has a flat front surface and its deformable part is made of polyurethane foam. The force/deformation laws adopted for this barrier are deduced from tests of frontal impact against a dynamometric wall at 50 km/h.

4) The TRRL Barrier (28)

TRRL have recently developed a mobile deformable barrier whose front zone is made up of 40 deformable blocks. Each block is made by stacking up rectangular and cylindrical steel cans which are partially filled with foam in order to make them more rigid. This construction allows the rigidity of various blocks to be varied. The front surface of this barrier is 1500 mm wide and 600 mm high, but, within limits any size and pattern of frontal stiffness can be represented.

5) The UTAC Barrier (29)

A collaboration between French automobile constructors and UTAC, at the initiative of the public authorities, has resulted in a definition of the specifications of a mobile deformable barrier representing the average car most often used in France.

For this, ten car models were chosen, and analysis of

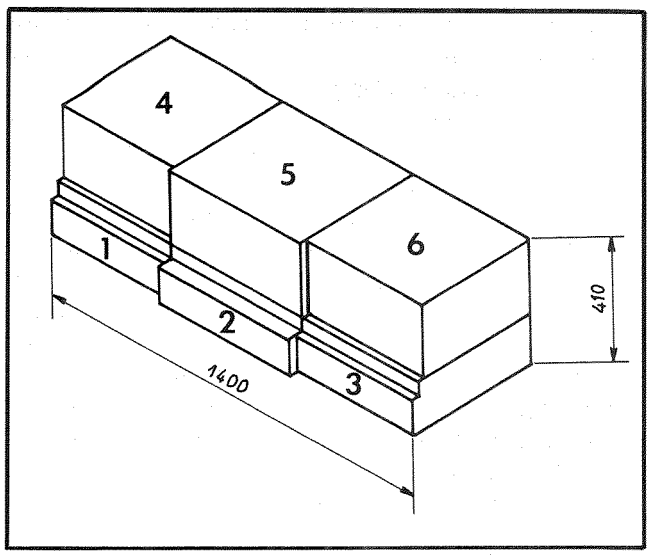


Figure 9. UTAC barrier front face (29).

their dimensions and of their force/deformation laws noted in the course of frontal impact tests at 35 km/h against a dynamometric wall, permitted the characteristics of this barrier to be determined. As indicated in Figure 9, the front face of this barrier is 1400 mm wide, 500 mm high and has a ground clearance of 350 mm. The profile of the front face is constructed in such a way as to simulate the average profile of the cars in question.

6) Comparison of the Characteristics of the Mobile Deformable Barriers

The principal characteristics of the 5 mobile deformable barriers described in this chapter can be compared in Table 2. It can be seen that the CCMC, TRRL and UTAC barriers have rather similar features.

The most notable differences concern the ground clearance and the force/total deflexion law.

With regard to the ground clearance, it is certain that it has a great influence on the results of the test and on the solutions to be taken into account to improve pro-

Table 2. Comparison of main characteristics of mobile deformable barriers.

	NHTSA	CCMC	UTAC	TRRL	FIAT
Weight (kg)	1566	950	915	1190	900/2300
Width (mm)	1676	1550	1400	1500	1830 (1600)*
Weight (mm)	559	490	410	600	700
Ground clearance (mm)	330	300	380	200	170 (200)
Shape of front face	flat+bumper	flat	flat+bumper	flat	flat
Thickness of deformable Element (mm)	483	400	500	560	300 (500)
Maximal crush (mm)	350	300	360	420	200 (360)
Total force (kn)					
For 200 mm crush	150	220	175	90/320	450 (400)
For 300 mm crush	490	350	205	320	N.A. (400)

* Values in bracket correspond to possible modifications of FIAT barrier.

tection in side impact accidents. Large ground clearance seems to correspond better to the geometry of present day vehicles, but smaller ground clearance seems to be likely in a desirable evolution of future vehicles and these allow use to be made of interesting protection solutions which, moreover, improves the compatibility.

With regard to the law of force/deformation, the UTAC and CCMC studies arrive at similar laws for a crush up to 250 mm; for higher values, CCMC's proposal is situated above that of UTAC, but this seems to be due to test conditions on a dynamometric wall which served to determine this law; UTAC used test results at 35 km/h, which seems more realistic than tests at 50 km/h which CCMC took into account; moreover the CCMC tests were made with dynamometric barriers which are different in the geometry and the number of force measuring blocks.

As the UTAC studies were made with nonbraking cars, and taking account the behind remark, the group members agreed on the complete definition of a deformable barrier which is the synthesis of all the elements defined by the CCMC, TRRL and UTAC barriers.

This result has to be pointed out, because the works of governmental authorities which have as objectives the definition of international standards would take into account the results of EEVC WG 6 works to improve in an acceptable delay the definition of a side impact full-scale standard test.

However the group thinks that the stiffness of the barrier deformable face would be modified if in the future the stiffness of car front end decreased.

CHAPTER 7: PROBLEMS RELATED TO THE CHOICE OF A SIDE IMPACT TESTING METHOD

This chapter summarizes the discussions of the Working Group and comments upon the alternative possibilities for the main features of a car side impact test. Chapter 8 gives the test procedure preferred by the Working Group as a result of their discussions.

1. A Full-Scale Side Impact Test or Systems Testing

When a car is struck in the side, occupants are injured almost instantaneously if they are adjacent to the point of impact: there may only be a light sheet steel door between them and the striking vehicle. Injuries may be by direct blows to the head or by being struck by the intruding side structure being forced inwards. A few injuries occur a brief instant later if the occupant becomes crushed between the intrusion and something inside. Other occupants further from the point of impact have a lower risk of injury but head injuries are common when they are thrown across the car.

For those close to the intruding side, their initial distance from the side is critical because the speed of intrusion declines rapidly as the intrusion proceeds. There are two means of protection. Firstly it is appropriate to pad all components likely to strike the human body in accidents. The stiffness of the padding should match the human tolerance level of the part of the body likely to hit it. The depth of padding should be large enough to prevent it bottoming out in the agreed test conditions. This depth depends on the attenuation of the initial velocity of intrusion (i.e., the relative velocity of the striking vehicle). The second means of protection is to strengthen the side structure so that it is pushed inwards more slowly and not so far. This reduces the depth of padding needed and so there is some scope for variation in design between having a large depth of padding and a mixture of side strengthening and padding.

The full-scale test records the combined effectiveness of the padding and the side strengthening. It uses a complete car with dummies inside, which is struck by a mobile barrier with its face representing striking cars. The dummy must be especially designed to record side impact loadings to the head, shoulders, thorax, abdomen, pelvis and femur, in so far as this is possible. Much work has been carried out to develop such dummies in both USA and Europe, the latter mostly under EEC sponsorship. It seems likely that all these loadings, apart from those on femurs, can be recorded if required. This being so there is much to be gained from having a full-scale dynamic test using these dummies. However only one accident situation can be simulated and side impact accidents are very variable in their details. It has been noted that head impacts occur against almost everything along the upper parts of the sides at one time or another. Impacts to the thorax occur both adjacent to the seated position and forwards of this and similarly so for the pelvis. It is considered that the best way of checking for the head impacts in accidents is to use a head form projected into various points along the cant rails, A and B posts, and possibly against the door.

It has been proposed by various organisations that an alternative to a full-scale impact test would be a set of sub-systems tests. These would include an external loading of the side structure of the car, either dynamic or possibly static. The internal design of the padding would be checked by separate head, chest and pelvic forms impacted into the parts of the side that these parts of the human body might possibly strike. There is no doubt that this system procedure would be cheap and convenient for vehicle manufacturers. One objection is that it presupposes a particular combination of side strengthening and depth of padding, whereas the full impact test leaves that choice to the vehicle designer. There is no doubt that the full test is needed for much of the preliminary study of side impact and for the development of a complete understanding of how much side impact protection can rea-

sonably be provided. A series of sub-systems tests is a good means of checking the whole of the side but the full-scale test is better at checking the interaction of the head, body and lower limb impacts with each other and for checking for unexpected effects from vehicle components. Some compromise between the two procedures may be the best answer.

2. The Barrier Face—Rigid or Deformable

In the past car front to car side impacts have been represented by mobile barriers running into the sides of cars being tested and some barriers have had rigid faces and other deformable faces. A deformable front face can be designed to accurately represent the front of a car as it crushes but because the designs of car fronts vary a great deal, it is necessary to choose a particular design to represent the whole range of car fronts. This is discussed elsewhere and it is pointed out that most side impacts are not truly perpendicular and so it is the front corners of cars which are primarily involved.

One advantage of a rigid barrier face is that the most violent impacts into the sides of cars are by Heavy Commercial Vehicles and when cars slide sideways into fixed objects such as trees. The most important difference is that a rigid barrier absorbs no energy in an impact whereas a deformable barrier can absorb its share of the energy to be dissipated. When a rigid barrier is used, the velocity of impact is reduced to compensate for this, possibly by reducing it by a factor of (½) when the impact being simulated is between cars of equal mass. Although this means that the correct degree of damage is caused in the car under test, it gives a low speed of initial penetration of the car door which may reduce the impact into occupants in some circumstances. It seems that a rigid barrier face cannot accurately represent a car-to-car impact but the approximation to it may be close.

The details of shape and design for a deformable face are discussed in Section 3.

Consideration of the design for a rigid face has led to using a narrow width of about 1 metre to avoid the impact being largely absorbed by A posts and wheel arches. Arguments can be made for either impacting the sills or having a face set up just to pass over them. In any case it is important that rigid barrier faces are rounded at their edges to avoid the edges cutting into the skin of the car and its doors.

One advantage of a rigid face is that it is cheap to use because it can be used many times. A deformable face can be used only once and its structure must be accurately reproducible.

With a rigid barrier it is possible to cover the face with load cells to measure the total load on each area during the impact and there might be say four cells in both upper and lower rows of a small face and double that number for a large face. With a deformable face there is less need for load cells because the exact imprint of the impact can be seen if the face material does not recover. The yield stiffness of the material is known and so unlike load cells, no measurement of car side stiffness can be recorded, but when the car local stiffness exceeds that of the face, it is the face that deforms and the resulting imprint can be measured. It is of course quite possible to mount sections of the deformable face on to load cells and so to record both loading and depths of crush. It is important to note that load cells and the overall deceleration of the barrier record the stiffness of the side as it collapses during the impact. With the deformable face the deceleration during the side impact may be lower because the barrier rather than the car may be deforming.

3. Barrier Design

The design of a mobile barrier for side impact testing with all the different possibilities in the selection of a deformable face, is discussed in the following five subsections.

3.1 Barrier Design—Effect of Barrier Mass

There are two obvious alternatives; either the barrier mass should be constant for all tests or it should be ballasted to equal the mass of the car being tested. The latter ensures that the cars under test are all subjected to a change of velocity of a half of the impact speed of the mobile barrier. The former gives greater changes in velocity to cars of lower mass. Although this former possibility may appear not to be fair to small cars, it is preferred because in real accidents each car model is exposed to the same mix of car models and on average smaller cars must suffer the more severe impacts.

Although previous test procedures have mostly used a barrier mass of 1100 kg, it is generally considered that for the future a mass of from about 900 and 950 kg will be appropriate.

3.2 Barrier Design—Height of Barrier and Position Above Ground

Because mobile barriers represent car fronts, their top forces are usually about 800 mm above ground which is about the height of the lower edges of the glass windows in doors. Only a few cars are struck in the side by heavy goods vehicles or slide sideways into fixed objects but these lead to about a third of the fatal side impacts. In these cases there is usually intrusion at up to the roof level and it is often the occupant head impacts which result from this that can be fatal. However this is not discussed for the moment.

With regard to the lower edge of the barrier face the question is whether this should interact with car sills by putting the lower edge at say 200 mm above ground, or be positioned just above them at 350 mm. At present

many models of car have little front structure below their front bumpers and these can easily override the side sills of other cars. This potentially dangerous situation must be prevented by encouraging car designers to build air dam structures lower down and of adequate strength for side impacts. With a rigid faced barrier it was found that a rounded lower edge just above the sills interacted with the B posts of cars so much that the sills were greatly distorted and absorbed almost as much energy as if struck. This would encourage strong sills and attachments to B posts. With a deformable face this loading of the sills would be less severe and the alternatives are either a face missing the sills which would be adequate for lesser impacts or one striking the sills for higher impact levels. The latter would be better for encouraging strong side sills for cars. A corresponding impact test into the fronts of cars is needed to ensure that in future car fronts are designed to be strong low down.

3.3 Barrier Design—Width of Barrier

Although it would appear logical to have a barrier of full car width (1600 mm), accident investigations show that almost all side impacts are not exactly perpendicular and a front corner of the striking car usually intrudes into the struck car and then slides round leaving a deep imprint of less than 750 mm width. This is injurious when the intrusion is into the passenger space. There are two ways in which this can be simulated in a perpendicular impact. Either the mobile barrier face can be deformable with its centre more rigid than its outer wings or the barrier face can be a metre or less in width and aimed to miss both the strong points of the body side at the A post and the rear wheel arch. The choice lies between these two extremes, that is between a rigid or deformable face of say 1 metre wide and a full width of 1600 mm wide with a suitable design of deformable face.

3.4 Barrier Design—Lateral Shape of Face and Stiffness Distribution

As discussed there are two basic assumptions for the design of a barrier face. It can either be representative of the fronts of cars, possibly averaged over a number of models in proportion to their popularity, or it can be modified from this to meet particular objectives. If it is desired to represent actual car fronts it should be flat or almost flat across its width with a stiffness which is greatest at the centre and somewhat less towards the sides. However some car models do not follow this pattern and the front ends of their wings may be relatively stiff. An averaged design might have the outer sections about two-thirds the stiffness of the centre. A modified design of barrier face to emphasise the most common impact whereby a corner of a front penetrates the side of a car might have a stiffness representative of a wing or front corner at its centre and still lower stiffness at its outer sections of perhaps a half of the center stiffness. This reduction at the outer sections would ensure that sufficient intrusion could occur at the doors however stiff the A posts and rear wheel arches might be. There are arguments for the centre section to be from 400 mm to 1000 mm wide.

This discussion implies that a deformable barrier should have three sections laterally, namely a centre section and two similar outer sections. It would be possible to have five sections rather than three, but this would seem to be an unnecessary complication. On the other hand to have a uniform lateral distribution of stiffness would seem to be unsatisfactory for the reasons discussed.

3.5 Barrier Design—Vertical Shape of Face and Stiffness Distribution

Currently there are several different front profiles for cars. Many are vertical or almost so, with just the bumper protruding forwards. Most have small bumpers but a few in the middle 1970s had large bumpers in both depth and forwards protrusion. Other cars have little structure above or below their bumpers. Recent cars often have a low top edge but a large air dam below for reasons of low aerodynamic drag. Looking to the future, low aerodynamic drag and the needs for pedestrian protection will have greater prominence. A good shape for the latter is a fairly flat vertical face or one that slopes back slightly from vertical. It would have no hard protrusions and would have an air dam low down.

With these considerations and those of section 3.2 in mind, it may be sufficient to have a vertical barrier face. Although a bumper protrusion could be added, it may be left out if future cars are being represented. In any case most bumpers are fairly soft and are partially crashed before a side impact is completed. (The exceptions are the large bumpers of the "safety" cars of the 1970s).

The stiffness distributions of fronts of cars are variable with from one-third to two-thirds of the strength being in the upper half (500 to 800 mm above ground) rather than in the lower half (200 to 500 mm above ground). However it is almost certain that if future cars are to have a good side impact performance in car-to-car impacts, then the upper halves of the fronts must be relatively soft. In other words good side impact protection cannot be provided by simple modifications to the sides of present day car designs unless the upper halves of the fronts of cars which will strike them are of similar low stiffness. In fact it is clearly desirable that the upper car fronts should be somewhat less stiff that the effective stiffness of doors and B posts.

There seems to be a strong argument for having only two levels to stiffness in the vertical pattern on upper and a lower, because it is desirable that the lower part of a car front is much stiffer than the upper. Bumper heights have varied through the years but their upper edges are usually not more than 450 mm to 500 mm above ground.

So it is convenient to divide the height into regions of from 200 to 500 mm and from 500 to 800 mm.

CHAPTER 8: DESCRIPTION OF THE PROPOSED SIDE IMPACT STANDARD TEST

This chapter contains a detailed description of the side impact test which the group adopted.

The information contained in this chapter corresponds to what the members of the group think, either after the work carried out on the mobile barriers, in particular by UTAC in France and by CCMC, or deduced from the contents of the regulations of integrated tests in frontal impact.

The information corresponds to the present stage of knowledge, and in any case, the test procedure must be supplemented by definition of the characteristics of the dummy to be used and by the protection criteria to be measured, and the values which must not be exceeded. These two fields are not the domain of the group, and moreover, the end of phase IV of the EEC's biomechanical programme (30) must be awaited in order to be able to clarify these two points.

1. Field Of Use

This test concerns private cars with a maximum seating capacity of 6 including the driver.

2. Test Conditions

2.1. The vehicle to be tested will be stationary.
The impactor will be mobile.

2.2. The trajectory of the impactor will be perpendicular to the collided car.
The median plane of the impactor will pass through point R (or its projection on the exterior face of the vehicle) from the driver's seat of the collided car.

2.3. The test will normally be carried out on the driver's side of the vehicle when this has a symmetrical structure.
However, when an asymmetrical structure is used which is likely to affect the performance of the structures of the opposite sides, one of the following solutions will be used:

a) upon the constructor's request, an additional test on the side opposite to the driver will be carried out.
b) the constructor will furnish the authority carrying out the ratification with information regarding the compatibility of performances in comparison to the initial test.
c) the ratifying authority, having assured itself of the merits of the vehicle's construction, decides to have a test effected on the side opposite the driver, this position being considered as the worst.

2.4. The impactor will weigh 950 kg.*

2.5. The impact speed will be 50 km/h (+0, −2). This speed will be stabilized at least 0,5 m before the impact.

3. Characteristics of the Impactor

3.1. The impactor will be a mobile barrier with a deformable front face.

3.2. The deformable impact zone should be 1500 mm wide and 500 mm high.

3.3. The ground clearance of the collision zone is 250 mm.

3.4. There are 6 deformable elements, divided into two rows of three elements.
All the elements have the same width (500 mm) and the same height (250 mm); the elements of the upper row are 440 mm in depth and those of the lower row 500 mm in depth.

3.5. The details of the barrier construction are indicated in Appendix 1.

4. Preparation of the Vehicle

4.1. The vehicle to be tested should possess all the equipment likely to have an influence on the results of the tests.

4.2. The weight of the vehicle at the time of the test will be the weight when empty and in working order.

4.3. The petrol tank will be filled with a nonimflammable liquid of a density between 0,7 and 1 whose weight corresponds to 90% of the weight of a full tank of petrol.

4.4. The other fuel circuits can be empty, but the weight of the liquid must be compensated.

4.5. The weight of the measuring instruments must be compensated by lightening some parts which do not have a great influence on the results of the test.

4.6. The windows should be closed. The back window may possibly be open.

4.7. The doors will be closed, but not locked.

4.8. Controls will be in a neutral position.

4.9. The other accessories will be in the most frequently used positions.

4.10. The arm-rests, if they exist, will be lowered.

4.11. The front seats will be positioned 50 mm in front of the point R, or in the closest notch to this position.

5. Dummies

5.1. Two dummies will be installed, one in the front seat, and one in the rear seat on the impact side.

*The German delegate would have preferred that the barrier weight should be 1100 kg in order to take into account a mass ratio of 1.3.

If it is not possible to put a dummy in the back seat, the test will be made with one dummy in the front *, but the constructor must prove that the protection offered in the back is at least equivalent to that of the front seats.

5.2. The dummies will comply with the specifications retained.

5.3. The dummies will be installed according to the procedure described in the ECE/ONU proposed standard for frontal impact.

5.4. The point R will be determined according to the procedure described in the ECE/ONU proposed standard for frontal impact.

5.5. The standard restraint system shall be put in use. If this apparatus includes belts, these should be of the approved type.

6. Evaluating the Results of the Tests

The completed test, carried out according to the above method, will be considered satisfactory if the following conditions are fulfilled.

6.1. No door should open during the test.

6.2. The performances noted from the dummies should comply with the criteria adopted.

6.3. Only slight fuel leaks are permitted during the collision. In the event of continuous loss of liquid after the collision, this should not be higher than 30 gr/minute.

6.4. It should be possible, after the collision, without having to resort to tools

—to open a sufficient number of doors to allow evacuation of all the occupants of the vehicle,
—to free the dummies from the restraint system without exceeding a force of 5 daN on the control,
—to take out the entire dummies.

6.5. After the test, no interior device, nor any component must have broken loose in such a way that projections or sharp bends in the metal could significantly increase the risk of injury.

NOTE

A generalization of the above remarks incorporating additional component tests, should be made before applying the rule.

CHAPTER 9: RECOMMENDATIONS FOR THE FUTURE

The standard test procedure described in chapter 8 was not validated as, in particular, the barrier described in that chapter is not yet built. Therefore, the first point to be examined is the validation of the barrier. This should be made in respect of the reproducibility by at least six tests.

Its deformations should be compared to those of real vehicles in car/car collisions under the same conditions. Finally, its reactions should be tested in tests against different vehicles.

The chosen value of the ground clearance is a compromise between what is presently realistic and what is desirable to improve the safety in side impact. This value could be decreased if it is possible in the same time to lower sufficiently the level of front end rigid parts.

The problem of compatibility is not resolved by this test and a test extended to the front of the car in a frontal impact against a mobile barrier should be envisaged in order to verify that the front of the car is compatible with the characteristics of the chosen barrier. This could be done by impacting the barrier described into the front of the stationary car at 50 km/h. Measurements would be made either of the barrier's peak deceleration (and hence the force it had experienced) or of its deformation (and hence the energy it had absorbed). In either case the measured values would be required to be below an agreed allowable figure. It is essential that a notion of omnidirectional compatibility in the conception of vehicles be recognized as a major objective to increase road safety, and protection in side impact is only a part of this general need. The test described above should be justified by a cost-effective study.

*The German car manufacturers propose that the mass of the car should be increased with 75 kg (equal to the dummy's mass) in that case.

REFERENCES

1. Hofmann J., Appel H. Mathematical simulation of side impact—A contribution to the problem of rigid/deformable barriers. 8th ESV conference, Wolfsburg, 1980.
2. Appel H., Hofmann J. Accident analysis of vehicle side collisions. 3rd IRCOBI, Berlin, September 1977.
3. Mackay G. M. Causes and effects of road accidents. Department of Transportation and Environmental Planning. University of Birmingham.
4. Riley B. S., Radley C. P. Traffic accidents to cars with directions of impact from the front and side. 6th International Technical Conference on ESV, Washington, 1976.
5. Danner M., Langwieder K. Car/vehicle side impacts—a study of accident characteristics and occupant injuries. 6th ESV Conference, Washington, October 1976.
6. Hartemann F., Tarrière C. Synthesis of statistical data on traffic accidents in France, West Germany, Italy and United Kingdom. 5th International Technical Conference on Experimental Safety Vehicle, London, 1975.
7. Danner M., Appel H., Schimkat H., Entwicklung

Kompatibler fahrzeuge abschlussbericht, Vorhaben TV 7661 des Bundesministers für Forschung und Technologie, Februar 1980.
8. Oberdiek W., Oehlerking C., Pommer E., Sinnhuber R. Vorschläge zur bildung einer rangreihe. DOK 3, 17.5.1977.
9. Hofmann J., Kramer F. Ermittlung der rangreihe der kollisionstypen aus dem HUK-Gesamtmaterial. DOK 20, TUB 4/1, 15.2.1977.
10. Hartemann F., Thomas C., Foret-Bruno Y., Henry C., Fayon A., Tarrière C., Got C., Patel A. Description of lateral impacts. 6th International Technical Conference on ESV, Washington, 1976.
11. Thomas P., Lanson S., Griffiths D., Breen J. An investigation of a representative sample of real world side impacts to cars EEC Biomechanics programme final report of contract UK1, 1981.
12. Lateral car collisions. SWOV report n° R 79-48, 1979.
13. Cesari D., Ramet M. Biomechanical study of side impact accidents. 5th ESV Conference, London, June 1974.
14. Langwieder K. Aspekte der fahrzeugsicherheit anhand einer untersuchung von realen unfällen. Dissertation, Technische Universität Berlin, 1975.
15. Suren E. G. et al. Verletzungsbild—Ursache und Mechanik beim fahrzeugseitenanprall Langenbecks Arch. Chir. Suppl. Chir. Forum 1975.
16. Cesari D. Influence of intrusion in side impact. 6th ESV Conference, Washington, October 1976.
17. Langwieder K., Schmelzing W. Geschwindigkeitsverteilung von striking/struck car mit resultierender gesamtverletzungsschwere beim kollisionstyp V. VI HUK-Dokument 2/3, München, Juni 1979.
18. Danner M., Langwieder K. Verletzungen von personenwagen-insassen bei unfällen und deren bezug auf äquivalente testgeschwindigkeiten. ATZ, Juni 1973.
19. Loyat B. Improvement in the protection against side impact. 7th International Conference on ESV, Paris, 1979.
20. Cesari D., Ramet M., Herry Martin D. Injury mechanisms in side impact. 22nd Stapp Car Crash Conf. Oct 24-26, 1978, 429-448.
21. Neilson I. D. Proposed design criteria to ensure compatibility in car front to car side impacts between cars of different models. TRRL Working paper n° 40.
22. Stcherbatcheff G., Provensal F. Identification des facteurs de compatibilité des véhicules en choc latéral. 17ème FISITA International conf., Hambourg, 1980.
23. Sievert W. Bewegliche deformierbare Barriere. BAST, in progress.
24. Burgett A., Wander J. A method for estimating the effect of the weight of the barrier in side impact. 8th International Technical Conf. on Experimental Safety Vehicles, Wolfsburg, 1980.
25. Franchini E. Fiat technical presentation. 6th International Conference on ESV, Washington, 1976.
26. Davis S., Ragland C. Development of a deformable side impact moving barrier. 8th International Conference on ESV, Wolfsburg, 1980.
27. CCMC. Development of the CCMC mobile deformable barrier for lateral collision testing, 1981.
28. Chinn B. P. The feasability of a crushable barrier face constructed from tins. TRRL Internal note 1981.
29. UTAC. Etude préliminaire du cahier des charges d'une barrière mobile déformable, 1981.
30. Aldman B., Benjamin T.E.A. European Economic Community support for major biomechanics research programme. AAAM. vol. 4, n° 1, 1982.

APPENDIXES

1—Characteristics of the deformable moving barrier proposed by E.E.V.C.
2—Checking test of characteristics of the moving deformable barrier

APPENDIX 1

CHARACTERISTICS OF THE DEFORMABLE MOVING BARRIER PROPOSED BY E.E.V.C.

1. GENERALITIES

The barrier consists of a rigid undeformable trolley, able to move freely at the moment of impact. Its front part supports a front impactor made of a material which can be deformed when impacted. This impactor is positioned symmetrically about the longitudinal midsaggital plane of the trolley.

2. CHARACTERISTICS OF THE BARRIER

The total mass must be equal to 950 ± 20 kg.

Front and rear wheel gauges must be equal to 1500 ± 70 mm.

The wheel base must be equal to 3000 ± 10 mm.

The centre of gravity must be situated in the longitudinal median plane, 1000 ± 10 mm behind the front axle and 500 ± 10 mm above the ground.

The distance between the front face of the front impactor and the centre of gravity of the barrier must be equal to 1800 ± 20 mm.

3. CHARACTERISTICS OF THE FRONT IMPACTOR

3.1. Geometrical Characteristics

The front impactor consists of six independent joined parts. Forms and sizes and position of these parts are indicated in Figure 1-1.

3.2. Front Impactor Stiffness

Parts 1 and 3 are identical parts. Figure 1-2 shows their stiffness. Their force-deflection curves must be drawn in the hatched region of graph 2a.

Parts 5 and 6 are identical parts. Graph 2d shows their stiffness, their force-deflection curves must be drawn in the hatched region of this graph.

Graph 2b shows the stiffness of part 2, its force-deflection curve must be drawn in the hatched region on this graph.

Graph 2c shows the stiffness of part 4, its force-deflection curve must be drawn in the hatched region of this graph.

The front impactor force-deflection must be drawn in the hatched region of graph 2e (Figure 1-2).

Verification of front impactor stiffness will be determined from moving deformable barrier to load cell fixed barrier tests. These tests will be conducted at 35 ± 2 km/h.

The dissipated energy (1) against parts 1 and 3 during the test will be equal to 10 (± 2) kJ for each of these parts.

The dissipated energy against parts 5 and 6 will be equal to 3,5 (± 1) kJ for each of these parts.

The dissipated energy against part 4 will be equal to 4 (± 1) kJ.

The dissipated energy against part 2 will be equal to 14 (± 2) kJ.

The total dissipated energy during the crash will be equal to 45 (± 5) kJ.

The front impactor deformation measured after the test on the level of points B (Figure 1-1) must be equal to 350 (± 20) mm.

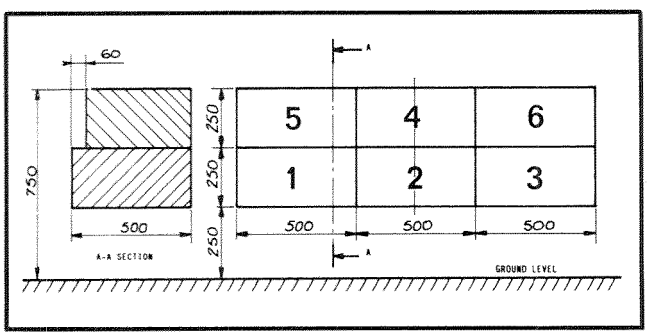


Figure 1. Proposed design of the front end (deformable part) of the EEVC barrier.

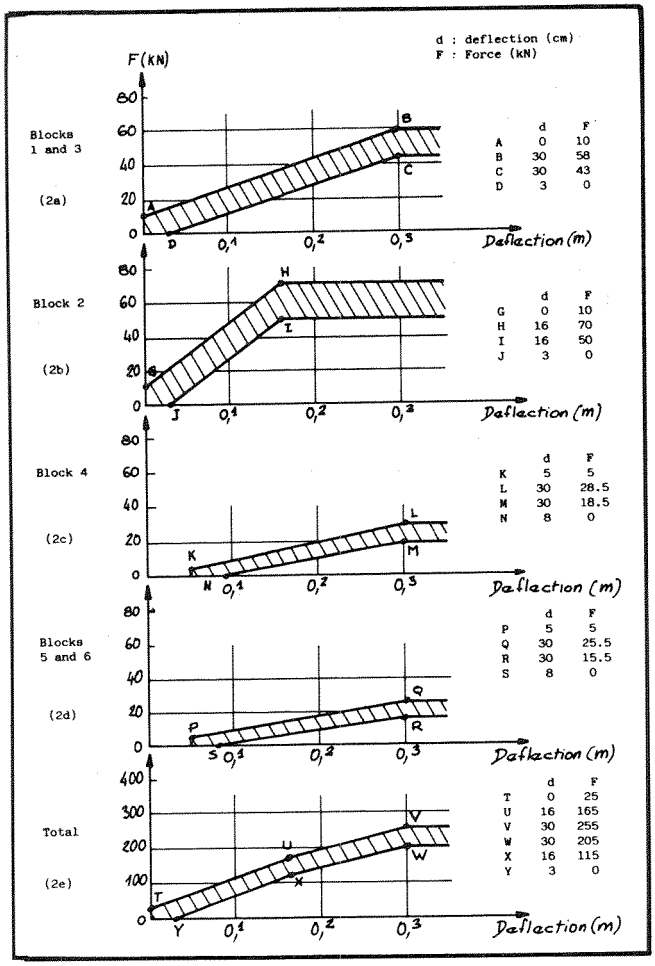


Figure 2. Force-deflection characteristics of the EEVC barrier.

(1) Indicated energies are energies which are absorbed by the system when the front impactor deflection reaches the greatest value.

N.B. Curves and tolerances given are objects to be reached and could be changed as a function of materials used to build the front impactor and of first results of tests made with a prototype.

APPENDIX 2

CHECKING TEST OF CHARACTERISTICS OF THE MOVING DEFORMABLE BARRIER

1. INSTALLATION

1.1 Testing Ground

The test area shall be large enough to accommodate the run up track of the moving deformable barrier, rigid

barrier and technical installation necessary for the test. The last part of the track, for at least 5 m before the rigid barrier, shall be horizontal, flat and smooth.

1.2 Rigid Barrier

The rigid barrier shall consist of a block of reinforced concrete not less than 3 m wide in front and not less than 1,5 m high. The rigid barrier shall be of such thickness that it weighs at least 70 metric tons. The front face shall be vertical, perpendicular to the axis of the run up track and covered with load cells being able to measure at the moment of impact the total load of each part of the moving deformable barrier front impactor.

The rigid barrier shall be either anchored in the ground or placed on the ground with, if necessary, additional arresting devices to limit its displacement. A rigid barrier with load cells with different characteristics, but giving results at least equally conclusive may likewise be used.

2. PROPULSION OF MOVING DEFORMABLE BARRIER

At the moment of impact the moving deformable barrier shall no longer be subject to the action of any additional steering or propelling device. It shall reach the obstacle on a course perpendicular to the collision wall.

3. MEASURING INSTRUMENTS

3.1 Speed

The instrument used to record the speed on impact shall be accurate to within 1 percent.

3.2 Loads

Measuring instruments shall meet the prescriptions set forth in the Norm ISO N° 6487. Channel class of load measuring chain must be class 60.

Mechanical resonances associated with transducer mounting should not distort readout data.

An Approach for the Design of a Deformable Mobile Barrier to Evaluate the Protection Afforded to Occupants of a Passenger Car Involved in a Side Collision

E. CHAPOUX,
Technical General Manager

J. C. JOLYS,
Head of Safety Department and

R. DARGAUD, Engineer
Union Technique De L'Automobile,
Du Motocycle Et Du Cycle (U.T.A.C.)

ABSTRACT

The statistical importance of the lateral impact, either in quantity and severity index of injuries, is stressed out. The various test procedures allowing to quote the degree of protection afforded to the occupants of a passenger car are analysed. It is also recalled that the only procedure capable to lead to a realistic and coherent approach of the problem is the test carried out with an impactor of which the front end features specific properties of rigidity and deformation.

The details of measurements carried out on 20 cars representative of present practices in automobile structural design, and affording good passenger protection in case of frontal impact, are discussed here. Precisions are also given on their treatment, thus leading through statistical way to the proposed solution for a deformable mobile barrier: mass, width, height from the ground level, usable height, number of blocks, rigidity of each block and possible procedure to follow with maximum accuracy the curve of mean rigidity issued from the actual tests. A validation procedure has been already set up, and right now, data are collected during side collision tests of 10 vehicles (selected out of the 20) against the same vehicle, also chosen among the 10 and taking account of its statistical importance in the registrations, and also of its own structural technology.

A comment discusses about some arguments already expressed at the meeting of the Working Group n° 6 (C.E.V.E.), showing the possible subsequent developments carried out with the proposed deformable mobile barrier (BMD: Barrier Mobile Deformable) for the improvement of regulations, taking account of performance criteria instead of geometrical ones.

INTRODUCTION

Since the governments became fully conscious of the importance of the frontal impact in the overall records of road accidents in which passenger cars are involved, this type of impact was submitted to extensive searches in the field of shock mechanics as applied to automotive

structures, and also in the field of biomechanics. Those studies resulted in the creation of official regulations making compulsory an array of safety standards, first applied in the USA, then in Europe and at a later date in other countries, and pertaining to the vehicles themselves as well as the restraint systems anchored to the structure.

The biomechanical incidences have led to the construction of dummies, allowing the possibility to evaluate the crashworthiness and then the quality of protection afforded to the occupants by means of protection criteria measured on the dummies. This is done in the target of a more efficient regulation, and keeping the manufacturers free for the choice of the most suitable solutions. Europe did not hesitate to follow the way paced by the USA, and has just adopted, in the frame of the UNO WP 29 working group of Experts, a regulation aimed to the same target.

If sectorial regulations could be applied without any criticism about their efficiency in the field of frontal impact, and have led to substantial improvements in the quality of occupant protection even before the creation of the test so called "global" or "integrated", nothing similar could be foreseen regarding lateral impact. This sort of shock has taken a growing importance in the statistical records of accidents, so far the effectiveness of the compulsory regulations was perceptible on the new vehicles. It must be said that a regulation laid down in the USA made possible some improvement on the American-sized vehicles, but this could be hardly applied to the European-sized vehicles, due to the differences in structure techniques and weights between the 2 kinds of vehicles.

The most severe injuries issued from a lateral impact are lesions concentrated in torso and pelvis regions (AIS 4, 5 and 6). Important studies, undertaken in the frame of the Physiology and Development Department of the PEUGEOT-RENAULT Association, in cooperation with the French government, gave evidence that the most determinant factor in the severe injuries resulting from a side impact was the velocity of the inner panel, on the side of the impact, at the moment of contact with the occupant.

At the moment, it must be noticed that, according to the intrusion, this inner panel velocity is fairly greater than the velocity of non-impacted structures of the vehicle.

The improvement of the protection against lateral impact, accordingly, makes necessary to reduce this velocity of contact between inner panel and occupant; this can be achieved by means of design changes of the lateral structure at one hand, and by a careful study of the compatibility between front end structures and modified side panels on the other hand. This problem of compatibility between frontal and lateral structures can arise the question of the effect of the ratio between the weights of the 2 cars involved in the collision.

Although some restrictions could be made about the response of the existing dummies used for tests of lateral impact, a study showed that, for given structures maintained constant, an increase of the weight of the impacting vehicle has a small influence on the value of the severity indexes of the injuries, as measured on the dummy.

As soon as they knew the incidence of the significant parameters on the occupants protection, the French experts, since the origins of those studies, have rejected the use of a rigid barrier, despite the fact they did a great deal of work in the preparation of a proposed ECE regulation at Geneva. In fact, such a rigid barrier cannot take account of the velocity variation of the inner panel area nearest the occupant.

The same experts found of interest, in view to solve simultaneously the problems of lateral protection and aggressiveness of the front end of a given vehicle regarding the other vehicles, to study an impact procedure of side collision between two identical vehicles. This assumption was founded on the analysis of the sturdiness of vehicles' side panels, and the door openings arrangement. It has been witnessed that, in the areas involved in actual accidents, the stiffness variations were small according to the gauge of the vehicles. Consequently, a vehicle of small aggressiveness against itself will have rather the same behaviour against other vehicles.

The drawback of this procedure was to neglect the weight effect. The procedure, in fact, must allow to take account of the various present and future cars' configuration, thus leading to us an impactor shaped as the front end of a vehicle which, thanks to its resilience properties and crashworthiness, will afford an acceptable protection to the occupants in case of frontal impact while preserving a fairly small aggressiveness.

This front end representative of modern cars' design must then be fitted on a mobile barrier, of a given mass, which will be propelled, according to some precisely preset conditions of speed and orientation against the side panel of the vehicle to be tested.

Thus basic principles led to detailed questions pertaining to the design of the impactor:

What shape must be adopted?
What rigidity distribution must be selected? Who speaks about distribution means variation in stiffness between spotted points on the front end. But in view to limit those variations, it has been accepted to divide the front end in a certain number of blocks.
How many blocks to retain?
What rigidity to be adopted for each of them? Will it be constant, or variable according to a given rate for each block?
So far those questions are given an answer, and the front end conveniently designed. Another question is:
What will be the overall mass of the complete mobile barrier?

DESIGN OF A DEFORMABLE MOBILE BARRIER

The working program carried out in France by U.T.A.C., and supported by the French government and the Automotive Manufacturers allowed to afford proper answers to the questions mentioned above and, taking account of the previsible fluctuations of car popularity by classes out of the grand total of French registrations, to present a project of deformable mobile barrier which, at a later date, has been compared with other European projects.

The American proposal could not be taken under consideration afterwards, due to the diferences in layout and masses between the American and European cars selected for the tests against the respective barriers.

Statistical Data Related to the Reference Vehicles

Twenty vehicles were selected according to two criteria:

1) They were well representative of the contemporary trends in automotive construction able to afford a convenient protection to the front seat occupants, in agreement with the proposed regulation presented by the French representatives to the ECE of GENEVA.

2) They were also well representative of the car registration distribution inside the French territory.

Those 20 vehicles were the basis of the investigations.

This proposed regulation, known as the "integrated test" or "synthesis test", is based on the biomechanial criteria measured on anthropomorphic dummies, and not on the structure construction criteria as it was in the previous regulations still enforced at the present time.

The following table shows the relative percentage of the total registration for each of the 20 selected vehicles.

Reference no. of the vehicle (i)	Relative quantity in percent (ni)
1	4,06
2	6,65
3	5,11
4	5,14
5	0,26
6	4,63
7	0,16
8	6,03
9	7,73
10	11,26
11	3,47
12	0,62
13	0,28
14	1,00
15	3,77
16	21,49
17	6,54
18	8,37
19	0,06
20	3,37
	100%

If A_i is the value of one of the parameters (measured on the reference vehicles, i varying from 1 to 20 according to the above table), the mean average in function of the various values of n_i mentioned in the above table will be expressed by the formula:

$$A = \sum_{1}^{20} \frac{A_i \times n_i}{\sum_{1}^{20} n_i}, \text{ say } \sum_{1}^{20} \frac{A_i \times n_i}{100}$$

Impact Tests Against a Dynamometric Fixed Barrier

Except for the steering system assembly, which interferes very little in the general crashworthiness, due to its own longitudinal stiffness and the one of its attaching brackets, a car may be considered as symmetrical regarding its longitudinal axis plane. Considering the presence of the engine, centrally located in front either in longitudinal or transverse position, it was agreed to divide the front end of the impactor in six blocks. Taking account of the variations in height and width from one sample vehicle to the other, U.T.A.C. was led to build a dynamometric fixed barrier as pictured on Figure 1. This barrier can integrate all the stresses applied on any vehicle, considering the gap between the two rows of blocks located at a height of 550 mm above the ground level.

Description of the U.T.A.C. Dynamometric Fixed Barrier

Each element of the dynamometric fixed barrier consists of:

—a 10 mm thick steel plate, fitted with stiffness,
—a 150 mm thick wooden block,
—a 19 mm thick (± 1 mm tolerance) sheet of plywood.

The assembly of each plate is fastened on a 34 mm thick steel plate through 4 load-responsive sensors (Fig. 1).

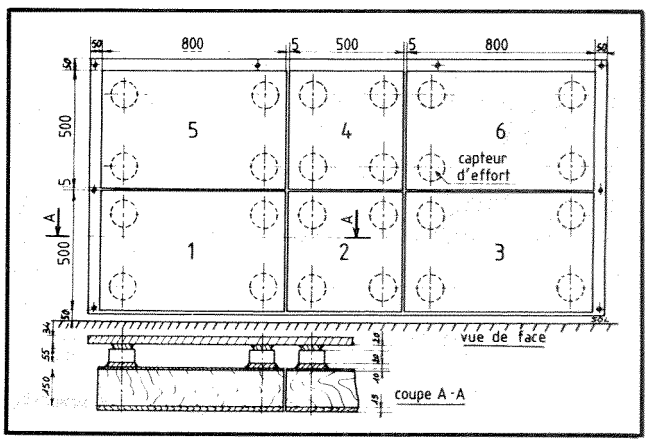


Figure 1. The U.T.A.C. dynamometric fixed barrier.

This latter plate is used as the base for the dynamometric unit, and is itself fastened on a concrete barrier by means of ten 16 mm in diameter screws. Dimensions of the concrete barrier are: width: 3 meters—usable height: 1.50 meter. The thickness has been calculated to obtain an overall mass of the concrete barrier not inferior to 70 metric tons. The verticality of this barrier, and its perpendicularity related to the trajectory imposed by the propulsive unit are afforded with an accuracy of ± 0.5 degree.

The measuring device consists of 24 load-responsive sensors. The signals emitted by the 4 sensors of each element are added through an electronic totalizer which calculated the total value of the load applied on each considered element.

The range of possible measurements for each sensor is:

—20,000 daN for each of the upper side blocks (N° 5 and 6)

—40,000 daN for each of the upper central section, and for all the lower blocks (N° 1, 2, 3 and 4).

The measuring channels are in agreement with the ISO Standard N° 6487 for the frequence class 60.

The whole assembly of the dynamometric fixed barrier and its attached recording equipment is pictured on Figures 2 and 3.

Determination of the Laws Relating Load to Crush Characteristics

On each dynamometric plate, loads are measured related to time. The curve of the crush variation of the front end of the vehicle related to the time can be obtained by means of a double integration of accelerations values measured on the structure. This curve can be checked from the analysis of the moving pictures taken during the actual test. Consequently, it becomes easy for each vehicle (i) to determine the law between load and crush for each dynamometric plate (Fig. 4), and the total load in regard of this amount of crush (Fig. 5).

For each value of crush, the above mentioned formula

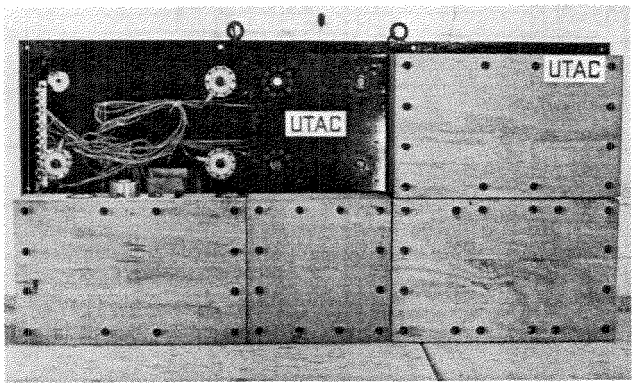


Figure 2. The U.T.A.C. dynamometric fixed barrier.

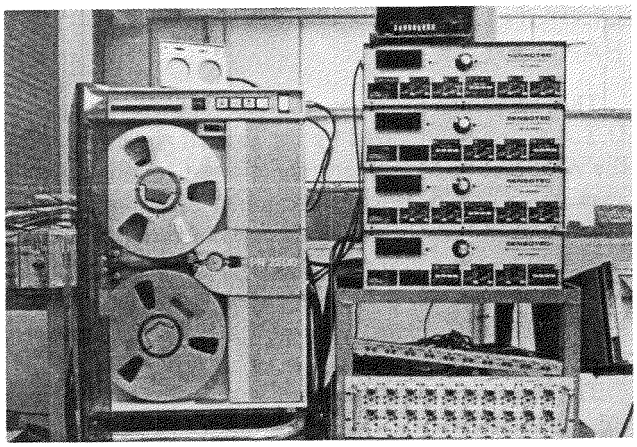


Figure 3. The recording equipment, shown during an actual vehicle test.

is applied, the base of calculation being the values of the load recorded on the 20 selected vehicles, and this for each plate of the dynamometric barrier.

As a matter of example, if $(\overline{A})$ represents the mean load $(\overline{F})$ measured on the dynamometric plate (j) for a crush value (e), the measured loads on each of the vehicles (i), for the same value of crush (e), being f_{ij}, this mean load on each plate will be:

$$\overline{F}_{j(e)} = \frac{\sum_{1}^{20} f_{ij}\,(e) \times n_i}{100}$$

with j varying from 1 to 6.

This formula makes possible the determination of the mean average load on each plate related to the crush value (Fig. 7), and, by summing up, the total mean average load related also to the crush value (Fig. 6).

From the notations mentioned in the Fig. 8, the Tables 1 to 7 added in the appendix give the characteristic values issued from the analysis of curves F = f(e) for each plate j (1 to 6) and for each vehicle i (1 to 20).

Determination of the Mean Average Mass

If one applies the load formula to the particular load of each sample vehicle i (1 to 20) as mentioned on Table 7, A being the mass m_i, the mean average mass will be given by the formula:

$$\overline{M} = \sum_{i=1}^{20} \frac{m_i\, n_i}{100}$$

This calculation leads to a mass of 903 kg. Should the same calculation be applied to 100 models of vehicles registered in France, and having a consistent statistic significance, the result is $\overline{M}$ = 915 kg.

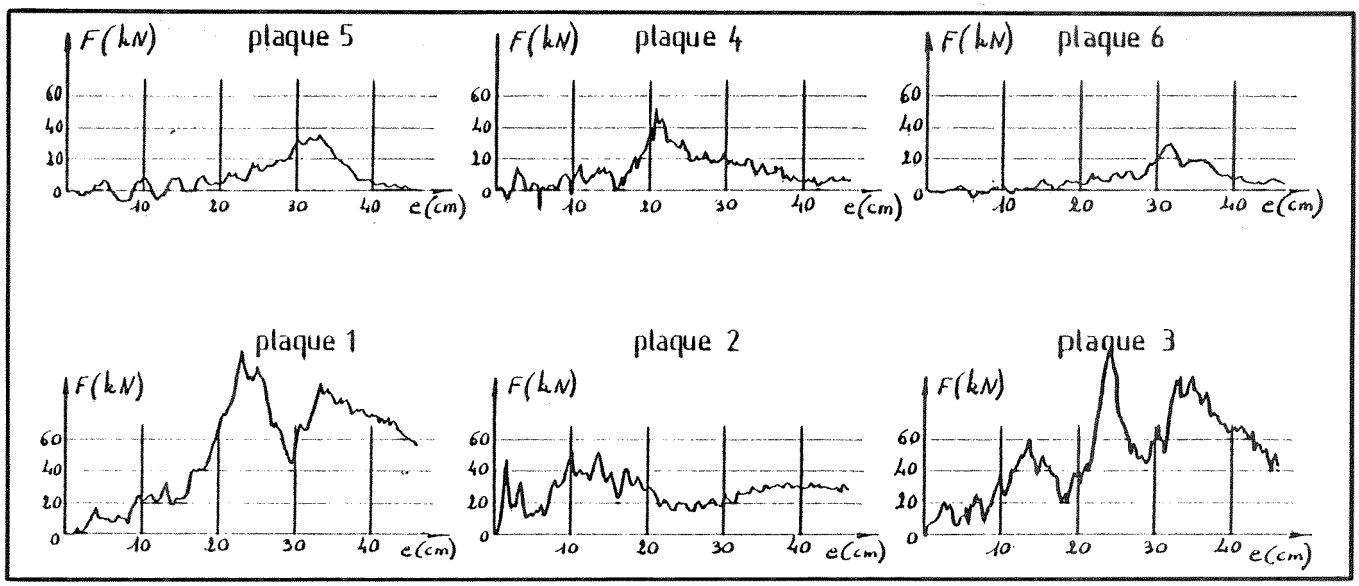


Figure 4. Curves of loads variation related to the value of crush of a vehicle tested against the U.T.A.C. dynamometric fixed barrier.

DIMENSIONAL CHARACTERISTICS

The silhouettes of the 20 vehicles supplied by the automotive manufacturers have been numbered.

If the already introduced calculation procedure is applied to each point of the silhouettes, starting at the front bumper level and according a given pitch, one can obtain in a vertical plane a mean average profile, as well as a mean average projection on an horizontal plane (Fig. 9).

Determination of the Crush To Be Considered

The front end of the deformable mobile barrier must be compatible with the mean average stiffness of each constitutive block to simulate the crashworthiness of the sample vehicles, and, accordingly, to produce similar effects on the lateral structures of the cars to be tested.

The mean maximum average, as defined from the maximum crush values mentioned in the Table 7, and following the previous calculation procedure to determine mean values, is Emax = 355 mm.

On the same Table 7, a minimum value of 260 mm is mentioned for Emax.

The maximum dynamic crush value of the front end of the barrier will be chosen at the level of the mean average value of maximum crushes, say 360 mm.

Taking account of the advantage to oversize the blocks, avoiding them to be used at their maximum capacity, it appeared highly suitable to adopt a block "depth" equal to 500 mm.

Composition of the Working Section of the UTAC Deformable Mobile Barrier (BMD)

If the target of the test is a direct average simulation of the effects of the 20 vehicles on the side panels of the

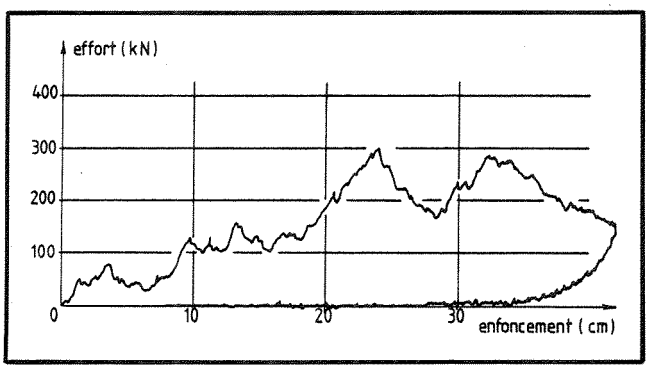


Figure 5. Curve of the total load variation related to the value of crush of a vehicle tested against the U.T.A.C. dynamometric fixed barrier.

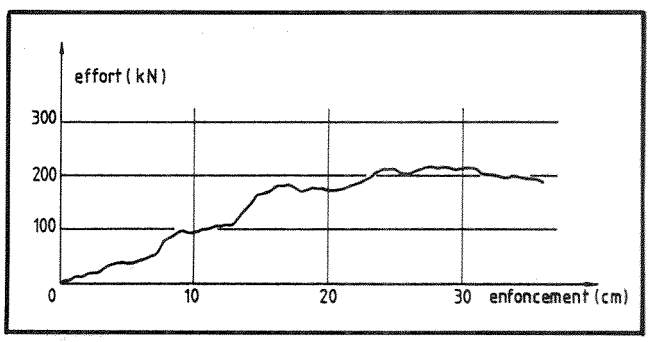


Figure 6. Curve of the variation of the total load mean average value obtained by calculation.

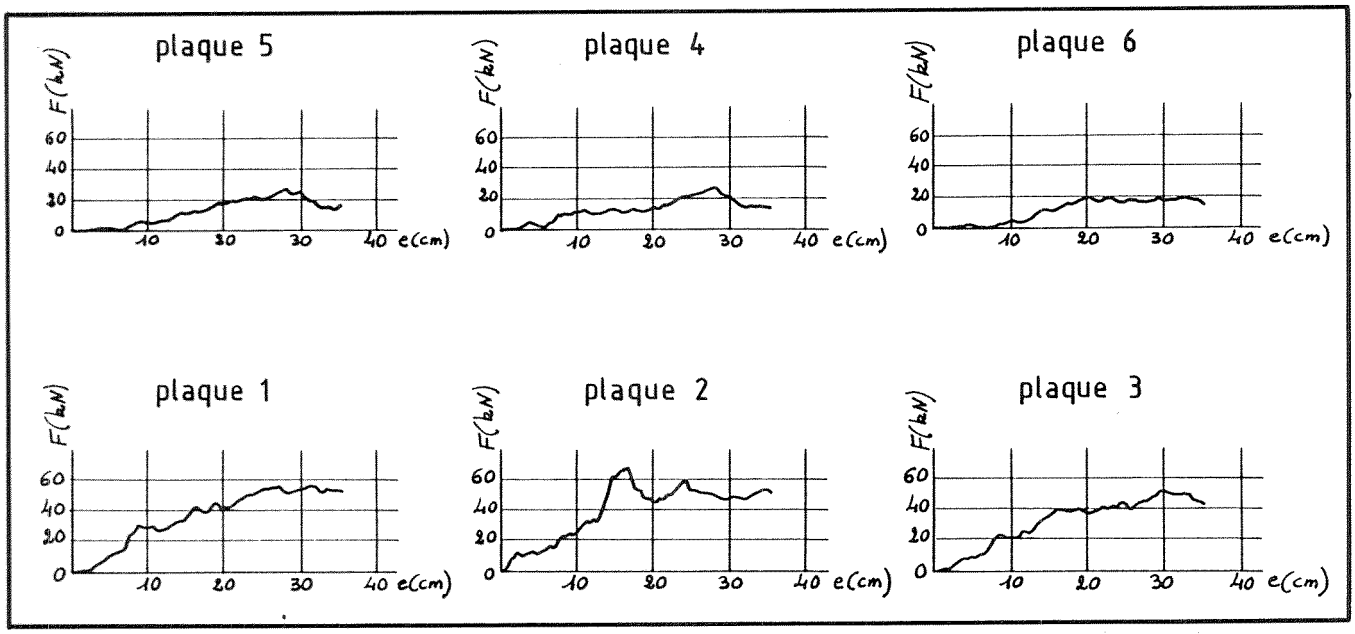
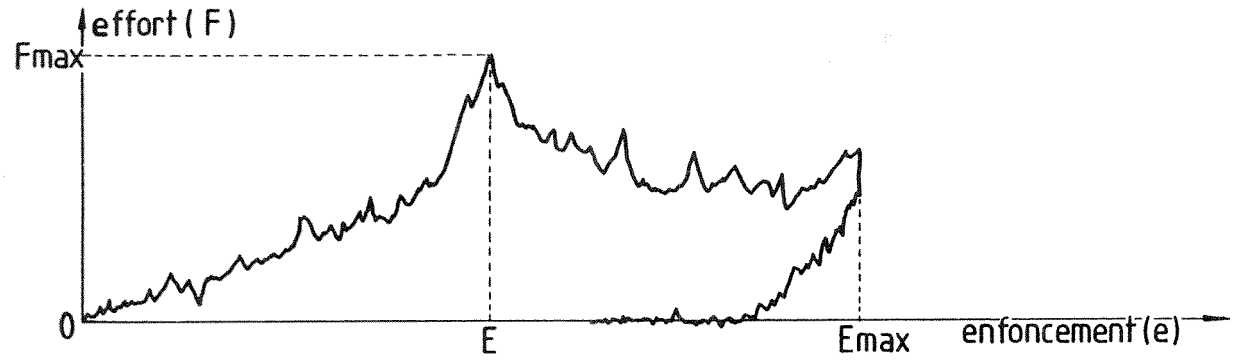


Figure 7. Curves of the variation of the loads mean average values calculated on each dynamometric plate.



M = mass of the sample vehicle

E = e (F max)

F_1 = average value of F calculated up to E max.

$\mathcal{E}$ = coefficient of elastic regeneration, given by the formula :

$$\mathcal{E} = \frac{\int_0^{t_1} \gamma \, dt - V_0}{V_0} \quad \text{with } t = t_1 \text{ when } \gamma = 0$$

V_0 = velocity at the very beginning of impact

F_{moy} = average value of F calculated for the duration of the impact

Pente = value of the ratio $\frac{\Delta F}{\Delta e}$

E_n = rate of energy absorbed by each dynamometric plate.

Figure 8. Definitions of the parameters mentioned in the Tables 1 to 7.

Table 1. Values recorded on the dynamometric plate no. 1.

VEHICULE	M	V_o	F_{max}	F_{moy}	F_1	F_{max}/F_{moy}	F_{max}/F_1	E_n
	kg	km/h	kN	kN	kN	-	-	%
1	1410	37,7	71,7	16,3	37,8	4,41	1,90	22,3
2	1320	34,8	99,9	22,1	56,1	4,52	1,78	34,6
3	1285	35,3	103,5	23,3	59,7	4,45	1,73	34,2
4	1205	36,3	98,0	15,9	40,3	6,16	2,43	25,4
5	1145	35,3	38,0	8,1	20,4	4,72	1,87	15,5
6	1060	36,2	76,2	17,6	43,6	4,32	1,75	26,7
7	1090	35,5	95,2	19,9	38,1	4,78	2,50	30,5
8	920	34,9	97,6	14,2	37,3	6,89	2,62	30,2
9	990	34,4	71,5	9,8	29,1	7,28	2,46	20,4
10	955	35,0	54,8	10,9	22,8	5,04	2,41	19,5
11	925	35,8	80,5	11,4	40,4	7,08	1,99	24,3
12	860	35,1	65,0	8,2	25,6	7,94	2,53	20,9
13	800	34,7	69,3	13,0	36,6	5,33	1,09	30,2
14	775	35,3	69,6	8,4	33,6	8,32	2,07	22,1
15	695	34,3	14,5	1,9	5,7	7,70	2,56	5,0
16	600	34,5	35,8	7,2	16,6	4,97	2,16	19,7
17	600	34,1	23,7	4,3	13,6	5,44	1,75	15,3
18	1150	37,6	119,4	23,8	53,9	5,03	2,22	33,1
19	660	32,5	53,1	4,9	22,4	10,83	2,37	16,3
20	800	33,7	88,8	11,8	37,8	7,55	2,35	28,1

Table 3. Values recorded on the dynamometric plate no. 3.

VEHICULE	M	V_o	F_{max}	F_{moy}	F_1	F_{max}/F_{moy}	F_{max}/F_1	E_n
	kg	km/h	kN	kN	kN	-	-	%
1	1410	37,7	77,4	16,0	39,8	4,82	1,94	23,5
2	1320	34,8	127,4	35,5	67,7	3,58	1,88	41,6
3	1285	35,3	98,8	17,6	49,6	5,62	1,99	28,4
4	1205	36,3	100,4	16,3	44,3	6,15	2,27	27,9
5	1145	35,3	79,2	13,9	29,9	5,70	2,65	22,7
6	1060	36,2	72,7	14,9	45,3	4,89	1,61	27,8
7	1090	35,5	47,0	11,7	22,6	4,01	2,08	18,1
8	920	34,9	59,8	10,7	25,4	5,60	2,36	20,6
9	990	34,4	84,2	13,8	39,2	6,09	2,15	27,7
10	955	35,0	27,5	5,9	12,7	4,69	2,17	10,9
11	925	35,8	102,2	15,1	48,7	6,76	2,10	29,2
12	860	35,1	93,9	15,4	46,1	6,08	2,04	37,6
13	800	34,7	27,5	3,3	8,9	8,24	3,08	7,3
14	775	35,3	14,6	2,2	4,6	6,63	3,18	3,1
15	695	34,3	43,8	6,8	19,7	6,44	2,22	17,3
16	600	34,5	30,7	6,4	17,3	4,82	1,78	20,4
17	600	34,1	53,0	8,5	25,4	6,23	2,09	28,7
18	1150	37,6	120,1	20,5	51,4	5,85	2,34	31,6
19	660	32,5	83,5	6,5	27,1	12,80	3,08	19,8
20	800	33,7	102,7	10,9	38,2	9,41	2,69	28,4

vehicles to be tested, it is important that the barrier consisting of deformable blocks having rigidity properties such that, during a test of frontal collision of this barrier against a dynamometric barrier, the curve "total load related to crush value" is maintained as identical as possible to the average curve already traced (see Fig. 6) and that this average load will be distributed on each block as mentioned on the curves of the Fig. 7.

It can be concluded that, to reproduce (or simulate) the direct effects, it is not possible to use blocks of constant stiffness, and that this stiffness of each block must be calibrated as the more suitable to the recorded mean average rigidity values.

At the moment, it seems difficult to obtain a continuously variable rigidity to reproduce the curves issued from calculation.

Besides that, the manufacturing process having to be reproducible at the minimum cost, it has been contemplated to call for well proven techniques in favour at U.T.A.C., and, to use, for example, the well known honeycomb structures with adjustable rigidities.

Using current products having deformation specific

Table 2. Values recorded on the dynamometric plate no. 2.

VEHICULE	M	V_o	F_{max}	F_{moy}	F_1	F_{max}/F_{moy}	F_{max}/F_1	E_n
	kg	km/h	kN	kN	kN	-	-	%
1	1410	37,7	59,5	13,3	22,7	4,47	2,63	13,4
2	1320	34,8	29,2	7,8	16,8	3,74	1,74	10,3
3	1285	35,3	93,4	11,4	27,6	8,16	3,39	15,8
4	1205	36,3	118,8	12,5	28,6	9,48	4,10	17,9
5	1145	35,3	87,0	12,5	18,0	6,95	4,75	13,7
6	1060	36,2	54,2	10,1	25,2	5,39	2,15	15,5
7	1090	35,5	65,8	10,7	25,3	6,14	2,60	20,4
8	920	34,9	87,9	13,7	33,8	6,40	2,60	27,4
9	990	34,4	99,4	19,2	42,8	5,17	2,32	30,1
10	955	35,0	57,0	10,5	24,6	5,41	2,32	21,1
11	925	35,8	90,8	13,1	51,5	6,93	1,76	31,1
12	860	35,1	69,0	9,0	22,8	7,66	3,02	18,6
13	800	34,7	77,5	14,2	37,8	5,47	2,05	31,0
14	775	35,3	194,4	21,4	84,5	9,10	2,30	55,7
15	695	34,3	213,9	20,6	74,5	10,37	2,87	65,7
16	600	34,5	59,4	10,3	24,1	5,79	2,47	28,7
17	600	34,1	117,0	12,1	36,0	9,63	3,25	40,4
18	1150	37,6	53,1	13,0	27,9	4,10	1,91	17,1
19	660	32,5	333,9	11,3	56,6	29,46	5,90	41,3
20	800	33,7	65,4	6,5	17,8	10,10	3,68	13,2

Table 4. Values recorded on the dynamometric plate no. 4.

VEHICULE	M	V_o	F_{max}	F_{moy}	F_1	F_{max}/F_{moy}	F_{max}/F_1	E_n
	kg	km/h	kN	kN	kN	-	-	%
1	1410	37,7	65,7	9,8	21,8	6,73	3,02	12,8
2	1320	34,8	18,4	3,8	7,7	4,80	2,40	4,7
3	1285	35,3	125,5	6,9	20,1	18,30	6,24	11,6
4	1205	36,3	44,4	5,8	13,9	7,65	3,20	8,8
5	1145	35,3	56,5	6,6	14,8	8,54	3,81	11,4
6	1060	36,2	19,9	3,5	9,6	5,66	2,08	5,9
7	1090	35,5	24,0	3,3	8,9	7,25	2,71	7,2
8	920	34,9	58,6	5,8	16,8	10,04	3,48	13,5
9	990	34,4	23,0	2,3	5,4	10,23	4,27	3,7
10	955	35,0	38,4	7,7	17,9	4,96	2,14	15,4
11	925	35,8	35,3	5,3	14,6	6,60	2,83	8,8
12	860	35,1	32,3	4,1	8,0	7,86	4,04	6,6
13	800	34,7	34,8	5,0	14,0	6,98	2,39	11,4
14	775	35,3	31,6	2,8	9,6	11,39	3,28	6,4
15	695	34,3	15,1	1,5	2,2	10,04	6,96	2,1
16	600	34,5	38,9	2,6	9,8	14,75	3,97	11,8
17	600	34,1	21,7	3,5	10,2	6,17	2,14	11,4
18	1150	37,6	55,3	5,6	13,3	9,92	4,16	8,2
19	660	32,5	24,9	1,8	7,0	13,94	3,55	5,2
20	800	33,7	37,3	6,3	15,1	5,91	2,47	11,2

Table 5. Values recorded on the dynamometric plate no. 5.

VEHICULE	M	V_o	F_{max}	F_{moy}	F_1	F_{max}/F_{moy}	F_{max}/F_1	E_n
	kg	km/h	kN	kN	kN	-	-	%
1	1410	37,7	71,8	11,9	26,4	6,02	2,72	15,5
2	1320	34,8	26,2	4,3	8,8	6,11	2,96	5,4
3	1285	35,3	37,7	3,6	11,3	10,34	3,35	6,4
4	1205	36,3	37,6	6,0	14,2	6,25	2,65	8,9
5	1145	35,3	61,0	9,9	24,8	6,15	2,46	19,0
6	1060	36,2	46,5	5,9	17,9	7,87	2,59	11,0
7	1090	35,5	44,6	7,0	18,3	6,35	2,44	14,7
8	920	34,9	25,6	1,7	5,3	15,25	4,83	4,3
9	990	34,4	39,0	6,0	14,0	6,52	2,78	9,9
10	955	35,0	73,0	9,4	22,6	7,74	3,24	19,3
11	925	35,8	17,2	1,7	4,4	9,89	3,92	2,7
12	860	35,1	27,4	3,5	9,3	7,92	2,87	7,7
13	800	34,7	41,4	4,6	14,9	8,98	2,78	12,3
14	775	35,3	35,0	3,0	11,1	11,52	3,16	7,4
15	695	34,3	17,9	1,3	4,9	14,19	3,64	4,4
16	600	34,5	27,8	2,7	8,8	10,48	3,17	10,4
17	600	34,1	13,2	1,6	1,9	8,30	7,09	2,0
18	1150	36,6	36,2	2,8	9,3	12,96	3,90	5,7
19	660	32,5	33,9	4,3	12,7	7,93	2,67	9,2
20	800	33,7	25,3	3,7	11,4	6,88	2,23	8,4

Table 6. Values recorded on the dynamometric plate no. 6.

VEHICULE	M	V_o	F_{max}	F_{moy}	F_1	F_{max}/F_{moy}	F_{max}/F_1	E_n
	kg	km/h	kN	kN	kN	-	-	%
1	1410	37,7	65,2	9,5	21,0	6,87	3,11	12,4
2	1320	34,8	22,8	2,6	5,2	8,84	4,41	3,2
3	1285	35,3	17,4	1,6	6,2	10,58	2,81	3,6
4	1205	36,3	44,7	7,7	17,9	5,80	2,50	11,3
5	1145	35,3	57,2	9,5	23,1	5,99	2,48	17,7
6	1060	36,2	47,4	7,2	21,0	6,62	2,26	13,0
7	1090	35,5	35,4	4,4	11,7	7,96	3,03	9,3
8	920	34,9	29,4	1,8	4,9	16,43	6,06	3,9
9	990	34,4	34,1	4,0	11,5	8,60	2,97	8,2
10	955	35,0	52,9	7,2	16,0	7,33	3,30	13,7
11	925	35,8	26,1	2,8	6,5	9,36	4,02	3,9
12	860	35,1	26,2	4,5	10,6	5,76	2,46	8,8
13	800	34,7	30,8	3,3	9,5	9,37	3,26	7,8
14	775	35,3	28,6	2,3	7,9	12,21	3,52	5,3
15	695	34,3	22,8	2,2	6,7	10,16	3,39	5,9
16	600	34,5	24,0	2,4	7,5	9,82	3,18	9,0
17	600	34,1	13,5	1,5	2,0	9,08	6,28	2,3
18	1150	37,6	29,2	3,0	7,2	9,82	4,06	4,4
19	660	32,5	40,1	3,1	11,4	12,95	3,52	8,4
20	800	33,7	34,0	5,2	14,4	0,75	2,37	10,8

Table 7. Values related to total loads variation curves (related to crush values).

VEHICULE	M	V_o	F_{max}	F_{moy}	F_1	E	Emax	E/E_{max}	F_{max}/F_{moy}	F_{max}/F_1	ε	Pente moyenne
	kg	km/h	kN	kN	kN	m	m	-	-	-	-	kN/m
1	1410	37,7	294,5	76,8	169,4	0,20	0,52	0,37	3,84	1,74	0,21	1345
2	1320	34,8	310,8	76,2	162,2	0,36	0,41	0,88	3,96	1,86	0,25	940
3	1285	35,3	404,3	64,4	174,3	0,27	0,40	0,67	6,28	2,32	0,14	1155
4	1205	36,3	320,0	64,3	159,2	0,32	0,47	0,69	4,98	2,01	0,11	920
5	1145	35,3	279,1	60,5	131,0	0,36	0,48	0,75	4,61	2,13	0,24	625
6	1060	36,2	226,4	59,1	162,5	0,38	0,40	0,97	3,83	1,39	0,13	2000
7	1090	35,5	258,0	57,1	124,8	0,32	0,49	0,65	4,52	2,07	0,11	625
8	920	34,9	308,1	47,9	123,3	0,30	0,38	0,78	6,44	2,50	0,17	880
9	990	34,4	249,9	55,1	142,0	0,24	0,38	0,63	4,54	1,76	0,21	780
10	955	35,0	216,0	51,6	116,5	0,24	0,44	0,55	4,18	1,85	0,21	660
11	925	35,8	312,1	49,5	166,1	0,26	0,31	0,85	6,31	1,88	0,10	1190
12	860	35,1	258,4	44,7	122,5	0,16	0,38	0,42	5,78	2,11	0,14	715
13	800	34,7	230,5	43,4	121,6	0,27	0,38	0,70	5,31	1,90	0,16	780
14	775	35,3	277,5	40,1	151,4	0,17	0,26	0,65	6,92	1,83	0,25	4375
15	695	34,3	275,8	34,3	113,6	0,17	0,30	0,56	8,04	2,43	0,11	3000
16	600	34,5	178,6	31,6	84,1	0,29	0,34	0,86	5,66	2,12	0,17	550
17	600	34,1	208,2	31,6	89,0	0,24	0,35	0,70	6,59	2,34	0,16	500
18	1150	37,6	304,8	68,6	163,0	0,24	0,46	0,52	4,44	1,87	0,09	1070
19	660	32,5	510,3	31,9	137,2	0,16	0,27	0,59	16,00	3,72	0,12	5000
20	800	33,7	279,8	44,4	134,6	0,19	0,34	0,57	6,31	2,08	0,11	1000

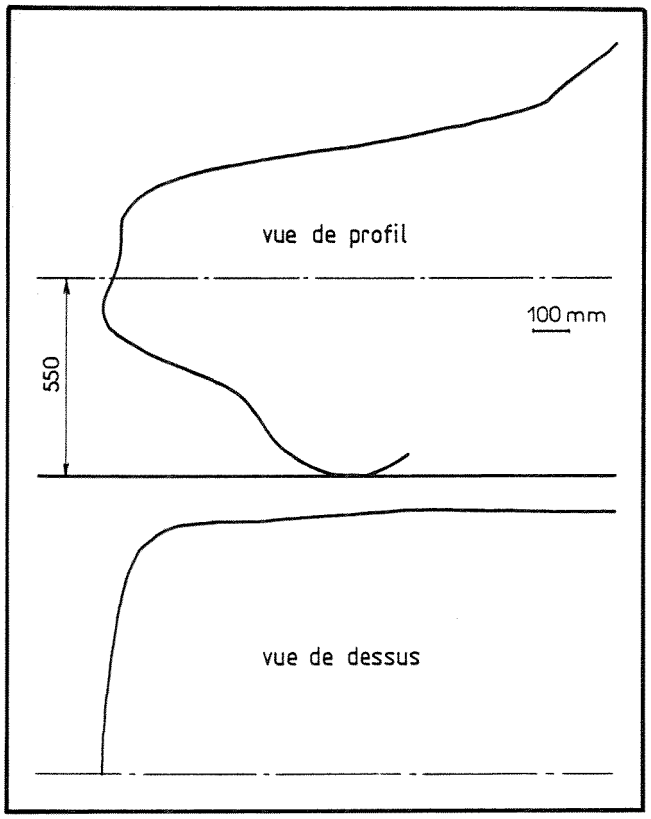


Figure 9. Definition of the front end of the vehicle obtained from the silhouette of numbered sample vehicles.

pressures of 15, 30, 45, 60 and even 75 N/cm^2, the curves pictured on figures 6 and 7 would be approached by using only a stepped variation of rigidity as mentioned on the graphs of Figures 10 to 14. In this case, the approximation, related to the curves F = f(e) of the various vehicles, would be as represented on Figure 15.

The honeycomb structures offer some advantages as:

—Deformation properties well known and reproducible,

—Reasonably easy operating conditions,

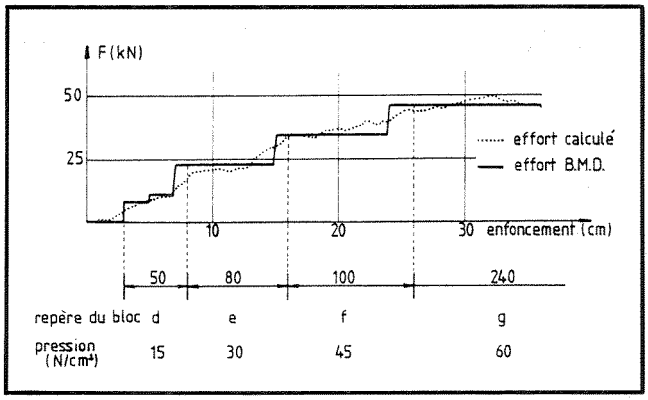


Figure 10. Mean curve "load/crush" related to dynamometric plates N° 1 and 3.

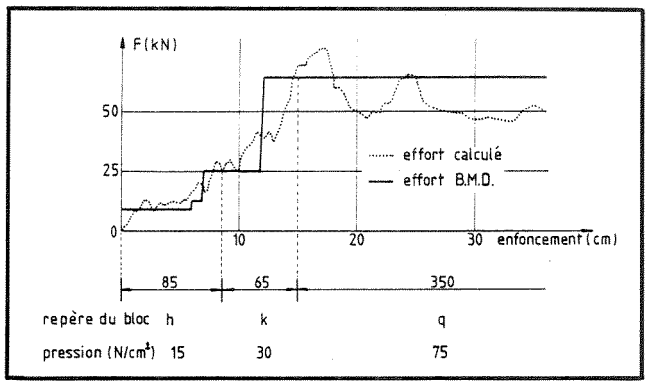


Figure 11. Mean curve "load/crush" related to dynamometric plate N° 2.

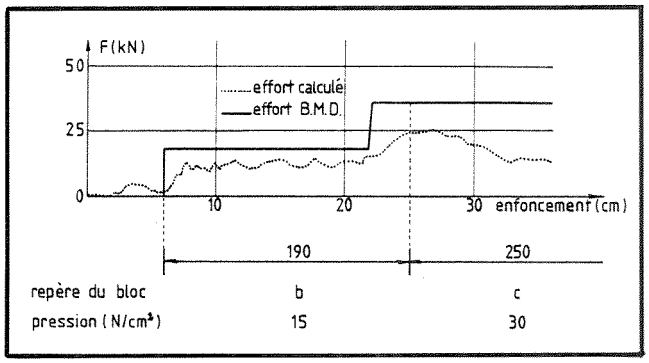


Figure 12. Mean curve "load/crush" related to dynamometric plate N° 4.

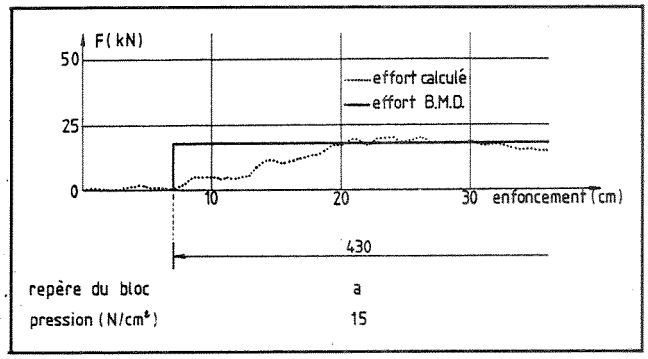


Figure 13. Mean curve "load/crush" related to dynamometric plates N° 5 and 6.

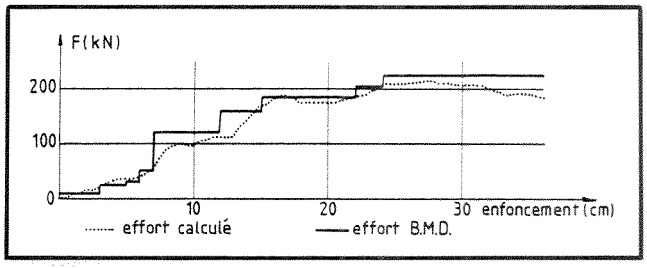


Figure 14. Mean curve of the total load related to crush values.

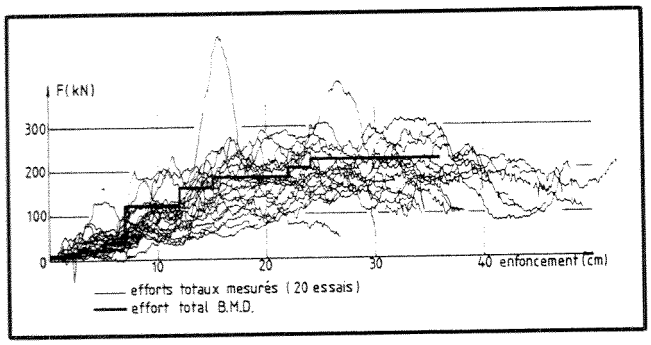


Figure 15. Position of the obtained mean curve related to total loads of various tested vehicles.

—Material early available due to its widespread use in aerospace industries,
—Minimal residual thickness.

They present also some disadvantages, such as:

—Privileged directional deformation,
—Stepped curves in the graph representing load/crush relation, due to the use of various types of honeycombs for a same block.

As future developments, it seems possible to study other types of materials or maybe evolutive structures; but this possibility supposes extensive searches of which expected results are questionable.

Description of the U.T.A.C. Deformable Mobile Barrier

Taking account of the above mentioned considerations, the front end of the proposed U.T.A.C. mobile barrier will follow the specifications shown on Figures 16, 17 and 18.

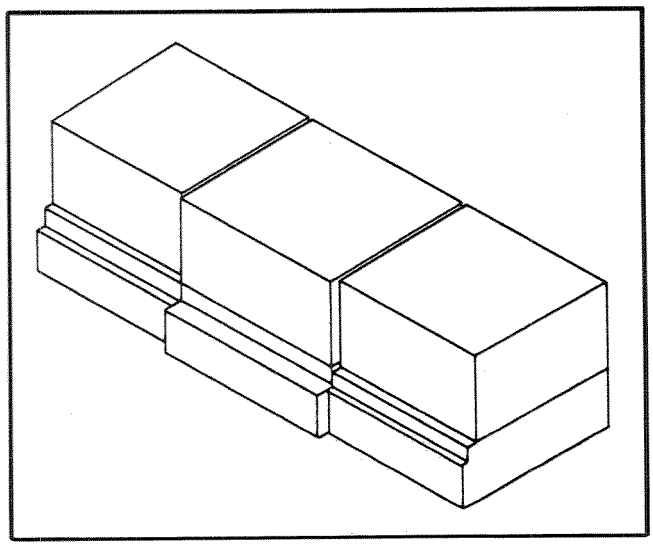


Figure 16. Front end of the U.T.A.C. deformable mobile barrier.

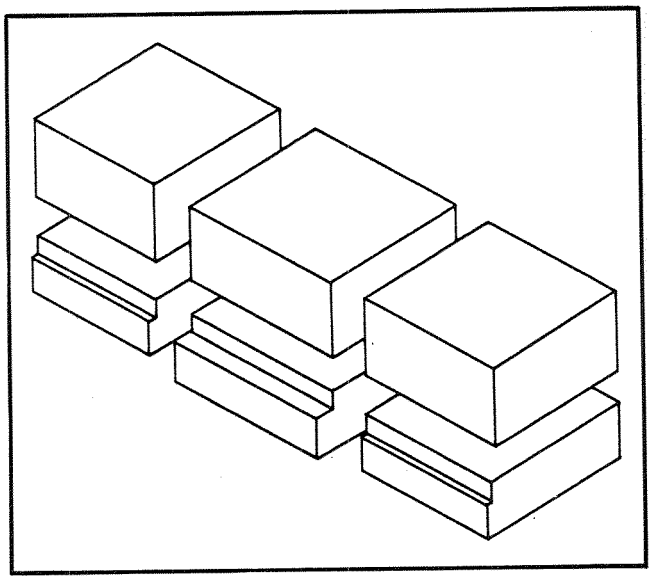


Figure 17. Exploded view of the front end of the BMD (U.T.A.C.).

The complete barrier, which weighs 915 kg, is schematically sketched on Figure 19.

Validation of the U.T.A.C. Deformable Mobile Barrier

In view to compare the consequences of a simulated side collision, the impacting vehicle being replaced by the BMD barrier, with those recorded in a vehicle to vehicle deformation, 10 tests have been performed according to this latter configuration. The impacting vehicle was selected out of the 20 already mentioned, regarding the particularities of the front structure. The impacted vehicle was always the same.

The 10 impacting vehicles were those numbered as 3, 6, 7, 10, 11, 16, 17, 18, 19 and 20. The impacted vehicle was the N° 17.

This impacted vehicle was fitted with 2 "HYBRID II" belted dummies occupying the front seats, and another

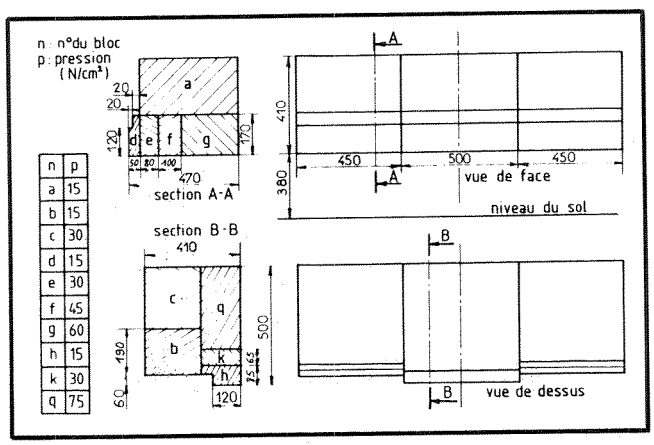


Figure 18. Definition of the front end of the BMD (U.T.A.C.)

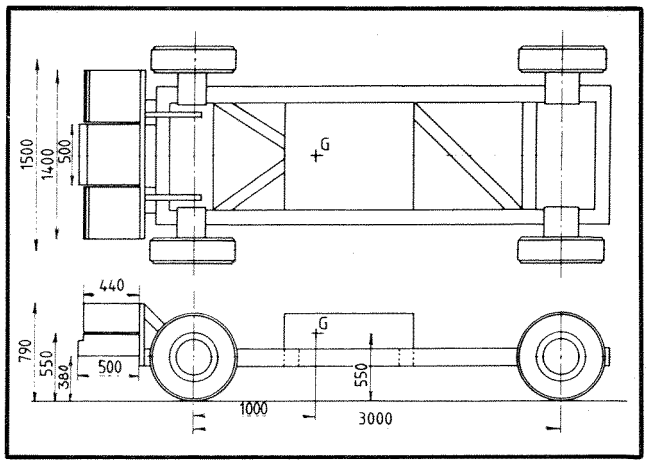


Figure 19. The U.T.A.C. deformable mobile barrier equipped with its front end.

Hybrid II dummy, unbelted, sat on the rear seat behind the driver.

The shock was applied on the driver's side. The dummy simulating the driver was the only one fitted with recording devices to measure accelerations on the head, the torso and the pelvis.

For each of the impacting vehicles, the parameters mentioned hereafter were measured:

—Accelerations:
- of the engine
- of the front axle assembly
- of the structure at the level of the B pillar.

—The masses being already known, the corresponding energies could be calculated.

—The crush value of the vehicle and its vertical deformations were obtained from the analysis of the movie pictures of the test.

Besides that, the rearward motion of the engine and of the front axle assembly were calculated.

On the impacted vehicle, the accelerations were recorded:

—on the B pillar of the side opposed to impact,

—at the level of the A pillar of the side opposed to impact,

—on the inside door panel, impact side, at the levels of shoulder and pelvis.

After the impact, deformations were recorded on 3 levels, on the side of the shock:

—plumb with the side rail (girder),

—plumb with the R reference point of the driver,

—plumb with the joint between side glass and door glass frame.

On the 2 vehicles, contact between dummies and inside panel of the habitacle, and contacts between dummies, were also stressed out after the actual test.

The front seats were adjusted so that the reference point corresponding to R point was in a fore position of 50 mm.

The impacted vehicle was standing. The impacting vehicle followed a path perpendicular to the longitudinal axial plane of the impacted vehicle. His axial plane contained the H point corresponding to the driver's dummy seated as mentioned above for the front seat adjustment. The test speed of the impacting car was 50 ± 2 km/h.

The data and values measured in the course of the test, or obtained by calculation, are considered as representing the "envelope" within the values recorded with the help of the BMD, or recorded on the BMD itself, will be contained. The deformations of the BMD will be also compared with the ones suffered by the 10 impacting vehicles, and this on a convenient number of tests (6 seem to be the necessary number), all performed with the same impacted vehicle (N° 17). Decelerations and deformations recorded on the BMD during those 6 tests must be kept within acceptable dispersion limits.

The aimed target is that the measured parameters of the impacted vehicles and on the driver's dummy would stay inside an acceptable area of average values recorded during vehicle to vehicle tests. It is not before a complete study of the results that, after discussions with the technical teams carrying the same kind of researches in other countries, the final profile book of the barrier will be worked on.

Possible Developments of the U.T.A.C. Deformable Mobile Barrier

To take account of the International conjuncture, the French representative has presented to the CEVE Working Group 6 the results of his works, and a detailed proposal about the U.T.A.C. BMD. Discussions promptly resulted to a synthesis of the various types of European-designed barriers designed in accordance with the same methodology (TRRL—CCMC—U.T.A.C.).

The conclusions, and the proposal for a European "BMD", are the basic theme of the (EEVC) Report at the present ESV conference.

POSSIBILITIES RESULTING FROM A FUTURE DEVELOPMENT OF A EUROPEAN DEFORMABLE MOBILE BARRIER

During the sessions of the Working Group N° 6 of the CEVE, the French representative, together with his Italian colleague, stressed out the possibility to solve the important and difficult problem of compatibility through the use of a BMD.

The "integrated test", adopted as a regulation both by the Federal Republic of Germany and France, represents an important step forward in the improvement of the safety afforded to occupants as, to meet the required

protection criteria, the front end of the vehicles must feature some possibilities of deformation which are not compulsory, and even contrary, to fulfill the requirements of the Safety Standard N° 12.

If the side panels must fulfill the protection requirements for the occupants' safety during an impact with the European BMD, it seems logical, in a not so distant future, to foresee that the protection of the occupants must be also fulfilled during a frontal impact against the same BMD, the trajectories being offset to take account of the most frequent type of road accidents (test offset 1/3 or 1/2 car). This test would supersede the one against an oblique stationary barrier which simulates the same type of accident.

To take account of the different severity levels of those two types of tests, the impact speed could be increased and, in view to reproduce more accurately the dynamic phenomenon appearing during the staggered impact, the vehicle and the BMD would be both in motion, either at the same or at different speed(s). During such a test, attention would be focused on certain weaknesses in the restraint systems behaviour, particularly on the seat belts which have a tendency in certain actual accidents to get loose from the bearer's shoulder, a situation not recreated during the test against the stationary oblique barrier. Furthermore, cohesion in the safety tests would be achieved if the same BMD would be used for the evaluation of the occupants' protection in case of impact from the rear.

Without any excess of optimism, it can even be anticipated, as proposed by the French delegate at the most recent meeting of the GRCS in August 1982, in Geneva, to use the same deformable mobile barrier to evaluate the protection that heavy vehicles would have to feature to minimize the consequences of accidents resulting from frontal collisions with passenger cars. This is to take account of this future evolution, which consists to make compulsory performance criteria instead of geometrical criteria, that, due to the foreseen evolution at the horizon 1990, France has withdrawn its projected regulation pertaining to the organization of the front end for heavy vehicles having a weight exceeding 19 metric tons.

To close the subject of possible uses of this BMD, it seems possible to replace the present protection criteria pertaining to lights and traffic signals, based on geometrical requirements concerning the bumpers, as well as their sturdiness, by a global test at low speed against the front end of the vehicle.

At least, if it would appear that the technical specifications of the BMD would become no longer representative of those of current vehicles in an unpredicted future, it should be possible, without changes in technique and alterations to the biomechanical criteria, to modify the impactor in order to make it more up-to-date in line with the contemporary production automobiles.

Such prospective considerations outline the interest associated to the design and to the validation of the European BMD, in view to make possible the evolution of the regulations pertaining to safety, and this in a more realistic direction, the automotive manufacturers keeping the benefit of the free selection of solutions they will consider as the most adequate ones to obtain the best possible balance between safety, energy and environment saving, and comfort, all vital factors for the vehicles of the future.

Compatibility Between Car Front and Side Structures to Improve Side Impact Protection

I. D. NEILSON and P. M. WATSON
Transport and Road Research Laboratory

ABSTRACT

While test procedures are being devised to check that side impact protection is being provided to some predetermined standard, it is important to know what level of protection is practically achievable. Early work has shown that protection depends on three design features—

—the padding of components likely to be struck by occupants
—the strengthening of the side structure to reduce the speed of impact of the side into the occupants
—the shapes of the sides of the car and of the car fronts which strike the side.

The Marina SRV of 1974 showed that side impact protection could be provided. Further tests are reported on this design which show how the protection varies with speed of side impact and indicate how important are padding, strength and shape.

Tests are also reported on the fronts and sides of twelve models of car when impacted by a mobile barrier with load cells on its rigid face. Analysis of these results suggests how some compatibility between the fronts and sides of all future models of car can be achieved and what sort of impact test might be required to check the design of both the fronts and the sides of cars. Some verification of these ideas is being arranged.

INTRODUCTION

Now that many studies have been carried out to show how car occupants are injured when their cars are struck in the side and there have also been structural design studies to find how car sides can be strengthened, it is appropriate to consider whether the shape and stiffness of whatever strikes the car side is important to the outcome. One conclusion from the design study which produced the SRV Marina car in 1974 (1) was that the shape of the impacting object was important. Some further results of this work are now presented. However there has been a trend away from low protruding car front bumpers since 1974 and bumpers are now mostly small and light. Considerations of pedestrian protection also require that the car fronts shall be almost flat and nearly vertical. It will be necessary if car fronts are not to unnecessarily injure the legs and knees of pedestrians, for them to crumple under pedestrian impact to a depth of up to 200 mm (2). The question is whether these design features can contribute to the car front to car side impact problem.

Although most serious injuries in car side impact accidents result from car impacts into the sides of other cars, a smaller proportion, but under a half of the fatal injuries, occur when either the impacting vehicle is a Heavy Goods Vehicle or other large vehicle or control is lost of the car and it slides sideways into a rigid fixed object such as a tree. It is clear that modifications to the fronts of cars cannot improve these situations. Despite this it would seem to be worth matching car fronts to car sides. This being so, some regulation of car design could be achieved by declaring a maximum stiffness for car fronts.

One possible test procedure would be to have a mobile barrier with a deformable face which is the size of the fronts of cars. When impacted into the side of a car under test it would be required that the car side is stronger than the barrier face so that the latter collapses rather than the side. The same design of barrier face is then impacted into the fronts of other cars under test but the car fronts should collapse and not the barrier face on these occasions. If all cars were designed with these ideas in mind, there could be great reductions in side impact injuries if car interiors are also suitably padded. However, it will not be possible to reach this situation because car fronts at present are highly variable in terms of their stiffness. It is not practicable to require car sides to be slightly stiffer than all existing car fronts.

The key lies in compatibility, and with lighter weight structures and pedestrian impact considerations the future car should materialise with a comparatively soft front end and a strong matching energy-absorbing side structure. So the stiffness of the barrier face may have to be progressively reduced over a period of time to achieve the desired levels of compatibility and weight saving.

A previous paper (3) has outlined the earlier work leading up to the study of car front to car side compatibility which is discussed in this paper. As an illustration of the effects of car fronts on side impact two small cars of very different frontal stiffness have been impacted into the sides of Princess cars. However, the main analysis of this paper is that of impacts into the fronts and sides of cars of twelve different models using a mobile barrier with a rigid but small face on which were load cells to record the loadings on each. The results enable proposals to be made about suitable levels and patterns of stiffness for car front and side structures.

EXAMPLES OF THE CAR FRONT TO CAR SIDE IMPACTS

It is appropriate to illustrate the effects of current frontal designs of cars when impacted into a typical car side. Accident evidence such as in references 4, 5 and 6 shows that the most typical severe side impact into a car occurs when the striking car hits the struck car at an angle slightly forward of perpendicularly at a point on the front door so that the deforming side structure intrudes upon an occupant. Two tests were carried out to represent this situation with the struck cars stationary and the striking cars at 20° forwards of perpendicular moving at 49 km/h with their centrelines in line with the gap between the front and rear door on the offside. Both struck cars were Leyland Princess models, chosen because their side stiffness is relatively high. The striking cars were a Ford Fiesta and a Renault 5. The former has relatively stiff upper and lower front structures, while the latter has a relatively weak upper front structure, weak lower (bumper level) outer bumper sections but a stiff central bumper section. These two frontal designs represent the extremes of the frontal designs of small cars as is shown in Section 4. The Side Impact Dummy used was an early TRRL SID with a stiff shoulder and Table 1 shows the effects of car frontal design.

Improved dummies have shoulders which deflect at low loadings, so that the upper body is decelerated by the thorax, possibly by the head, but not by the shoulder. However, the sum of the peak loads on the ribs and shoulder is a good indicator of upper body loading when this early dummy is used. The results suggest that the pelvis can be overloaded in impacts of this severity by cars of present day design but that even if the pelvic load is somewhat reduced it is likely that the upper body loading is excessive.

It appears that severe injury is likely in these conditions and also that the detailed design of a car front does influence the injuries to occupants of a car that it strikes.

THE SRV MARINA SOLUTION FOR SIDE IMPACT PROTECTION

As already mentioned this 1974 project demonstrated the occupant protection levels which could be obtained

Table 1. Dummy loadings for side impact tests of Fiesta and Renault 5 into Princess cars.

Impacting car	Peak loads			
	Pelvic loads (kN)	Rib loads (4)* (kN)	Shoulder loads (kN)	Ribs + shoulder loads* (kN)
Fiesta	7.40	0.42,0.59,0.38,0.09	11.2	12.68
Renault 5	11.43	0.63,0.23,0.10,0.73	3.95	5.64
Possible safe tolerance loads (kN)	6	1,1,1,1	(7)+	(11)

* Peaks not at same instants of time and so sums in fifth column only generally indicative.
+ Human tolerance much below 7 kN, but this value suitable for the rigid dummy used.

by designing cars which were compatible with each other. The design considerations included:

a) the relative stiffness of the front and side structures to absorb the maximum amount of energy while keeping intrusion to an acceptable level in the struck car.
b) the shape of the front of the striking car.
c) the provision of padding materials to limit loads on the occupants.

The front structure of the striking car incorporated a soft headlamp surround in a sloping front, to limit the loads transmitted at waist level, and a protruding absorbing front bumper centred at 370 mm above ground level which contacted the overlapping door and sill panels in the struck car.

The combined strength of the door and sill panels was to be sufficient to reduce penetration into the struck vehicle which was fitted with crushable materials to protect the occupant in the pelvic, rib, shoulder and head areas.

Three tests were carried out with the striking car impacting the driver side of the struck car at 49 km/h at 90°. A fully instrumented TRRL side impact dummy was seated in the driver seat with a standard dummy in the rear passenger seat behind the driver. As a basis for comparison the first test used two identical standard production cars, followed by a standard car striking a modified vehicle. Two modified vehicles were used in the final test at this speed. Two similar tests were conducted using modified vehicles but the test speeds were 33 km/h and 16 km/h.

The dummy loads for the side impact dummy for the five tests are given in Table 2.

These results clearly show that serious multiple injuries in standard cars (Test 1) should be eliminated using modified vehicles at similar speeds (Test 3). To obtain this significant improvement however, the front of the striking car needs modification (compare Tests 2 and 3) and so a compatibility requirement for the fronts of cars seems to be essential.

Analysis of the results showed that the energy absorbing bumper system absorbed 20% of the impact energy at 49 km/h, 38% at 33 km/h and 44% at 16 km/h. The sloping front of the striking car caused the struck vehicle to roll towards the striking car 6½° for the 16 km/h impact and 14½° for the 33 km/h impact. This vehicle roll emanating from the low impact line was beneficial in delaying occupant contact so that it was at a reduced relative

Table 2. Dummy loadings for side impact tests of standard and SRV Marinas.

Test	Speed (km/h)	Striking car	Struck car	Peak loads			
				Pelvic loads (kN)	Rib loads (4)* (kN)	Shoulder loads (kN)	Rib + shoulder loads* (kN)
1	49	Standard	Standard	9.2	0.37,0.75,1.57,1.43	12.5	16.62
2	49	Standard	Modified —2 door	4.9	1.21,0.95,1.59,0.57	9.35	13.67
3	49	Modified front	Modified —2 door	3.2	0.75,0.40,0.33,0.29	3.6	5.37
4	33	Modified front	Modified —2 door	1.87	0.44,0.16,0.10,0.15	0.849	1.70
5	16	Modified front	Modified —2 door	0.11	0.04,0.07,0.02,0.07	0.243	0.44
Possible safe tolerance loads (kN)				6	1,1,1,1	(7)+	(11)

* Peaks not at same instants of time and so sums in fifth column only generally indicative.
+ Human tolerance much below 7 kN, but this value suitable for the rigid dummy used.

velocity when it did occur and this contributed to the very low dummy loads in these tests (5 and 6). The vehicle roll was less pronounced in the 49 km/h test because of the increase in structural collapse of the two vehicles and there was little roll before the occupants actually hit the interior. It is concluded that the roll in this case had little influence on the dummy results.

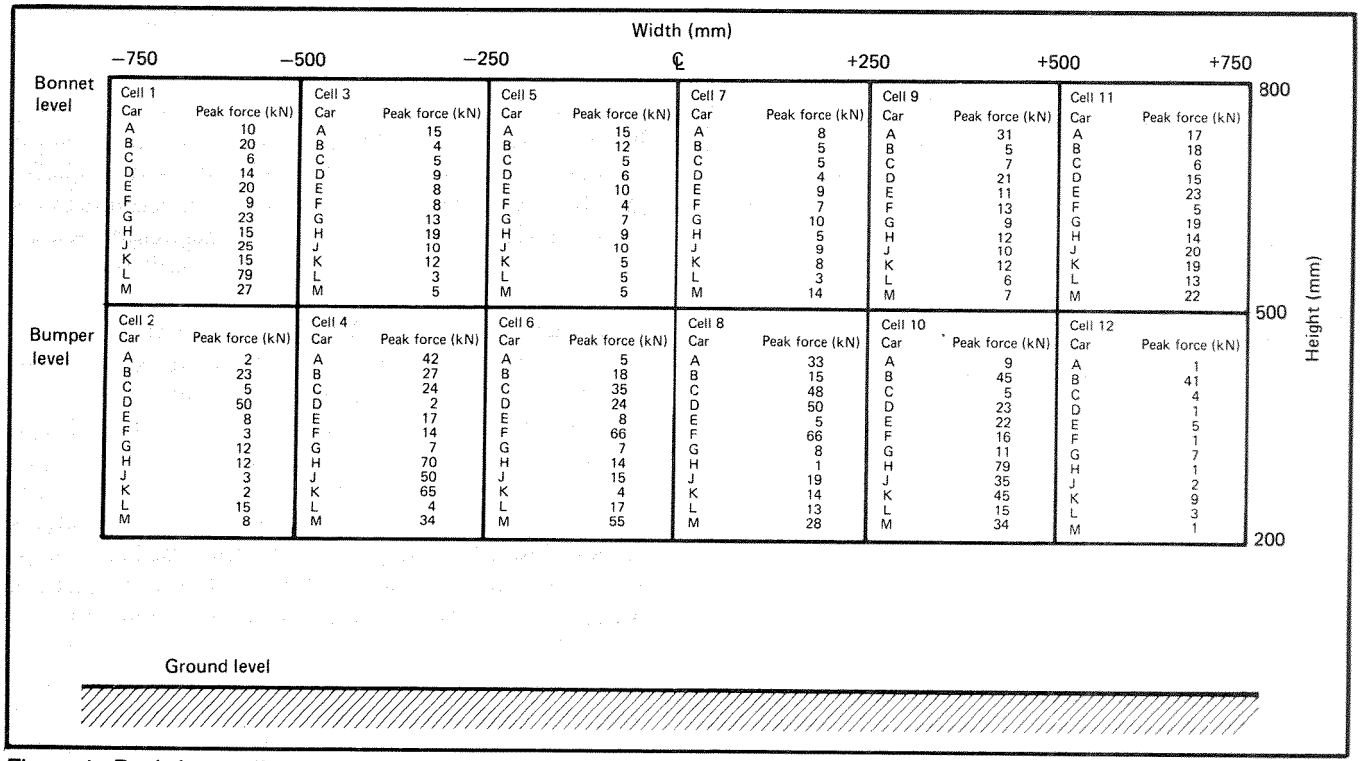
Examination of the vehicles used in Tests 4 and 5 showed only very minor damage in Test 5 and for Test 4 a damage level which would be well within the limit for economical repair. In both tests the interior door padding was virtually undamaged.

TESTS OF THE STIFFNESS OF CAR FRONT AND SIDE STRUCTURES

The stiffness patterns of the fronts and door and sill side structures of twelve models of small cars were measured by impacting them with a mobile barrier with a rigid test face on which were placed a number of load cells. The barrier for the front impact was larger than the car fronts but the one used in the side impacts was smaller and directly struck only the doors and the B post on each car. This size was 1 m wide and 600 mm deep with rounded edges to the rigid face and it was flat and was mounted vertically for the impacts. These facts all contributed to the particular sets of values of load measured by the load cells as functions of time during the impacts. However these values gave useful results as is indicated later on. The patterns of the load cells (each being 300 mm high and 250 mm wide) are given in Figures 1 and 2. The bottom edge was 200 mm above ground level and so although car side sills were partially impacted they were overridden. The impact was centred on the driver R point and the barrier width was chosen to avoid the main A post and rear wheel arch structures.

The frontal impact tests were generally similar to those into the side except that the barrier was extended sideways to be 2 m wide with two rows of eight cells each. The impact was symmetrical and there was little or no loading of the outer cells, most cars being about 1500 mm wide. For both side and front impacts, reduced impact speeds were chosen to allow for the fact that the rigid face could absorb no energy, but it was intended that the impacts should approximate to 50 km/h impacts into stationary cars by a barrier of 1100 kg mass. The front impacts were at about 40 km/h and the side impacts about 36 km/h.

Typical load cells results are given in Figures 3 and 4 for front and side impacts respectively. One method of analysis was chosen which was to average the loading of each cell over periods of 10 ms starting at 0 to 10 ms from the beginning of the impact and continuing the 10 ms intervals until the impact was complete at from about 70 ms to 130 ms. The highest average loadings for each cell over a 10 ms period are plotted in Figures 1 and 2 for all available data for the twelve cars. A few cells became overloaded and estimates which are probably fairly accurate have been made of the loads on these cells after the instant of overload. It may be noted that the



Cell 1		Cell 3		Cell 5		Cell 7		Cell 9		Cell 11	
Car	Peak force (kN)	Car	Peak force (kN)	Car	Peak force (kN)	Car	Peak force (kN)	Car	Peak force (kN)	Car	Peak force (kN)
A	10	A	15	A	15	A	8	A	31	A	17
B	20	B	4	B	12	B	5	B	5	B	18
C	6	C	5	C	5	C	5	C	7	C	6
D	14	D	9	D	6	D	4	D	21	D	15
E	20	E	8	E	10	E	9	E	11	E	23
F	9	F	8	F	4	F	7	F	13	F	5
G	23	G	13	G	7	G	10	G	9	G	19
H	15	H	19	H	9	H	5	H	12	H	14
J	25	J	10	J	10	J	9	J	10	J	20
K	15	K	12	K	5	K	8	K	12	K	19
L	79	L	3	L	5	L	3	L	6	L	13
M	27	M	5	M	5	M	14	M	7	M	22

Cell 2		Cell 4		Cell 6		Cell 8		Cell 10		Cell 12	
Car	Peak force (kN)	Car	Peak force (kN)	Car	Peak force (kN)	Car	Peak force (kN)	Car	Peak force (kN)	Car	Peak force (kN)
A	2	A	42	A	5	A	33	A	9	A	1
B	23	B	27	B	18	B	15	B	45	B	41
C	5	C	24	C	35	C	48	C	5	C	4
D	50	D	2	D	24	D	50	D	23	D	1
E	8	E	17	E	8	E	5	E	22	E	5
F	3	F	14	F	66	F	66	F	16	F	1
G	12	G	7	G	7	G	8	G	11	G	7
H	12	H	70	H	14	H	1	H	79	H	1
J	3	J	50	J	15	J	19	J	35	J	2
K	2	K	65	K	4	K	14	K	45	K	9
L	15	L	4	L	17	L	13	L	15	L	3
M	8	M	34	M	55	M	28	M	34	M	1

Figure 1. Peak forces (for periods of 10ms) at load cells on face of rigid barrier impacting fronts of 12 models of car.

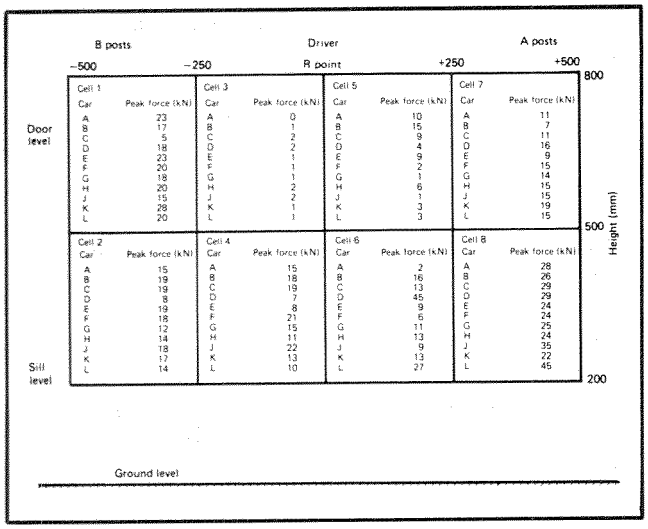


Figure 2. Peak forces (for periods of 10ms) at load cells on face of rigid barrier impacting sides of 11 models of car.

final static crushes of the fronts ranged from 90 mm to 315 mm with most towards the higher value. The final static intrusions for the side impacts ranged from 150 mm to 280 mm again with most closer to the higher value.

Figure 1 illustrates some typical features of the design of car fronts. At the bumper height the outer of the six cells record mostly low peak loadings when compared with the four inner cells. This is only to a small extent

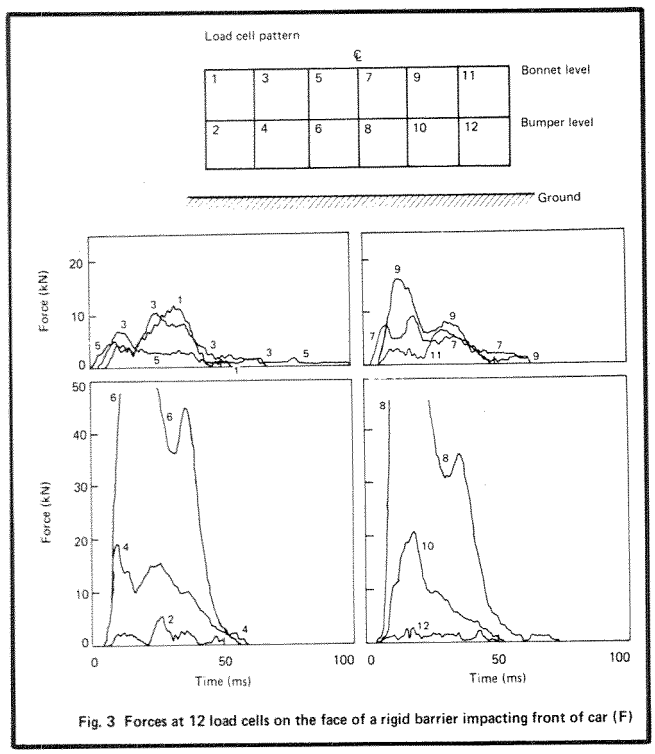


Fig. 3 Forces at 12 load cells on the face of a rigid barrier impacting front of car (F)

Figure 3. Forces at 12 load cells on the face of a rigid barrier impacting front of car (F).

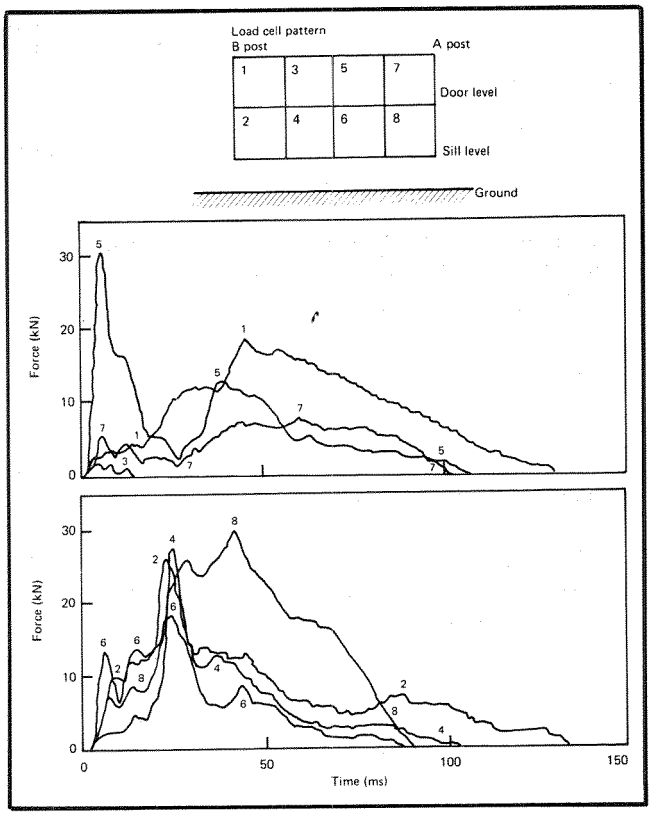


Figure 4. Forces at 8 load cells on the faces of a rigid barrier impacting side of car (B).

accounted for by the fact that the width of the cars does not cover all the two outer cells (for 10 of the 12 cars). The inner cells have very variable peak values with some designs having a strong structure stretching forward to this region of the front. The upper cells show that the outer wings are generally stiffer than the region between them, but that designs vary with the upper half providing between about one-third to two-thirds of the total impact resistance. Although the peak stiffnesses of wings differ greatly, there is generally less variation in absolute terms for the region between. Another big difference between one car model and another is that at the particular impact severity of the test, some cars exhibit little rebound whilst others have much more. This latter result is presumably because components have not quite collapsed at the instants when the peak loadings are reached.

Figure 2 illustrates some typical features of the design of car sides that may be shown up by this particular type of test. At the lower level the overriding of the sills leads to fairly high loads at most cells. In particular, structures are stiff just aft of the A posts and less stiff but perhaps surprisingly uniform at the B posts. The stiffnesses are usually lower between the outer cell positions at below the middle of the front doors. At the upper level the B posts give rise to the highest loads in all but one case. The loadings of the cell just forward of the B post were always negligible. The next one forward received variable loadings while the forward one close to the A posts re-

ceived fairly similar peak loads which were average in level. The upper cells recorded between one-third and two-thirds of the total impact and so design is far from uniform in this respect. One feature is particularly evident and that is the effect of impacting with a rigid faced barrier. This does not greatly load up components such as the door which are adjacent to stiffer components. A deformable face to a test barrier would crush into less resisting components until they built up their resistance when deformed and then they might possibly collapse.

PROPOSAL FOR ACHIEVING COMPATIBILITY

The results presented in Figures 1 and 2 suggest that at present there is no general compatibility between front and side structures of cars, but the situation may not be so unfortunate as had been predicted by some. It is to be remembered that the sample of twelve cars does not include any large cars and only one or two which could be regarded as of medium size. It is the larger cars which are generally the stiffer as regards nose structures and they also have additional mass to prolong these impacts.

Impacts into the sides of cars during accidents are not usually perpendicular ones directly into the passenger compartments; much more often they have a resultant relative direction just forwards of perpendicular, but many other situations arise. The most common impact is car to car although impacts with fixed objects and Heavy Goods Vehicles do give rise to a large minority of fatal injury accidents. When the impact is forward to perpendicular it is the wing of the striking car and the lower structure beneath it which strikes the car door, biting into it and causing injury by intrusion and by excessive loadings through the door panels.

The proposal postulates that injury would be reduced if car front structures were weaker than the side structures of all the other models that they might impact. This could be achieved if mobile barrier tests were set up in which the barrier face was to be stiffer than the front structures of cars but the same face was to be weaker than the structures at the sides of the passenger compartments of cars. The selection of a suitable design of barrier face is one aim of the analysis of the tests now being reported. They show how designs are at present. From these results it is possible to suggest a suitable barrier face design for future tests. A further consideration is to consider cars not as they are today but as they should be later this century if weight savings in pursuit of energy savings are to be achieved. Although there might be a weight saving to cars if the stiffness of the test barrier face is reduced, this is counteracted by the fact that front and side crush depths would increase somewhat for a given speed of impact and so car front structures would have to be slightly greater in depth.

Consideration of these matters in relation to the data in Figures 1 and 2 suggests that the barrier face stiffness might be about:

—20 kN, or rather more at the centre, at the lower (bumper) level of the barrier (below 500 mm above ground) for each cell of 250 mm width
—10 kN at the upper level of the barrier (above 500 mm above ground) for each cell of 250 mm width.

It would seem from Figure 2 that doors at the sides of cars might not be strong enough to withstand 10 kN for 250 mm width, but these results are using a rigid faced barrier and a resisting load would build up if the barrier face were deformable.

These suggestions for the stiffness pattern for a deformable face are very close to the deformable face proposed by the EEVC group, reference 7, for the fullscale side impact tests and so it would be appropriate to use it for the frontal compatibility test as well as for the side test. This barrier is designed to crumple in six cells, 3 upper and 3 lower, each being 500 mm wide and 250 mm deep with the division between upper and lower being 500 mm above ground. The mean fully developed yield levels are 20.5, 23.5 and 20.5 kN for upper cells and 50.5, 60 and 50.5 kN for lower cells. Suppose it impacts a car front which is 1500 mm wide and extends from 300 to 700 mm above ground. Then it should exert loadings of 4/5 the full figures, namely, 16.4, 18.8 and 16.4 kN upper and 40.4, 48 and 40.4 kN lower, which are very close to the $2 \times 10 = 20$ kN upper cells and $2 \times 20 = 40$ kN lower cell levels suggested above.

Check testing is needed to show that car side structures can be designed to withstand impact from the deformable barrier under consideration without much inwards collapse of the side structure and doors. If it is assumed that the car side does not crush but that the barrier face crushes C (mm), then $C = m\ M\ u^2/[2k(m + M)]$ where the barrier is mass m and the car mass M, the barrier crushes at k (Newtons) and the initial barrier speed is u (m/s) with the car at rest. $C = 236$ mm (equivalent full stiffness crush depth) for a car and barrier both of 1100 kg, an impact speed of 50 km/h and a barrier contact extending from 250 to 750 mm above ground with a crumpling resistance of 225 kN. In these circumstances it may be reasonable to require that the average crush of the barrier be above two-thirds of this (say at least 160 to 200 mm) and that the barrier crush adjacent to the front and rear dummies should exceed a half of the total (120 to 150 mm). To these crush depths must be added an allowance for the weaker nose section of the EEVC barrier. Supposing that the frontal stiffness of the same car is checked by a frontal test with a contact area from 300 to 700 mm above ground, then the crumpling resistance would be 180 kN and the equivalent full stiffness crush depth would be $C = 295$ mm. The car front should crumple most and it might be appropriate to require the full stiffness part of the barrier to crumple no more than say one-third or

100 mm on average. This depth of crush should not be exceeded opposite the wings of the car.

The actual test requirements for permitted crush depths will have to be determined after trials of the proposed EEVC deformable barrier have been carried out using the frontal and side impact procedures.

CONCLUSIONS

Present day car designs are vulnerable to side impact from the fronts of other cars and the resulting injuries suggest that it is worth trying to improve side impact protection.

Earlier studies showed structural strengthening and padding the interiors of car sides are both necessary for improvement. This study shows that the frontal design of cars is also important. It is not possible to ensure side impact protection when sides are impacted by the fronts of the 12 small car models which were tested. However the SRV Marina of 1974 demonstrated that a high level of protection is possible.

It is shown that compatibility between the structural strengths and designs of car fronts and sides can be checked by means of impacting car fronts and sides by a mobile barrier whose face is intermediate in yield strength between car fronts which should be weaker and car sides which should be stronger.

The EEVC proposal for a deformable barrier face may be suitable for such a test although it would be preferable for it not to have the front sections which have the increasing stiffness but only to have the main uniform yield sections. The lower (bumper) half of the face should be at least twice the stiffness of the upper half; the division between them being at 500 mm above ground level. The outer sections of both halves should not be much reduced in strength compared with the centre sections, although the ends may preferably be weaker. The effects of car front shape and the possibility of enabling the striking car to pitch tail upwards are considered but it would seem adequate to have an almost vertical front face suitable for pedestrian protection.

Further testing of the EEVC barrier face is needed to ensure that it can be used for the compatibility checking of car fronts and sides.

It appears to be practicable to place limitations on car frontal design to assist in car side impact protection and designs need not be greatly different from some present layouts to achieve this.

ACKNOWLEDGEMENT

The work described in this paper forms part of the programme of the Transport and Road Research Laboratory and the paper is published by permission of the Director.

REFERENCES

1. Finch, P. M. British Leyland/TRRL experimental safety systems contract. Proceedings of 5th ESV Conference, London 1974, p137, published by NHTSA.
2. Harris, J. Safer cars for the pedestrian. Paper C178/80 at Conference "Progress towards safer passenger cars in the United Kingdom", Institution of Mechanical Engineers, London 1980.
3. Neilson, I. D., Penoyre, S., Petty, S. P. F. and Dyche, A. K. "Improved test procedures for side impact". Proceedings of the Seventh Technical Conference on Experimental Safety Vehicles, Paris 1979, p444, published by NHTSA.
4. Hartemann, F., Thomas, C., Forot Bruno, J. Y., Henry, C., Fayon, A., Tarriere, C., Got, C. and Patel, A. "Description of lateral impacts". Proceedings of 6th Technical Conference on Experimental Safety Vehicles, Washington 1976, p544, published by NHTSA.
5. Riley, B. S. and Radley, C. P. "Traffic accidents to cars with directions of impact from the front and side". Proceedings of 6th Technical Conference on Experimental Safety Vehicles, Washington 1976, p563, published by NHTSA.
6. Thomas, P., Lawson, S., Griffiths, D. and Breen, J. "An investigation of a representative sample of real world side impacts to cars". Accident Research Unit, University of Birmingham. Unpublished.
7. Report of EEVC, Working Group 6, Structures, Improved Side Impact Protection in Europe. Proceedings of 9th Technical Conference on Experimental Safety Vehicles, Kyoto 1982. Published by NHTSA.

CROWN COPYRIGHT 1982. Any views expressed in this paper are not necessarily those of the Department of the Environment or of the Department of Transport. Extracts from the text may be reproduced, except for commercial purposes, provided the source is acknowledged. Reproduced by permission of Her Britannic Majesty's Stationery Office.

Side Collision Tests and Simulations

E. FRANCHINI
Former Director of FIAT Safety Center

ABSTRACT

The results Fiat obtained in the wide area of compatibility were presented at the 7th ESV Conference. In the present research the following tests have been carried out:

—No. 9 car-to-car side collisions and No. 9 moving barrier-to-car side collisions.
—A methodology has been developed for evaluating car and occupant behaviour in side collisions.
—Mathematical models for the use of the methodology have been developed.
—The methodology has been used in side collision situations and experimental results have been compared to simulation results.

The results are considered to be in accordance with expectations.

The simulation cannot be better than the scatter of experimental data.

It is important to point out that the methodology requires more reliable dummies and more reliable tolerance criteria.

INTRODUCTION

On the basis of the studies we presented at the Paris ESV Conference in 1979 a further research effort has been conducted in the context of a biomechanics program sponsored by the Commission of European Community. It is divided into the following parts:

—Part 1: Car-to-car collisions
—Part 2: Moving barrier-to-car collisions
—Part 3: Methodology

PART 1: CAR-TO-CAR COLLISIONS

The tests have been carried out under the following conditions:

—perpendicular side collision
—50 km/h velocity
—stationary impacted car
—impact point in correspondence of driver's R point
—two dummies, both on impacted side (with the exception of the minicompact that has been tested with the driver-dummy only).

As far as the structural behaviour is concerned we have chiefly considered deformations inside the occupant compartment, that is, intrusions. These are characterized by three factors (Fig. 1):

—"How", that is, the intrusions involving a large side area or concentrated in a limited area.
—"How much", that is, the extent of penetration which, if deep, can crush the occupants.
—"How fast", that is, at which velocity the wall is moving; if the velocity is low, the result is a push only, at high velocity the result is an impact.

The impacted car is equipped with transversal sliding tubes, instrumented in such a way as to give dynamic and static values for wall intrusion, acceleration and velocity (Fig. 2).

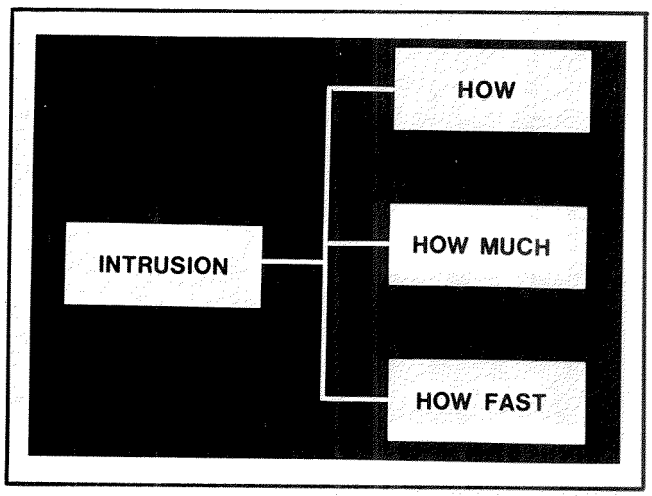


Figure 1. Structural behavior.

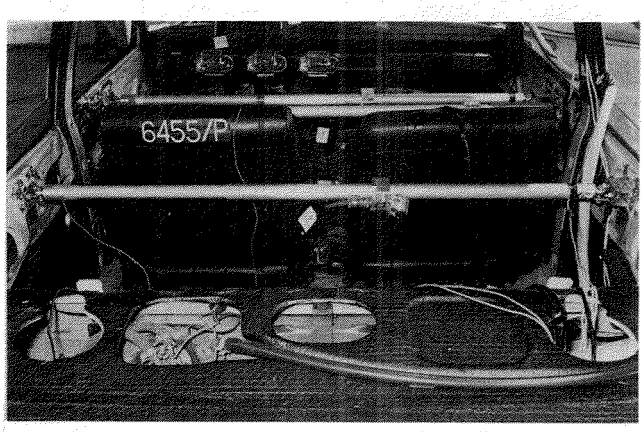


Figure 2. Transversal sliding tubes.

As far as the dummy is concerned the following values are given (Fig. 3). It is worth stressing that present dummies must be improved, particularly in side collisions and their limitations must be kept in mind when considering the values they yield.

Three Fiat car models, having different dimensions and weight, have been selected, namely (Fig. 4):

—126, minicompact
—128, subcompact
—132, compact

Nine tests have been carried out, launching each model against the side of the others.

In the first set of tests the minicompact is impacted by an identical car, then by the subcompact and next by the compact. The permanent intrusions are shown in Figure 5. The maximum value lies at R point height, but, as the impacting car is changed, both the vertical section and the amount charge.

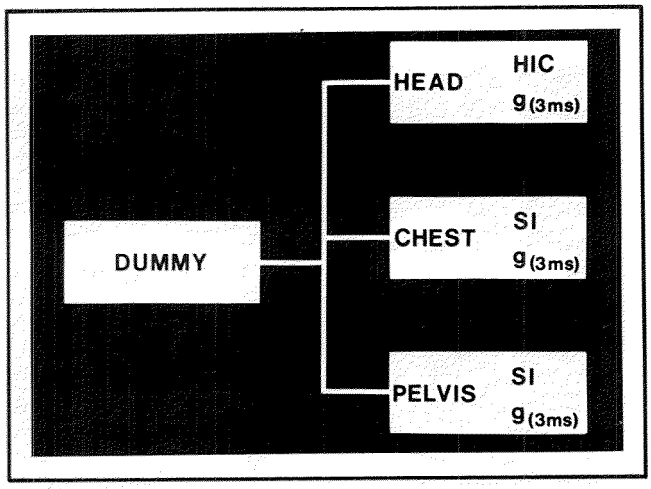


Figure 3. Dummy behavior.

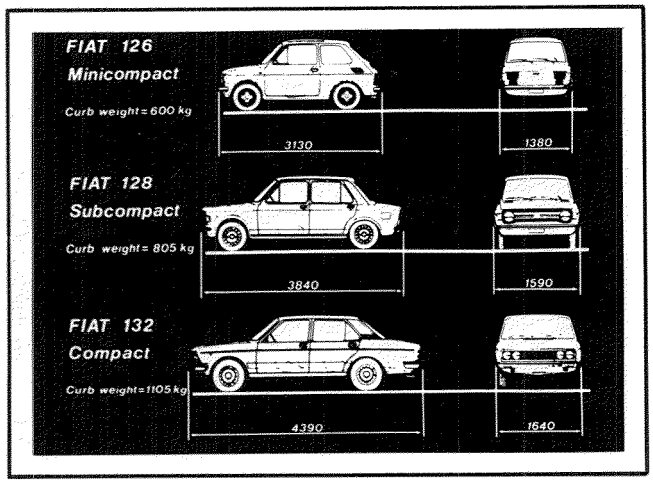


Figure 4. Car models.

In the second set of tests the subcompact is impacted by the minicompact, then by an identical car and next by the compact. The permanent intrusions are shown in Figure 6.

The intrusions involve the B pillar area. The comments made above apply again in this case. It is worth stressing that the intrusion is higher on this model than on the minicompact.

In the third set of tests the compact is impacted by the minicompact, then by the subcompact and next by an identical car. The permanent intrusions are shown in Figure 7.

On this model the maximum value is generally a little below R point and somewhat backward the B pillar.

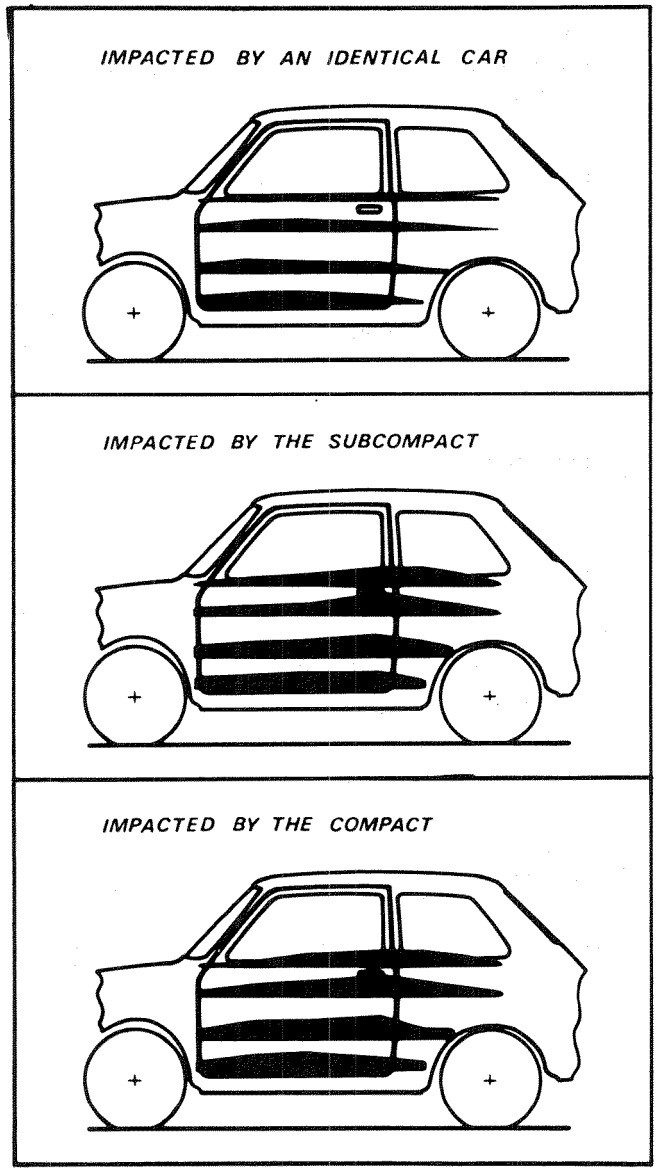


Figure 5. Intrusions in the minicompact impacted by the three models.

Velocity being equal, the intrusion extent depends on the aggressivity of the impacting car. By way of example note that it is the subcompact that always produces the maximum intrusions, while the minimum intrusions occur on the minicompact.

Now let's see the values recorded on the Hybrid II dummy onboard the minicompact impacted by the three models (Fig. 8).

—The most stressed part is the pelvis, next the chest and then the head.

—When this car is impacted by an identical car, the values are the lowest, while, when impacted by the subcompact (the most aggressive), the values are the highest.

Now the values recorded on the two dummies onboard the subcompact, impacted by the three models, are shown in Figure 9.

The conditions for the driver dummy are similar to the previous ones and the values recorded on this model and the previous model can be almost superimposed. For the rear passenger dummy (nearside) the values are lower than those for the driver dummy as far as the pelvis and chest are concerned while the head values are higher.

At the end the values recorded on the two dummies onboard the compact, impacted by the three models, are shown in Figure 10.

The comments are the same as made on the impacted subcompact.

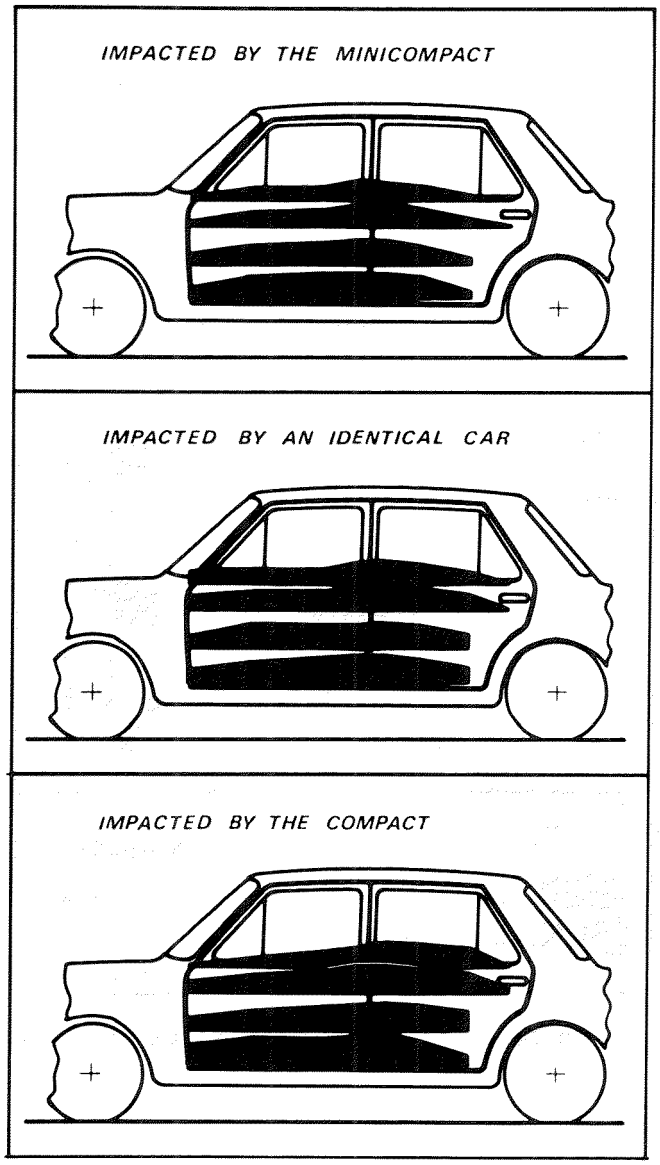


Figure 6. Intrusions in the subcompact impacted by the three models.

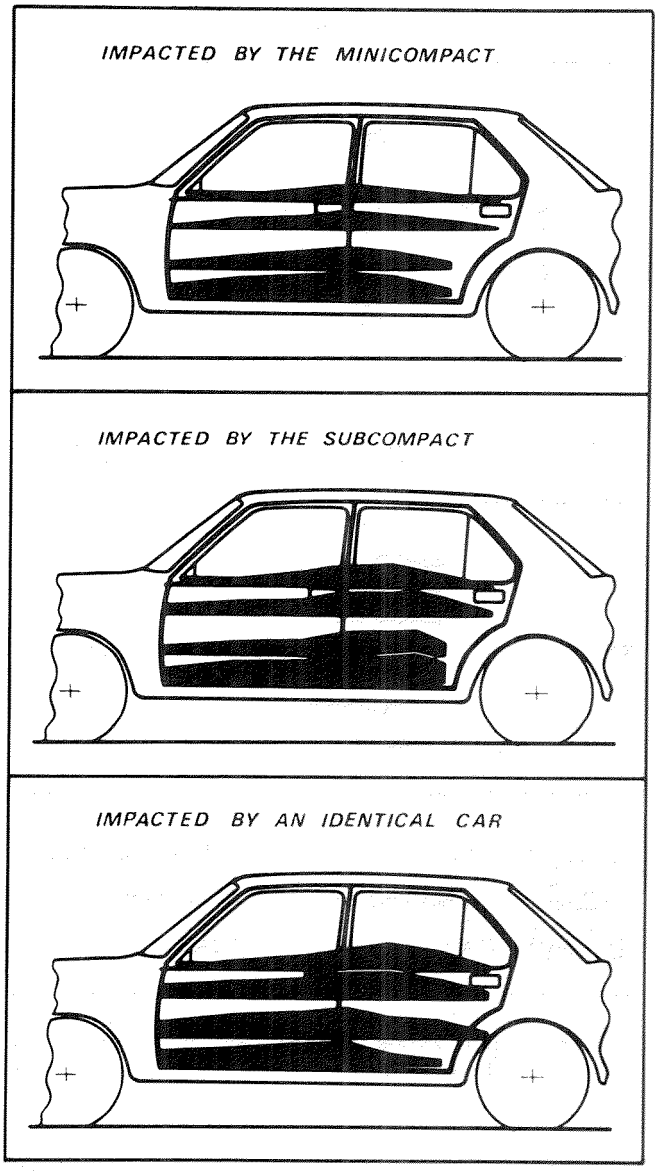


Figure 7. Intrusions in the compact impacted by the three models.

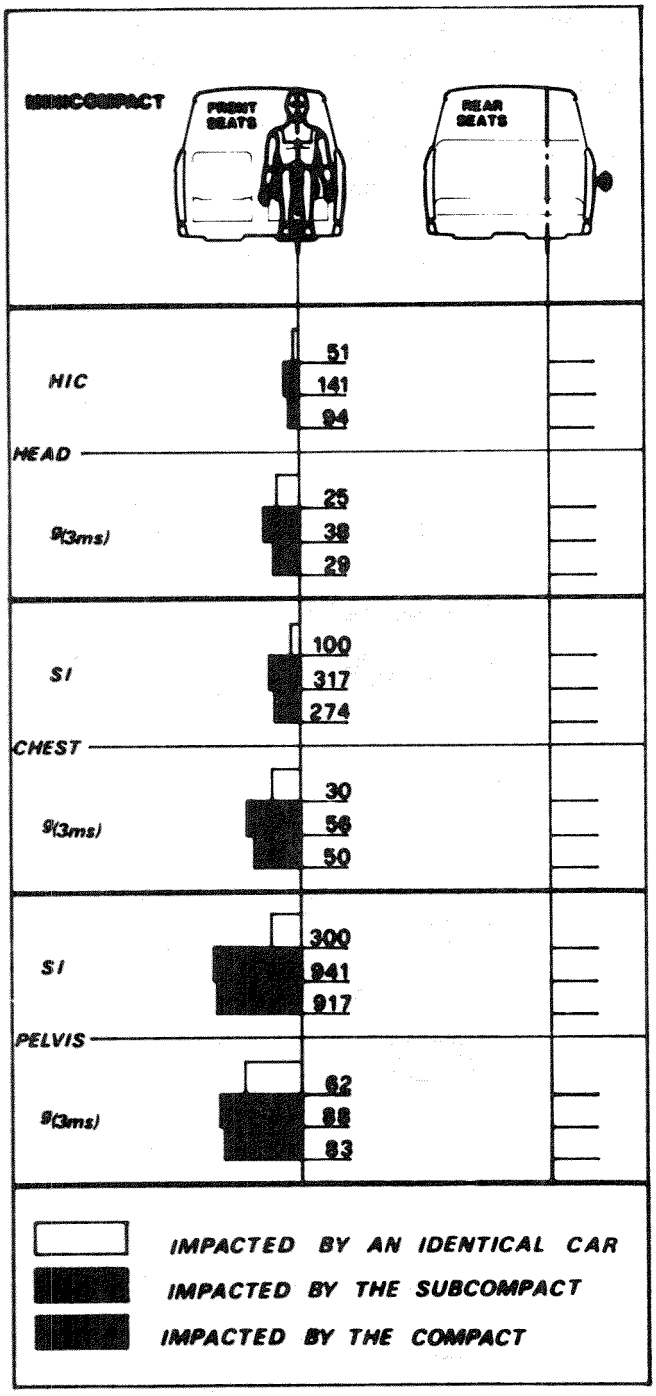


Figure 8. Dummy values on the minicompact impacted by the three models.

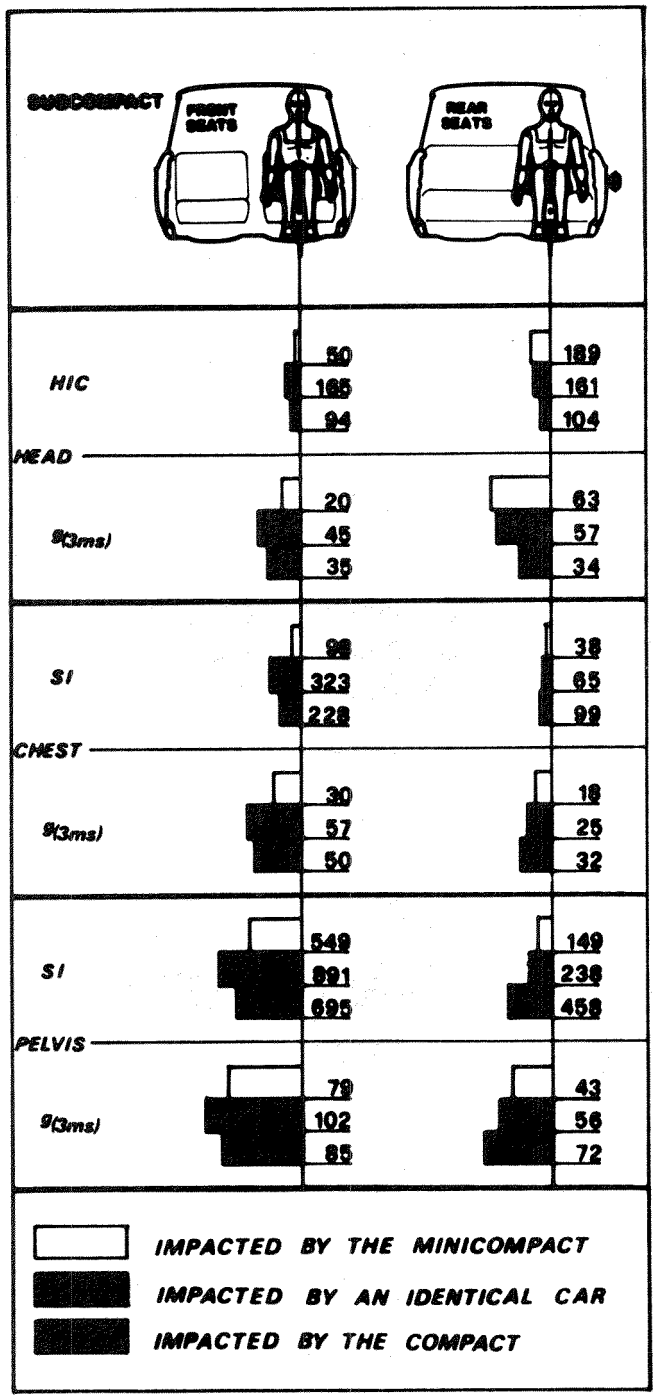


Figure 9. Dummies values on the subcompact impacted by the three models.

PART 2: MOVING BARRIER-TO-CAR-COLLISIONS

The tests have been conducted by means of the moving barrier we described in the previous ESV Conferences.

The Figure 11 shows the size of Fiat's moving barrier; its weight can be varied from 900 to 2000 kg.

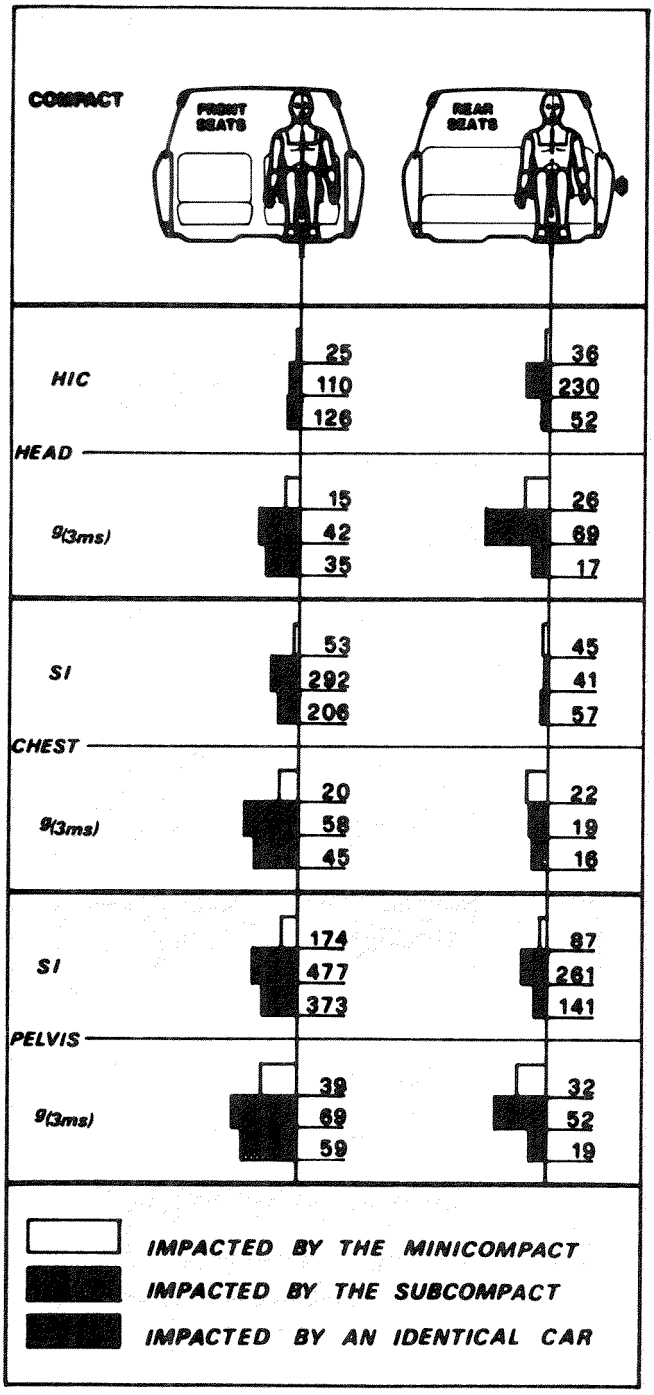


Figure 10. Dummies values on the compact impacted by the three models.

Thirty-six honeycomb modules are fixed to the front face (Fig. 12).

By means of load cells, each supporting a honeycomb module, and by means of potentiometers, whose string passes through dynamometric cell and module (Fig. 13), it is possible to detect the load distribution and deformation patterns during the collisions.

The car models and test conditions are the same as car-to-car collision tests. Each of the three models has been laterally impacted by the moving barrier at 40, 50 and 60 km/h velocity. As a whole, nine tests have been carried out.

In Figure 14 a comparison is shown of the intrusions recorded on the minicompact impacted at the three velocities.

As expected the extent of intrusion increases as the impact velocity is increased but the area of maximum intrusion is not always the same. It should be noted that, due to the short wheelbase of this car, the wheels are involved in the contact with the moving barrier.

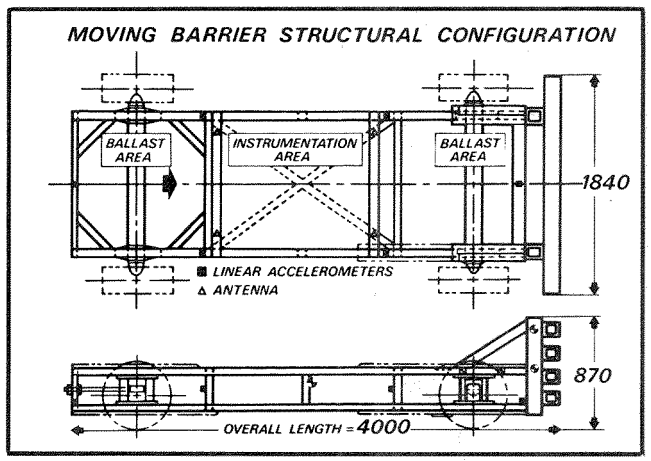


Figure 11. Moving barrier structural.

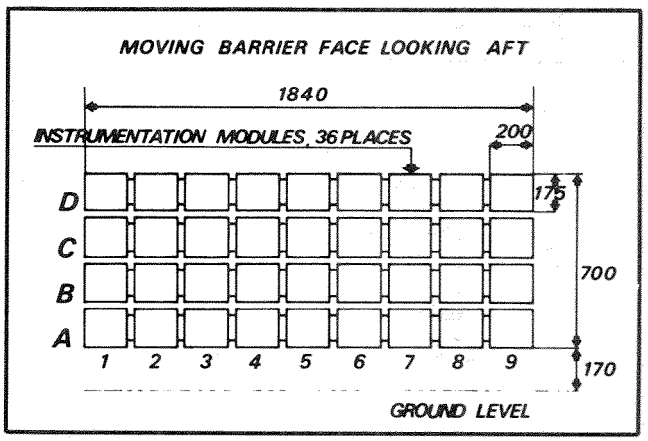


Figure 12. Moving barrier face configuration.

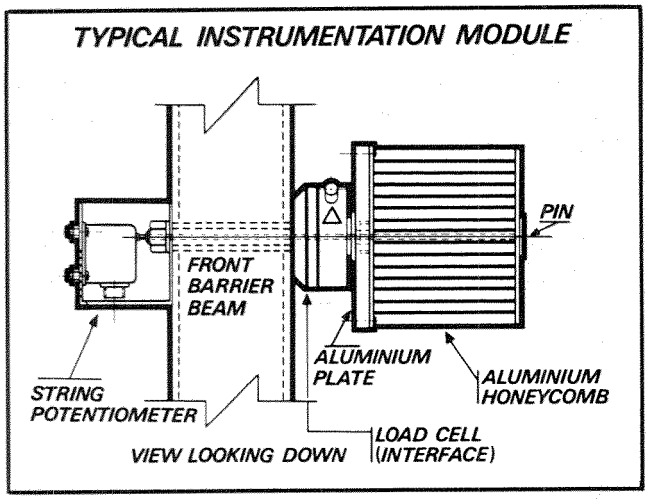


Figure 13. Typical instrumentation module.

Now let's see in Figure 15 the intrusions in the subcompact impacted at the three velocities.

The pattern of intrusions and location of maximum values are in good agreement with the results from car-to-car tests. Here again, the subcompact results to be the most deformable of all the models.

Figure 16 shows the moving barrier close to the subcompact before the test at 60 km/h.

The distribution of local stiffness is highlighted by the impression on the honeycomb elements after the test (Fig. 17). The pillar's and lower sill's impressions are clearly recognizable.

Figure 18 shows the values of loads, measured on the moving barrier in the collision at 60 km/h against the subcompact at 15, 30, 45, 60 milliseconds.

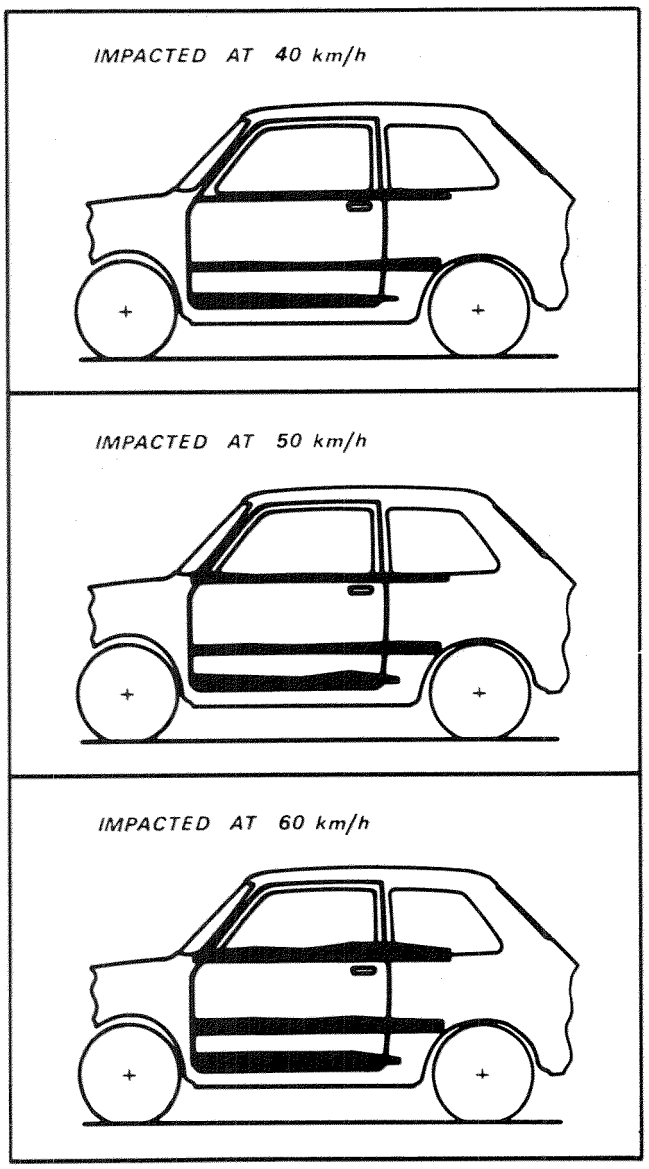


Figure 14. Intrusions in the minicompact impacted at the three velocities.

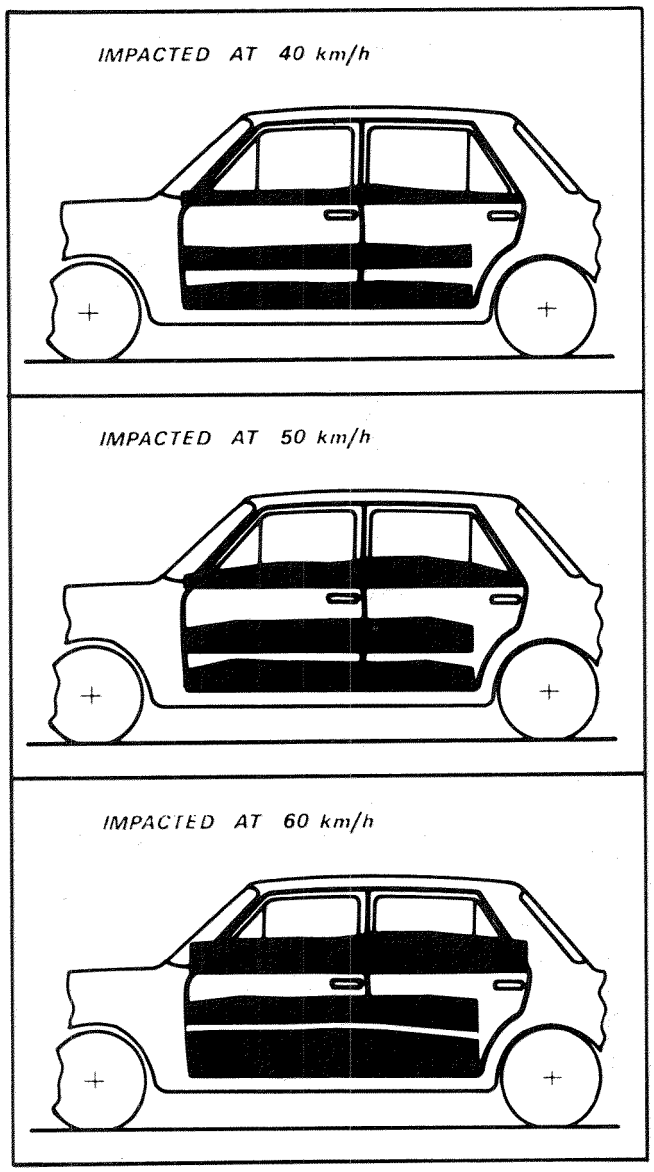


Figure 15. Intrusion in the subcompacted at the three velocities.

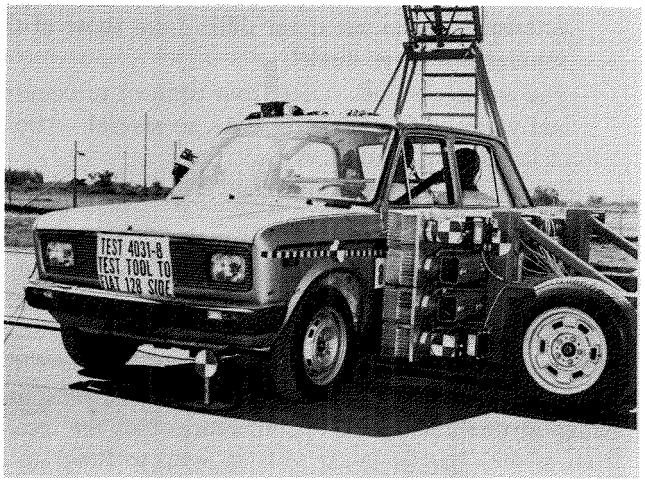


Figure 16. The moving barrier shown close to the subcompact before the test.

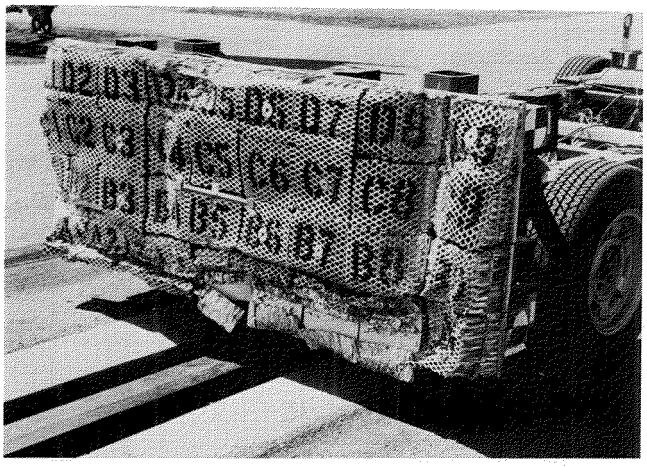


Figure 17. Impression on the honeycomb elements (subcompact impacted at 60 km/h).

It's evident that the forces involved essentially the pillars and the lower sill. Thus, a "negative" of the struck car's local stiffnesses and their evaluation during impact are obtained.

The intrusions on the compact, impacted at the three velocities, are compared in Figure 19.

Also for the intrusions measured on the compact the comments previously made on the subcompact are valid. The intrusion amount on the compact is a little lower than that measured on the subcompact, which results to be the most deformable.

Now we'll see in Figure 20 the data recorded on the dummy in the minicompact impacted.

—As expected, all the values increase as the impact velocity is increased.

—The most stressed part is the pelvis, next the chest and then the head, which confirms the results from car-to-car tests.

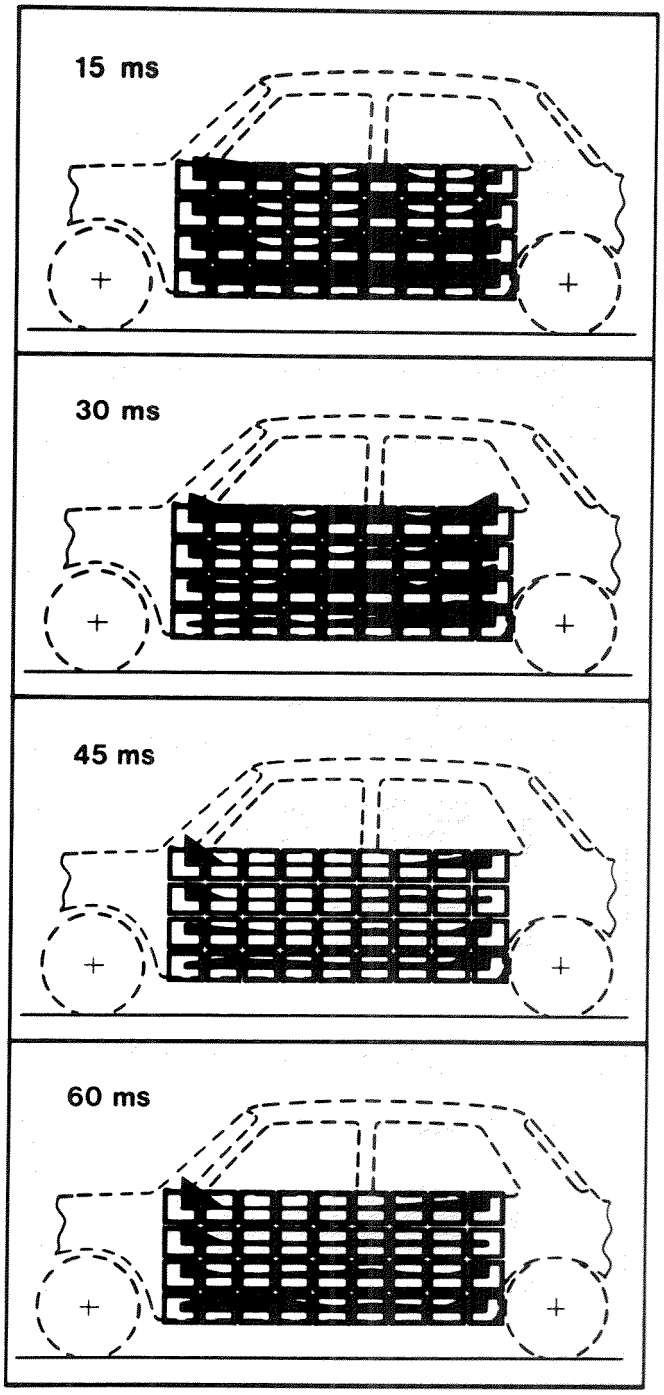


Figure 18. Loads measured on the moving barrier in the collision at 60 km/h against the subcompact.

In Figure 21 there are the values of the dummies installed in the subcompact impacted.

—Again, the values increase as the impact velocity is increased.

—The most stressed part of both dummies is the pelvis, just as with the models previously tested.

—The values on the rear passenger dummy are always lower than those for the driver dummy, which corroborates car-to-car tests.

The values on the compacts' dummies are shown in Figure 22.
These general considerations are confirmed:

—The most stressed part is the pelvis, next the chest and then the head.
—The rear passenger is always less stressed than the driver.

PART 3: METHODOLOGY

A deformable moving barrier is used to simulate an impacting car. A side collision test against the car under consideration is carried out and the values obtained are compared with the allowable limits. The barrier can simulate an average model, but with the following limitations:

—The evaluation is the less reliable the more the characteristics of the tested car differ from those of the simulated average model.
—The average model varies from country to country and varies in the course of time, so several versions of barrier are needed.
—The evaluation is of "pass/fail" type only.

The barrier we have developed makes it possible not only to compare the test results and the allowable values, but, through the use of mathematical models, a quantitative evaluation of compatibility for cars of different types could be obtained. Moreover it doesn't have the limitations mentioned above. The methodology we presented at the previous ESV Conferences uses the results from moving barrier-to-car tests as input to Program A (Fig. 23), to calculate the force-deflection relationship for

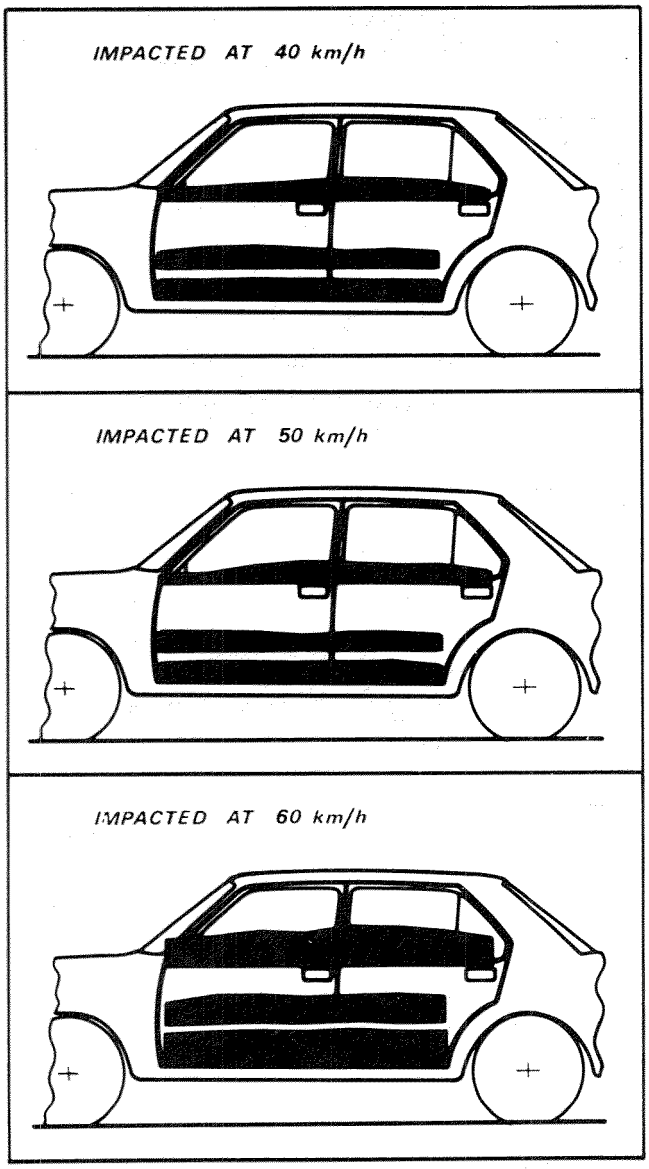


Figure 19. Intrusion in the compact impacted at the three velocities.

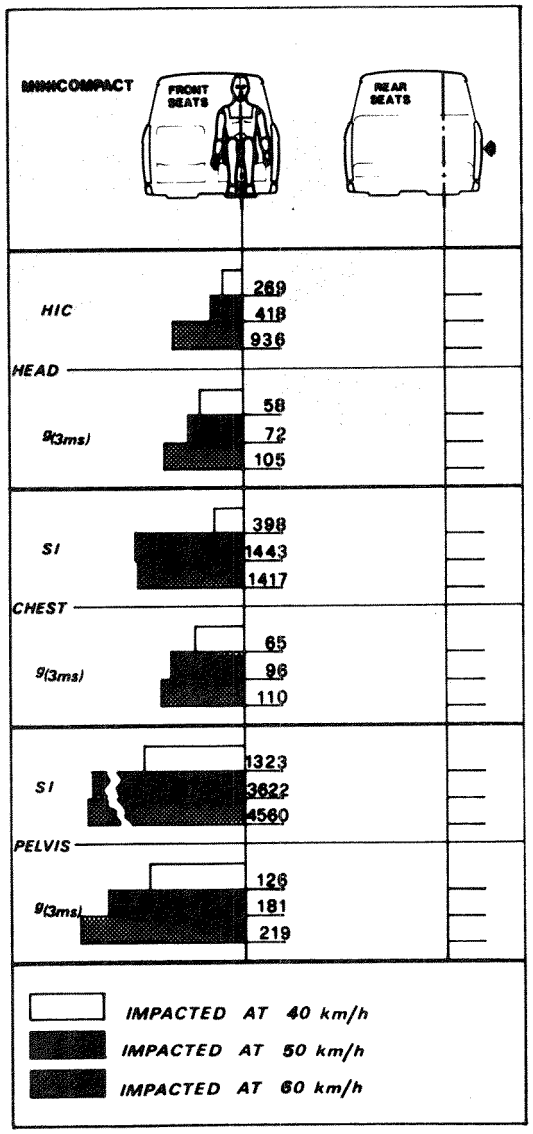


Figure 20. Dummy values in the minicompact.

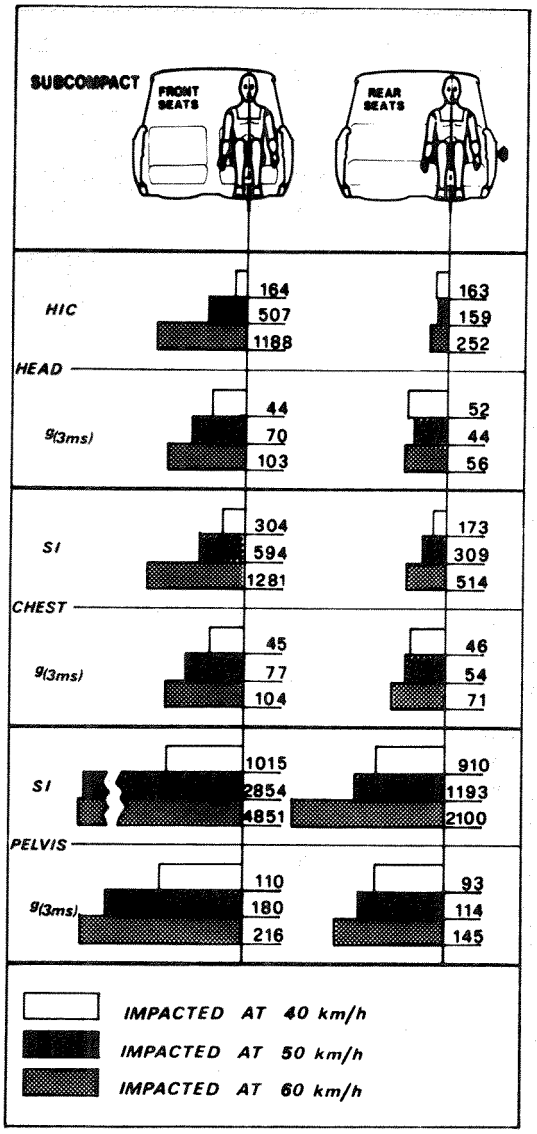


Figure 21. Dummies values in the subcompact.

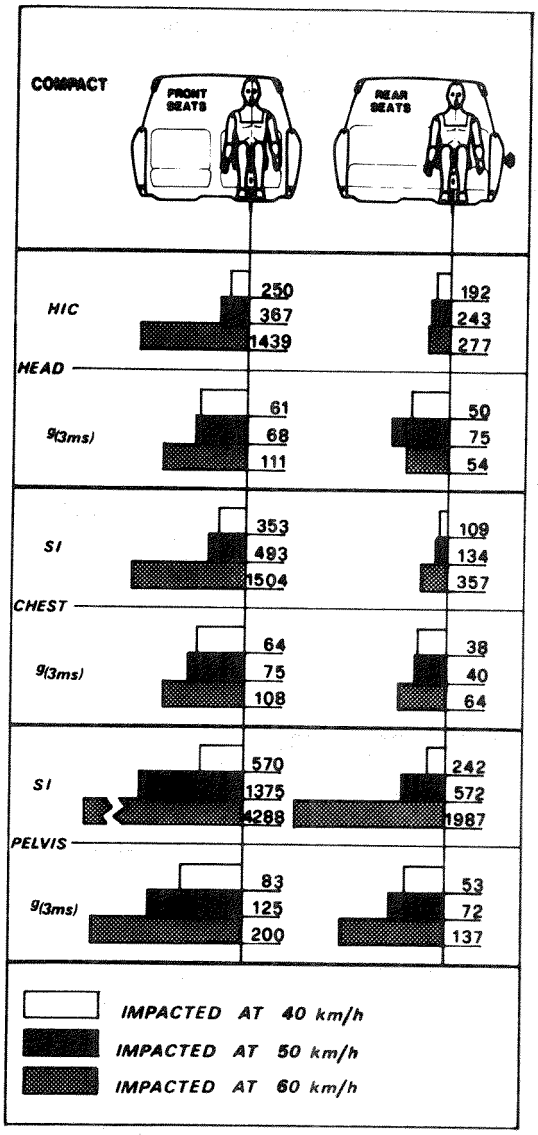


Figure 22. Dummies values in the compact.

the crushable elements of the mathematical model of the car.

The side model for the minicompact (Fig. 24) consists of lumped masses, representing the most significant parts of the car, and non-linear elastic elements connecting these masses.

For the subcompact and the compact (Fig. 25) the model is conceptually similar; here also the rear door and the rear passenger dummy are represented.

The use of Program B (Fig. 23) allows the car's structural response to be obtained at a given collision velocity.

To evaluate the behaviour at different velocities the sensitivity of force/deflection characteristic at the deflection speed, i.e., the crush rate effect, has been introduced.

By way of example, a comparison in Figure 26 is shown between the values experimentally measured on the compact and the values obtained through simulations, with and without crush rate effect, in collision at 60, 50 and 40 km/h. The influence of crush rate effect is considerable.

The computer program ROM (Restrained Occupant Model) allows the occupant response to be obtained (Fig. 23) through the use of the mathematical model shown in the Figure 27. It is made up of 11 lumped masses representing the most significant body elements. There are 10 joints, whose resistance depends on the user's selection of occupant, either human or dummy.

The external forces which are simulated are those generated by the impact surfaces, restraint system, seat and floor (Fig. 28).

The methodology provides information on structural behaviour, namely:

—maximal mutual crush

—velocity changes of moving barrier and impact car
—time histories of acceleration, velocity and displacement, in several areas of the impacted car

and information on occupant behaviour, namely:

—time histories of acceleration, velocity and position, for each body element
—impact (if any) between body elements and contact surfaces, and their time of occurrence
—resultant acceleration for head, chest and pelvis
—Head Injury Criterion and Chest Severity Index
—femur loads
—belt loads.

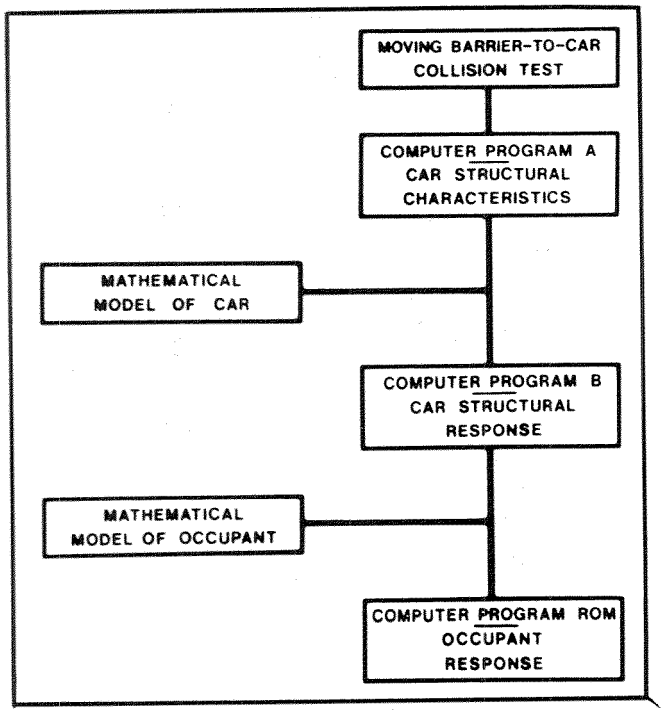


Figure 23. Methodology.

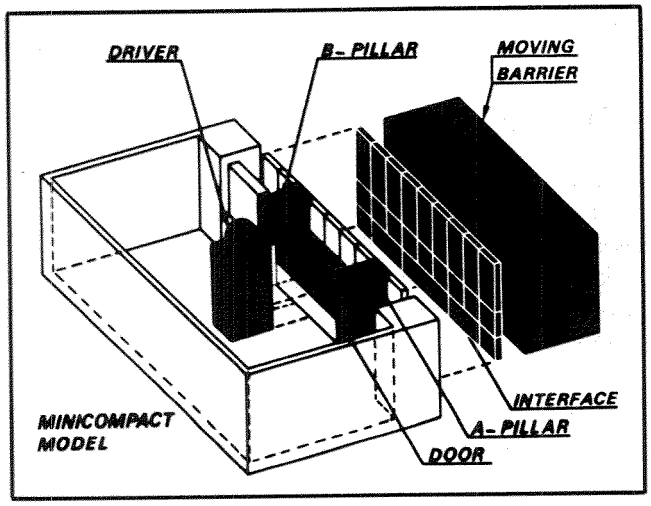


Figure 24. Side model for the minicompact.

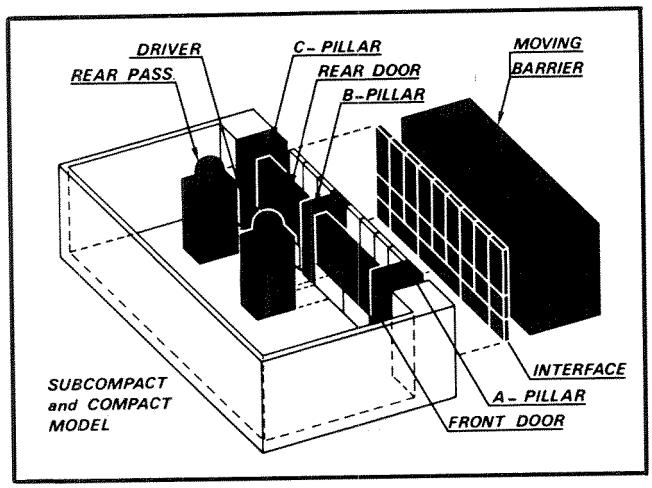


Figure 25. Side model for the subcompact and compact.

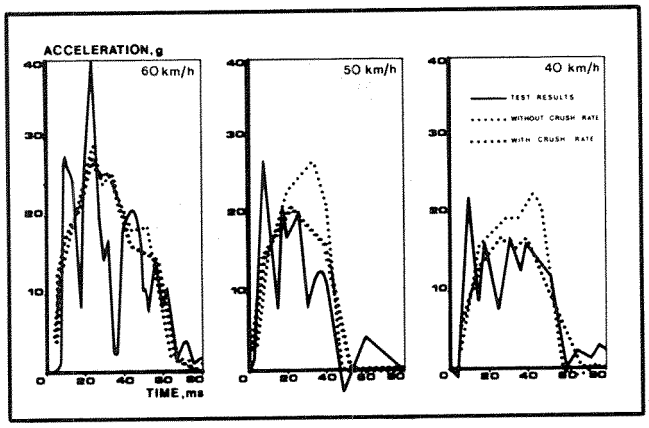


Figure 26. Crush rate effect.

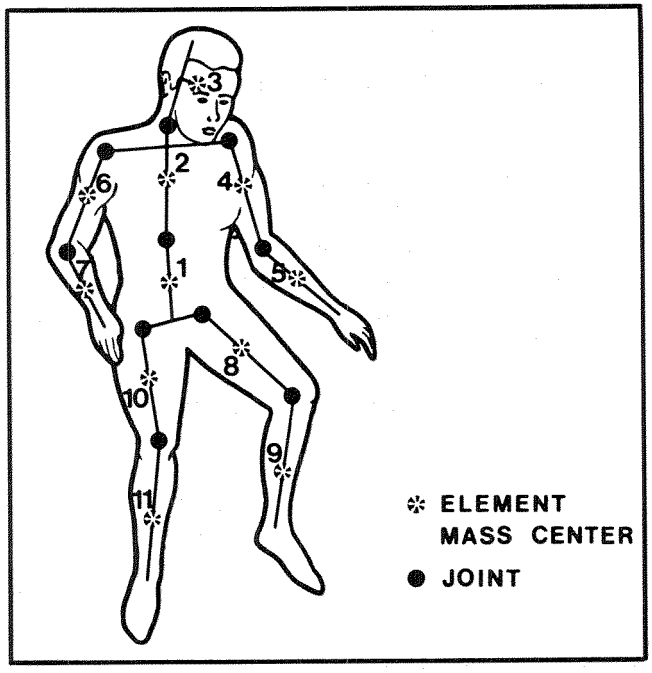


Figure 27. Occupant model.

The methodology validation has been carried out by comparing the values from the nine tests, moving barrier-to-car, with the simulated values. Due to the volume of data generated, a detailed comment of each is felt to be beyond the scope of this presentation. As an example only, some comparisons are presented between experimental and simulated values for the moving barrier-to-compact car collision at 60 km/h.

For the structural behaviour, Figure 29 shows the velocity pattern of the moving barrier and the occupant compartment area of the compact car, as obtained from experimental testing and simulation.

Superimposed on the diagram of Figure 29 is the velocity pattern of the rear door's upper panel, obtained from tests and simulation (Fig. 30). Near, there are the experimental and simulated results plotting the intrusion history for the same location.

In the same way, in Figure 31 the comparison is shown of the velocity of the rear door's lower panel. Near, the intrusion in such area is plotted.

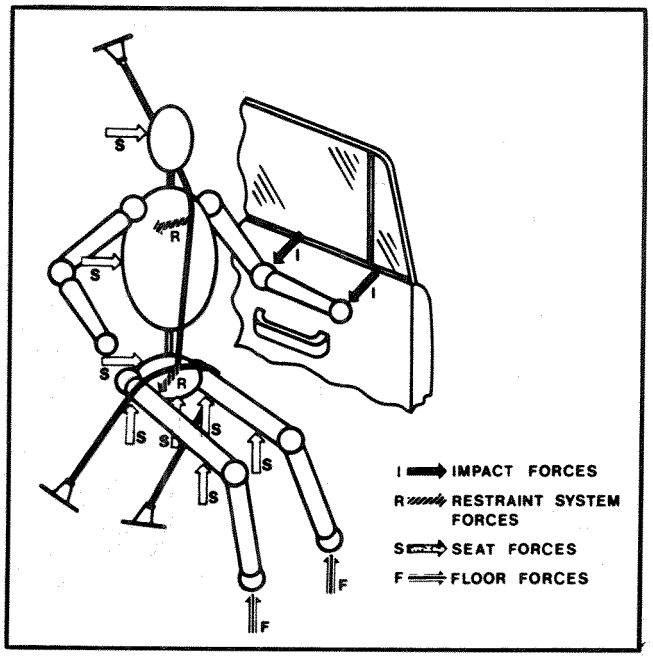


Figure 28. External forces on dummy.

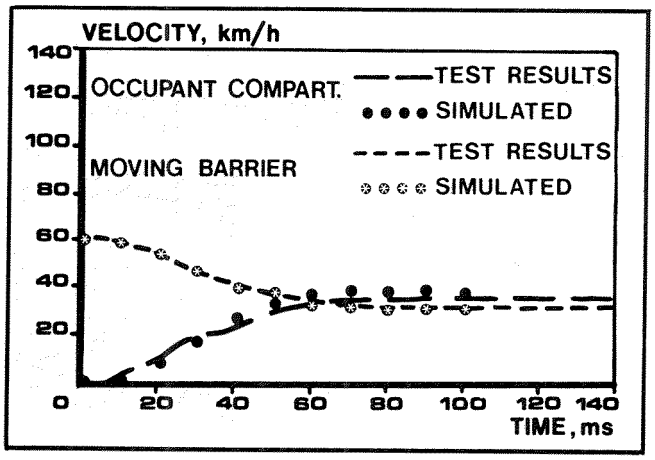


Figure 29. Moving barrier and occupant compartment velocity.

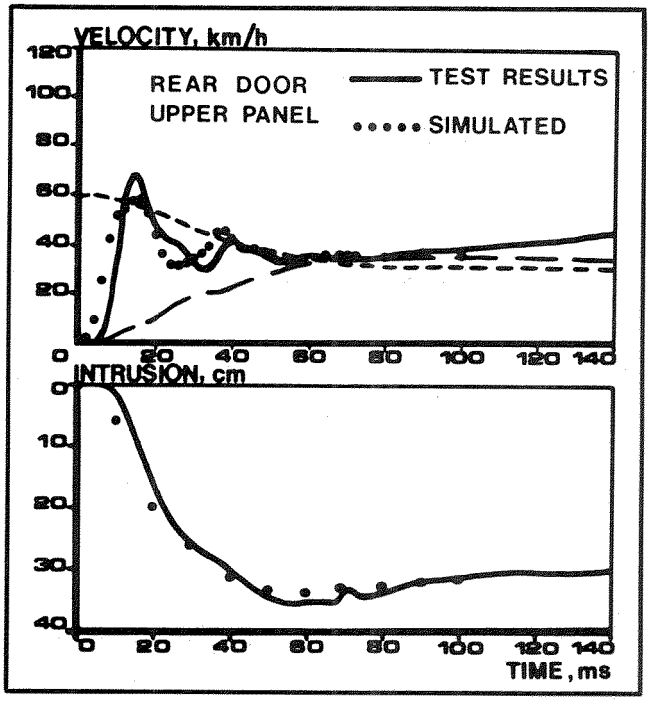


Figure 30. Rear door's upper panel velocity and intrusion.

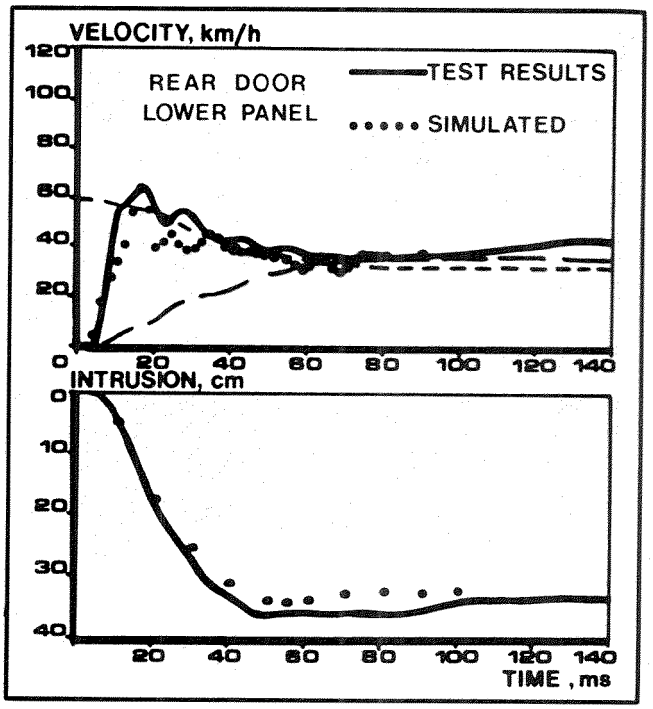


Figure 31. Rear door's lower panel velocity and intrusion.

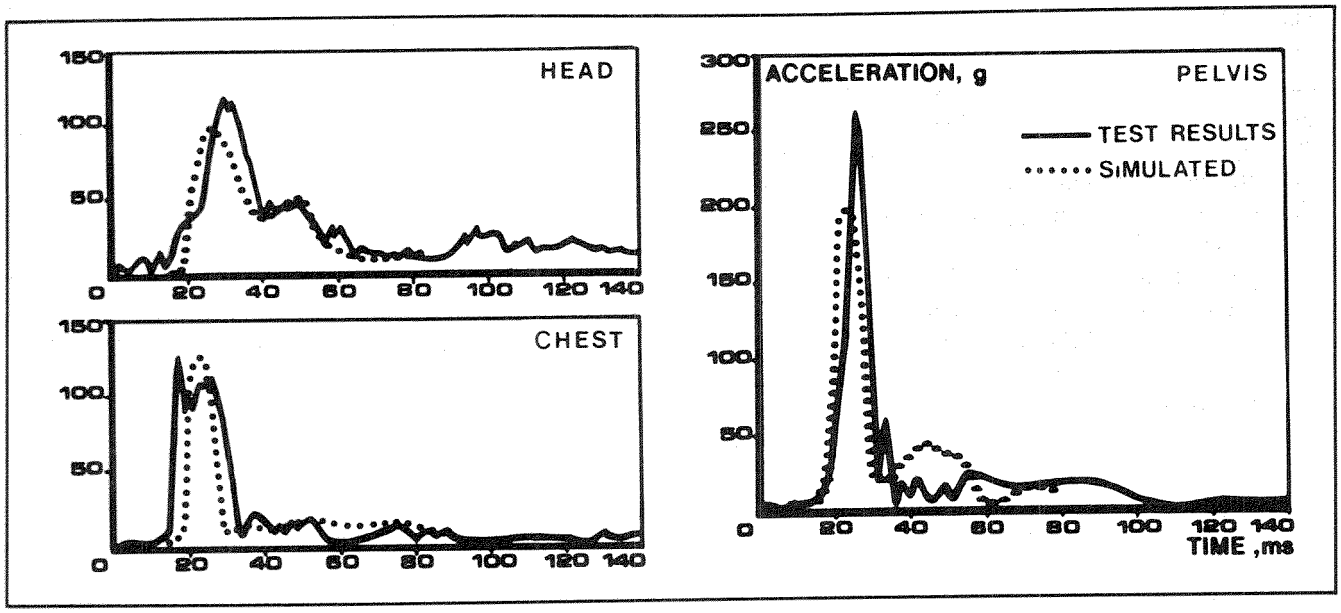


Figure 32. Driver dummy's head, chest and pelvis accelerations.

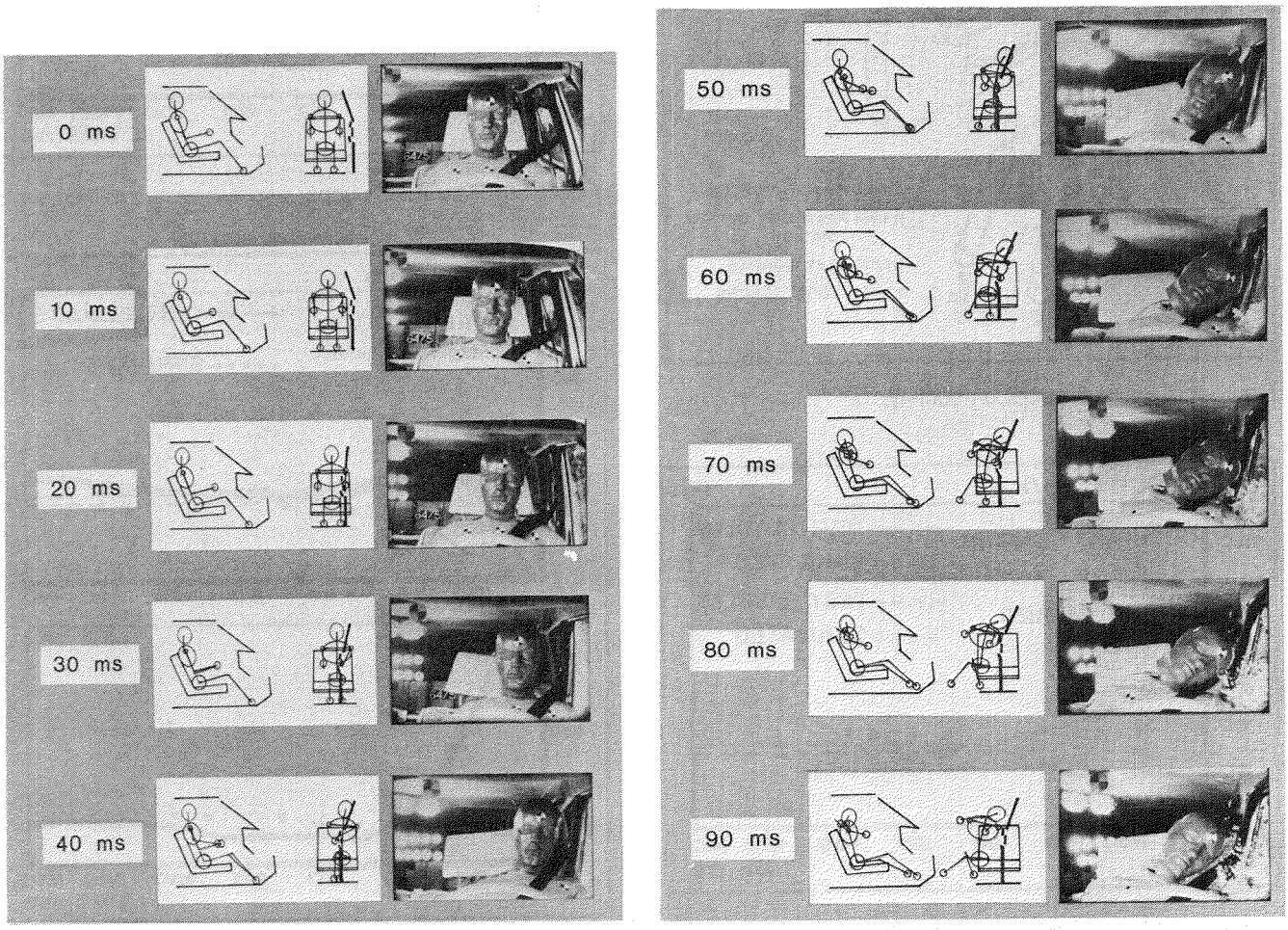


Figure 33. Occupant kinematics.

For the occupant behaviour, the figure compares the acceleration values for head, chest and pelvis of driver dummy, as obtained through tests and simulation.

The kinematics of the occupant model is plotted at rate of 10 milliseconds in comparison of the sequence of a car-to-car test, drawn from a high-speed film, which, at rate of 10 milliseconds, shows the motion of dummy's head and chest with respect to the occupant compartment. The kinematics is very similar.

The results of validation, for both the structural behaviour and occupant behaviour, can be considered to be in accordance with expectations. The methodology allows:

—Comparison of the values measured in moving barrier-to-car test, at a given velocity, with the allowable limits.

—Evaluation of structural and occupant behaviour for the impacted car as well as the impacting car.

—By simulating increasing collision velocity, identification of the velocity at which the allowable limits are reached by one car or by both cars, i.e., the quantitative evaluation of compatibility of this pair of cars.

—By extending the analysis to more models, it is possible to evaluate the compatibility between different models of a fleet and to considerably reduce the number of tests that would be necessary.

The simulation cannot be better than the scatter of experimental data. The use of reliable dummies and reliable tolerance criteria is of paramount importance.

Volvo Traffic Accident Research System as a Tool for Side Impact Protection Evaluation and Development

HANS NORIN, ANNA NILSSON-EHLE,
CHRISTER GUSTAFSSON
Volvo Automotive Safety Centre
Volvo Car Corporation

ABSTRACT

In this report Volvo Traffic Accident Research System is described. Volvo has a combination of multidisciplinary and statistical investigation which gives a representative picture of the traffic accident situation and also gives a deep insight into parameters that influence the occupant injury-production.

This accident material, which covers about 12.000 of the most severe Volvo accidents, in Sweden, has been the basis for an analysis of the side impact problem area.

The traffic environment as experienced by the Volvo car, in terms of accident type distribution, obstacles, etc., is compared with corresponding data in other accident materials.

Conclusions from this comparison and analysis of the distribution of different types of injuries, are used to determine important side impact parameters. These parameters indicate the test methods that should be used to give a good simulation of the real traffic environment.

The need of subsystem testing as a complement to full-scale testing is discussed with the complex traffic environment as background.

INTRODUCTION

The demands that are made on a modern car are comprehensive. This applies, not least, to the aspects of design that are intended to protect the occupants in case of a road accident. The requirements placed on the car manufacturer are controlled to some extent by current legislations. Reproducible test methods in laboratories represent only a certain number of specific collision situations which agree, more or less, with the actual accident situations that arise on the road.

In order to achieve designs which give the optimum possible protective effect, it is essential to obtain information on what actually happens in a road accident, in relation to the car design, including information on the injuries caused to the occupants of the car.

Consequently, we decided to carry out special accident research in parallel with the normal laboratory collision testing. The knowledge gained in this way can be related, in the laboratory, to the car design.

In this report, Volvo Traffic Accident Research work is described and applicated at the side impact problem.

VOLVO TRAFFIC ACCIDENT RESEARCH SYSTEM

The main task of the Accident Research System is to collect information on what happens to a car and its occupants in a traffic accident. In order to maintain the quality of this work at as high level as possible, we have divided up our activities into two main fields. (See Fig. 1.)

Multidisciplinary Accident Investigation

The multidisciplinary Accident Investigation Group studies approximately 100 road accidents each year. These are investigations in depth which means a thorough technical examination of the car (see Figure 2) together with a close analysis of the occupant injuries that occurred. Specially trained technicians are responsible for the vehicle examination, while the analysis of injuries is carried out by a doctor who is associated with the Group. In addition, records are kept of the traffic situation at the time of the accident. This helps us to obtain an understanding of the effect of the traffic environment on the accident and its consequences.

The multidisciplinary Accident Investigation Group operates in two zones—local and distant. The local zone covers a geographical area within one hour's driving time from our office in Gothenburg. At the scene of the accident, we document the traffic situation by means of photographs, measurements, interviews with the police, rescue personnel, etc. An examination of the vehicle is carried out and this is later supplemented by more detailed and extensive investigation after the vehicle has been transported to a workshop.

We obtain the information that a road accident involving a Volvo car has occurred, through our co-operation with the police, the rescue services and the regional SOS alarm centre. There is always one member of our group in readiness to visit the site of an accident, all round the clock.

The distant zone consists primarily of the rest of Sweden, but also includes other countries, if accidents occur which we consider to be of particular interest. We obtain information on these accidents from the police, the National Swedish Road Safety Office, the Insurance Companies and our own Service organisation. All have been informed on the type and severity of accident in which we are interested. This gives us wide flexibility; our areas of interest, naturally, change from time to time.

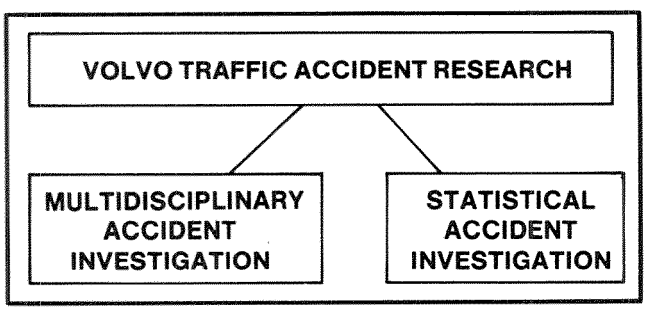


Figure 1. Volvo traffic accident research.

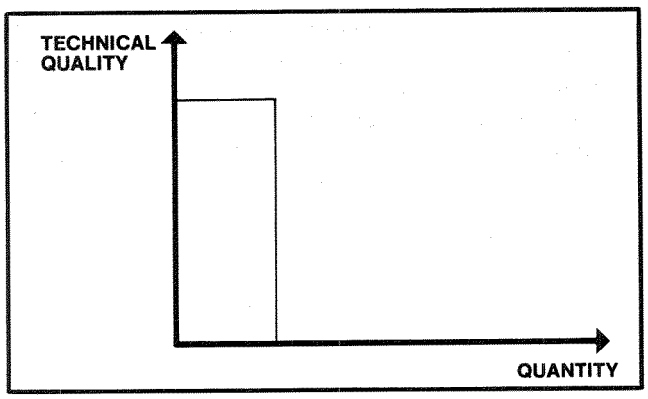


Figure 2. Multidisciplinary accident investigation.

Statistical Investigation

Our collection of accident statistics differs from the work of the multidisciplinary Accident, since these statistics cover a large number of accidents in which Volvo cars are involved. This activity is not regarded as a deep study of the design of the car. (See Fig. 3.)

Our association with our own Insurance Company, Volvia, gives us a unique opportunity of following up accidents to Volvo cars. At present about 400.000 Volvo cars are insured by Volvia and, of these, approximately 45.000 are involved in an accident of some kind each year. From amongst these accidents we select about 2.000 of the more serious accidents. (See Fig. 4.)

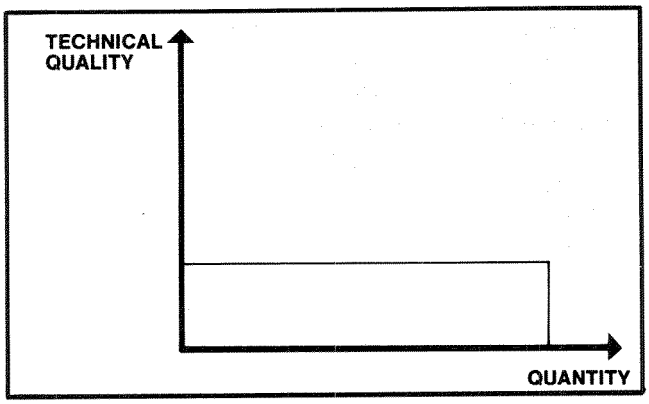


Figure 3. Statistical investigation.

In this way we gather information on all the serious accidents involving Volvo cars in Sweden. So far we have gathered statistics on 12.000 serious accidents.

Through the co-operation of the Volvia Damage Inspectors we obtain photographs of the cars damaged in all of these accidents. From the photographs, we assess the deformation of the car and this is then coded, using the International CDC System (1).

We also send a questionnaire to the owner of the car asking for information on how the accident occurred, how many passengers were in the car, etc. This questionnaire form is then supplemented by the police reports and the medical reports from the hospital which treated the injured. The injury reports are analyzed by our doctor who codes this information, using the International AIS System (2). All the information concerning the accident is processed and stored using a special computer program; it can then be used in various types of accident analysis work. The information routes are shown in Figure 5.

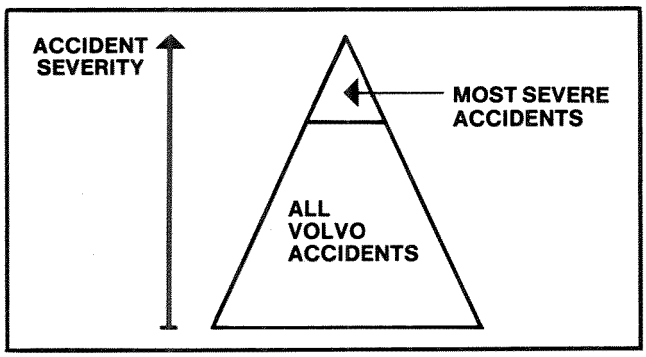


Figure 4. Selection of serious accidents.

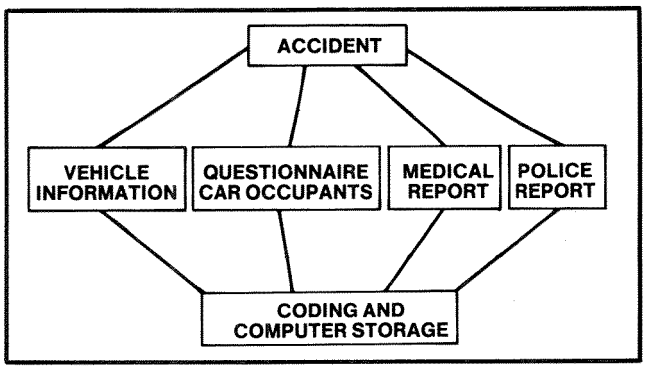


Figure 5. Data collection, accident statistics.

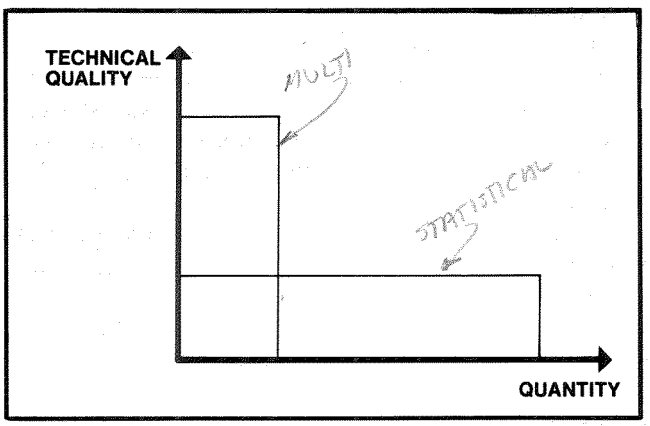


Figure 6. Combination of multidisciplinary and statistical accident investigation.

Combination and Use of Accident Investigations

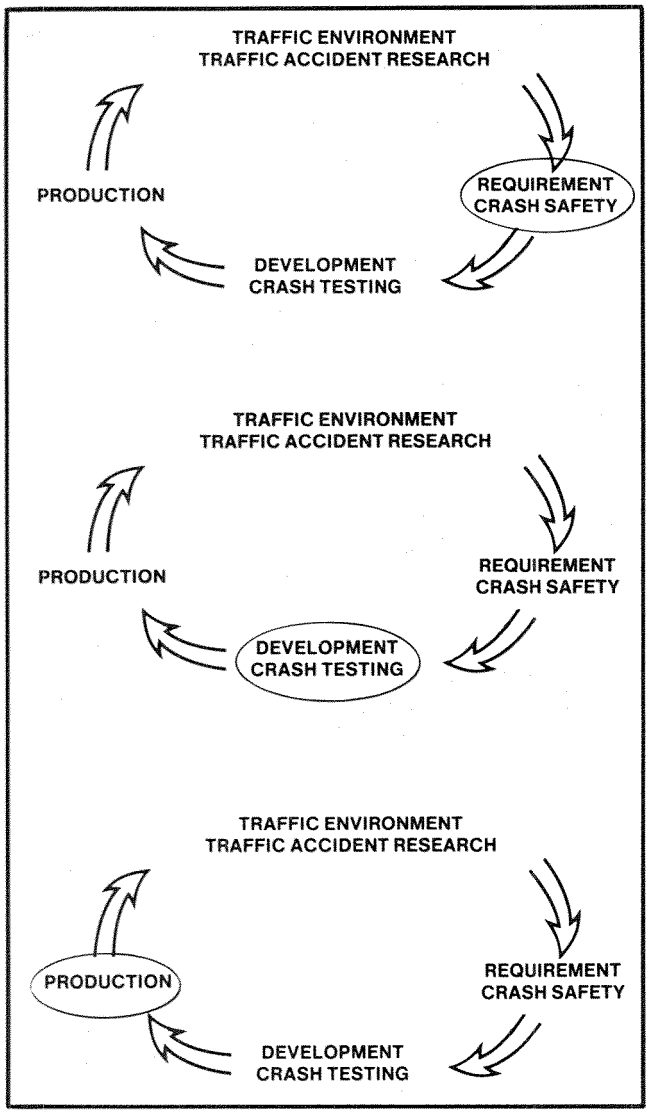
This combination of multidisciplinary and statistical accident investigation gives a deep insight into the crash behaviour of our vehicles and also a possibility to obtain a representative picture of the whole traffic accident problem area. (See Figure 6.)

An example from this work is described in the following example.

We discovered from study of accidents carried out by the multidisciplinary Accident Investigation Group that the steering wheel in our cars deformed in a front impact accident in such a way that drivers who were not wearing a seat belt received typical chest injuries on impact with the wheel. The wheel, nevertheless, fulfilled all the current legal requirements. To find out if this type of injury was common in this particular type of accident, we carried out an analysis of our extensive accident statistics. The result from this analysis showed that this typical chest injury was more common than we had previously thought. We contacted the designers involved and discussed with them various proposals for improvements in design of the steering wheel. The result was a completely new type of steering wheel, designed with a large impact area so that the force of impact would be spread out over a wider area of the rib cage. We then followed up accidents to cars fitted with the new wheel and we were able to show that in accident situations similar to those studied previously, this typical chest injury had been eliminated.

In the above example, we have described how our traffic investigation work can provide direct feedback of information to the Design Department.

Another important aspect of our work, is our co-operation in setting standards for collision safety in future products. The knowledge which is being continually built up by the members of the Group, on traffic accidents and associated problems, is used in setting standards which are as appropriate as possible to the actual traffic environment. This work can be described (3) as follows:



The knowledge gained from traffic accident research is used in establishing the requirements for the safety properties of a car.

These requirements then provide the basis for the work of design and development. Collision tests form a part of this work and the experience gained by traffic accident research is utilized.

Later the car is produced and sold to the customers. This means that it begins to be exposed to actual traffic environments. We can now follow up the road accidents in which our car is involved, and so obtain information on how well we have succeeded in suiting our car to the actual traffic environment.

ACCIDENT STATISTICS

During the past decades, large numbers of road accident statistics have been presented in many parts of the world. The statistics are, in many cases, contradictory and give a confused picture to those who try to use them.

The reason why particular aspects, e.g., side impact accidents, appear to give very different results depends on a number of factors. One of the most important of these is the manner in which accident information is gathered. This in its turn is often determined by the opportunities that are available for obtaining the accident information.

For example, a medical specialist, interested in traffic injuries, may select only those accident cases which arrive at this clinic. Research workers with alcohol and drugs as their main field of interest may, perhaps, guide the statistics so that they include accidents in which these factors are relevant. The selection of accidents may also be governed by the practical possibility of reaching the sites of accidents, for example, accidents occurring on a particular section of motorway, or in a particular town or district.

When accident statistics are being analysed, it is important that information should be available as to how the accidents included in the statistical material were selected. Thus it is possible to avoid use of the accident information in a manner which the author had not intended.

A large number of traffic accident research workers have presented results and summaries of accident investigations on side impact collisions.

The following is an attempt to analyse the Volvo accident statistics systematically, so that the different types of side impact collision can be quantified, with respect to the nature and severity of the injuries caused.

In the previous section we described how the accident data are collected. The information used here is from the

Volvo Accident Statistics gathered during the years 1974-1979.

This information covers all the serious accidents (from the point of view of vehicle deformation) that occurred to Volvo 140 and 240 cars, in Sweden, during the above mentioned years.

Complete documentation is available for each accident, giving vehicle deformation, information on occupants and their injuries and a description of the environmental conditions and the sequence of the accident.

The basic data used for this analysis covered 12.000 accidents. Accidents in which any of the occupants of the vehicle received injuries AIS 2 have been selected from this total.

The accidents to Volvo cars have been divided up into a number of different types. These are shown in Table 1. The table also shows the proportion of each type of accident where the maximum injury level in the car was AIS $\geq$ 2 and AIS $\geq$ 4.

An attempt has been made, in Table 1, to arrange the Volvo accidents according to their "traditional" type.

In most presented accident materials "front impacts" stands for more than fifty percent of all accidents.

"Multiple accidents" and "other accident" form normally a low proportion.

In our material (see Table 1) "front impacts" stands for less than forty percent. It may be thought that frontal collisions form a low proportion of the total, whilst multiple accidents and "Other" form a high proportion. There is however considerable deformation of the front of the car in accidents involving big animals, driving under trucks and in most multiple accidents, or in accidents caused by running off the road. It is believed that, in many statistical summaries, a large proportion of these accidents are classified as frontal collisions.

Analysis of the consequences of personal injury normally requires a relatively complete separation of the different types of accidents right down to such a level that assessment of each individual injury is as certain as possible.

The accidents shown in the upper part of Table 1 as side collisions, include the accidents where the significant deformation was applied to the side of the vehicle.

In addition to the accidents regarded in the Volvo accident classification as side collisions, there are also sideswipe accidents and certain offset accidents.

In Table 2 below, these have been extracted from the total number of accidents.

We see from Table 2 that about one third of the accidents with injuries AIS $\geq$ 2, and AIS $\geq$ 4 are accidents which are often called side collisions.

A corresponding proportion of side collisions is reported in many other investigations (4).

Sideswipe I accidents are those in which the vehicle is hit in front of the A-pillar, with deformation of the A-pillar and of the floor/bulkhead. This type of accident which, to some extent, is comparable with the severe Offset I accident, should not be regarded as a side collision, nor analysed statistically together with other side collisions.

The same applies to Sideswipe II accidents. According to our definition, these accidents are those in which the impact on the side is at an angle of less than 30° to the longitudinal line of the vehicle.

The nature of both the vehicle deformation and the occupant injuries differs between Sideswipe I and Sideswipe II accidents.

Sideswipe accidents are not included in the following analyses.

Impact Area

Based on the discussion in the previous section the analyses will now include only the accidents in which the impact takes place on the left or right side of the vehicle, as shown in Figure 7.

Table 1. Distribution of accidents types for accident with maximum injury level AIS 2-6 and AIS 4-6.

		AIS 2-6	
FRONT IMPACT	FRONT IMPACT	27.0	
	OFFSET I	4.8	
	OFFSET II	3.0	
SIDE IMPACT	SIDESWIPE I	4.2	1/3
	SIDESWIPE II	1.9	
	IMPACT L. SIDE	13.4	
	IMPACT R. SIDE	10.0	
REAR END IMPACT	REAR END IMPACT	2.1	
ROLLOVER	ROLLOVER	10.8	
	OVERTURNING	0.8	
MULTIPLE ACCIDENT	MULT. IMPACTS	5.1	
	IMPACTS AND ROLL.	8.2	
OTHER	RUN OFF ROAD	5.3	
	UNDER TRUCK	0.8	
	BIG ANIMAL	2.6	
		100%	

Table 2. Accident where the significant deformation is applied to the side of the vehicle.

	AIS 2–6	AIS 4–6
Sideswipe I	4.2 %	5.2 %
Sideswipe II	1.9 %	2.2 %
Left side	13.4 %	13.0 %
Right side	10.0 %	11.8 %
Total	29.5 %	32.2 %

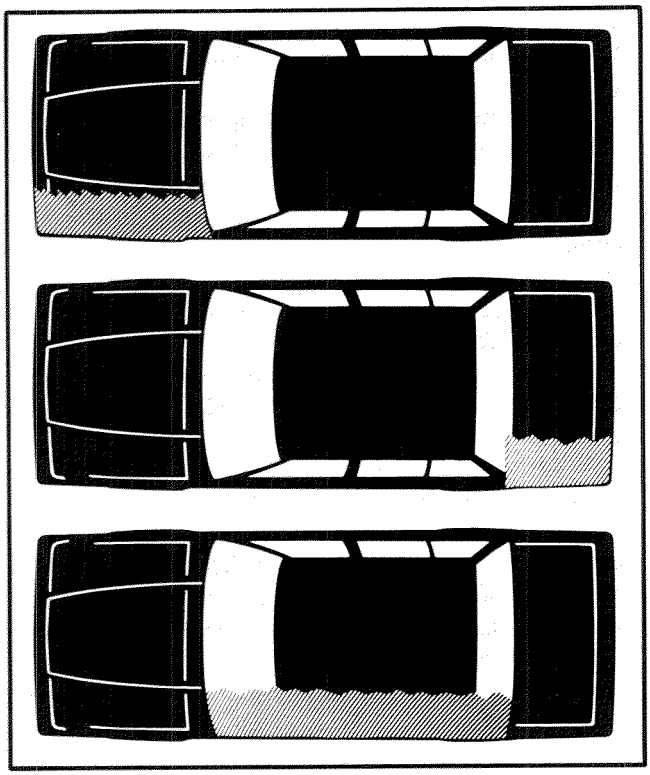


Figure 7. Impact area.

We can divide up these accidents into three different cases, according to the location of the deformation.

If we now consider these accident situations with reference to the frequency of the personal injuries, we find, as shown in Table 3 that the accidents in which there was significant deformation of the occupant compartment constitutes 73% of the accidents ≥ AIS 2 and 100% of the accidents ≥ AIS 4.

In most of the side impact collisions, where the impact takes place in front of, or behind the occupant compartment, the risk of severe injury is small.

It is clear, however, that collisions with the occupant compartment are those which, from the point of view of occupant injuries, should be given priority in development of better side impact properties. Only this type of accident is dealt with in the following analysis.

Table 3. Location of deformation vs. injury severity.

	AIS 2 – 6	AIS 4 – 6
DEFORMATION OF OCCUPANT COMPARTMENT	73%	100%
DEFORMATION OUTSIDE OCCUPANT COMPARTMENT	27%	0%
	100%	100%

Location of Occupants

The extent and type of occupant injuries caused by side impact collisions with the occupant compartment, vary according to where the occupant was sitting in the car.

If we compare the risk of injury to near-side occupants with that of off-side occupants, during side impact collisions against the occupant compartment, we see that the risk of injury, both ≥ AIS 2 and ≥ AIS 4, is approximately twice as great for those on the near-side. (See Table 4.)

We will now further concentrate our attention on the near-side occupants of the vehicle, but before this let us devote a few lines to the off-side occupants.

The frequency of different types of injuries (chest, head, etc.) to the off-side occupants differs from that for the near-side occupants. The occupants of the off-side are not affected as much by the vertical extent of the deformation. On the other hand, the extent of inward buckling is significant for the risk of injury to the off-side occupants. In most of the cases in which off-side occupants received serious or fatal injuries, the victim was thrown out of the car. For these, as for other car users, the seat belt has an obvious beneficial effect.

Comparison of the frequency of injuries to off-side occupants, wearing belts and not wearing belts (not including persons thrown out of the car), shows an injury-reducing effect of the wearing of belts. Corresponding comparisons for near-side occupants do not show any significant effect from use of the seat belts.

Now, let us return to discussion of the near-side occupants of the car.

Figure 8 shows the extent of the risk to various parts of the body in the case of near-side occupants with injuries ≥ AIS 2.

We can see from this figure that amongst the occupants with AIS ≥ 2 61% had chest injuries and 39% had head injuries, of severity ≥ AIS 2.

From Table 5 we can see that injuries of severity AIS ≥ 2 in our statistics, consist of 34% chest, and 22% head injuries. We can see that there is a change in the proportions between the parts of the body as severity

Table 4. Injury frequency for near-side and offside occupant for different injury levels.

	AIS 2 – 6	AIS 4 – 6
NEAR-SIDE OCCUPANT	28,0%	10,4%
OFF-SIDE OCCUPANT	15,2%	4,5%

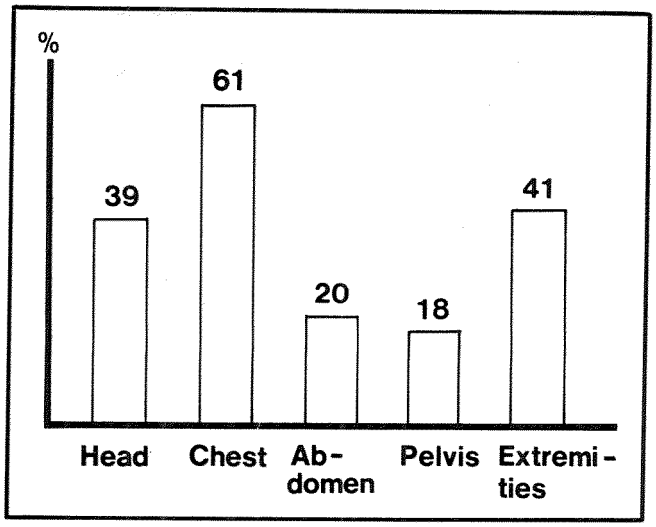


Figure 8. Frequency of injury to various parts of the body AIS $\geq$ 2, for near-side occupants with max injuries $\geq$ 2.

increases, but this is the result, to some extent, of the character of the AIS scale (2).

The part of the body which has the highest frequency of injury is the chest, which accounts for one-third of all the injuries of severity AIS $\geq$ 2. We can see that the proportion of chest injuries increases with increase in severity of injury.

The various objects with which collisions occur cause different deformations, and the question arises as to whether the distribution of injuries shown above, depends on the nature of the object with which impact takes place.

Table 6 shows the relationship between injuries AIS 2-6 and the collision objects: car, truck and pole/tree.

In Table 6, the lower part, "chest + head" means that 8% of the near-side occupants, in a car-to-car side impact, sustained both head and chest injuries $\geq$ AIS 2.

"Abdomen, due to chest", means that the abdominal injuries are caused by the chest injuries (broken ribs).

Table 5. Proportion of injuries to various parts of body.

	AIS 2–6	AIS 4–6
HEAD	22%	24%
CHEST	34%	44%
ABDOMEN	11%	24%
PELVIS	10%	4%
EXTREMITY	23%	4%
	100%	100%

Table 6. Frequency of injury, according to parts of body, AIS-2-6 and collision object, for near-side occupants with max injury AIS $\geq$ 2.

Parts of body	Car	Truck	Pole/tree
Head	21 %	56 %	56 %
Chest	63 %	72 %	33 %
Abdomen	21 %	28 %	–
Pelvis	13 %	28 %	11 %
Extremities	29 %	39 %	78 %
Chest + head	8 %	39 %	11 %
Abdomen, due to chest	17 %	17 %	–

We see that 21% of the near-side occupants who were injured (AIS $\geq$ 2) in accidents in which a car was the object of impact received head injuries, compared with 56% of near-side occupants with injuries AIS $\geq$ 2, in accidents where the object of impact was a truck.

In car and truck accidents, 63% and 72% respectively of the near-side occupants (AIS $\geq$ 2) received chest injuries, whilst only 33% of the accidents in which there was collision with a pole, caused injuries of this type. In pole accidents, on the other hand, injuries to extremities are much more frequent.

Table 6 above shows the relative frequence in each of the groups of accidents. Table 7 below shows the proportion of injuries to each of the parts of the body divided up according to the object of collision.

It is possible to read from this table that, of all the head injuries, 25% resulted from car-to-car accidents, 50% from car-to-truck accidents, and 25% from car-to-pole accidents.

Table 7 gives us some measure of the "true traffic environment". We see, for example, that although, according to Table 6, the risk of head injuries is equally great in pole accidents and in truck accidents; in actual fact half of all head injuries occur in truck accidents, whilst only a quarter occur in pole accidents. Most of the chest injuries occur in collisions with cars, even though the risk of chest injury is somewhat greater in the case of collisions with trucks.

The combination of injuries to chest and head is most

Table 7. Occupant injuries, classified according to object of collision.

	Car	Truck	Pole/tree	
Head	25 %	50 %	25 %	100 %
Chest	48 %	42 %	10 %	100 %
Abdomen	50 %	50 %	–	100 %
Pelvis	33 %	56 %	11 %	100 %
Extremities	33 %	33 %	33 %	100 %
Chest + head	20 %	70 %	10 %	100 %
Abdomen, due to chest	57 %	43 %	–	100 %

usual when the object of the collision is a truck, while injuries to the Abdomen resulting from primary chest injury is more usual when the object of collision is a car.

To study more closely the effect of deformation on injury, we have prepared Table 8 below, in which we show the relative injury distribution for the various objects of collision.

Table 8. Classification of injuries according to object of collision.

AIS 2 – 6	CAR	TRUCK	POLE / TREE
HEAD	14%	25%	31%
CHEST	43%	32%	19%
ABDOMEN	14%	13%	–
PELVIS	9%	13%	6%
EXTREMITY	20%	17%	44%
	100%	100%	100%

This shows us that in collisions with cars, chest injuries predominate; in collision with trucks, head and chest injuries are about equally frequent; and that finally, in the case of collisions with poles, head and extremity injuries are predominant.

On the basis of the accident material, we can put forward the following:

—Depending on the type of collision object, different types of deformation occur, and these in their turn cause characteristic occupant injuries.

—When collision takes place with a car, it is mainly the doors that are deformed, and there is no extensive damage to the floor and roof zones.

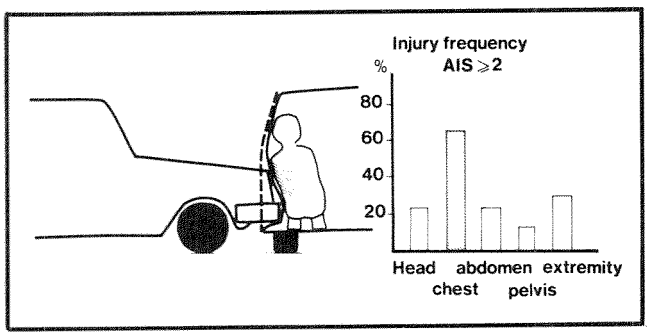


Figure 9. Injury risk in car-to-car side impact.

The force of the collision is concentrated at chest height and this causes a high proportion of chest injuries, many of them in combination with abdominal injuries.

In collisions with trucks, the door is deformed (often higher up than in collision with a car) and at the same time the roof zone is damaged.

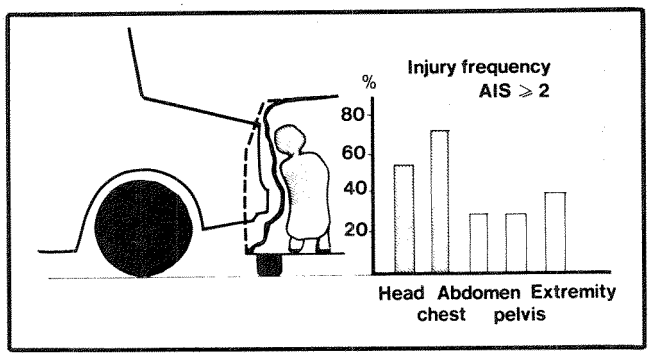


Figure 10. Injury risk in car-to-truck side impact.

—The force is concentrated at chest height, giving a high proportion of chest injuries, but there is also an increased risk of head injuries, because of deformation of the roof edge and risk of direct impact with the collision object.

—In collisions with poles, deformation extends evenly from the floor area up to the roof.

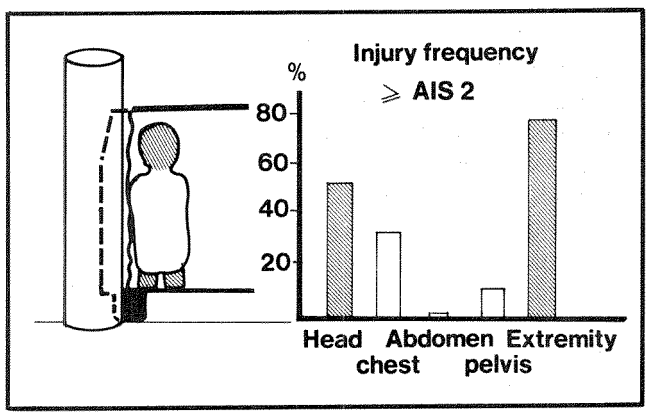


Figure 11. Injury risk in car-to-pole side impact.

In this case the force is distributed relatively evenly over the side of the car in the vertical direction. Severe deformation of the floor zone increases the probability of leg injuries. Furthermore, there is a considerable risk of head injuries caused by impact with the deformed roof and/or the collision object. The proportion of chest injuries is somewhat lower than in collisions with cars and trucks. The reason may be that the forces at chest height are not as concentrated as is the case in a pole accident.

DISCUSSIONS—TEST METHODS

Tabulation and analysis of the statistics on side impact collisions shows the following relationship.

Type of Accident—Type of Deformation—Injury

On the basis of this knowledge, it is possible to design laboratory test methods and to evaluate their potential as means of reducing injuries in traffic accidents.

This has, in fact, been done in a number of cases; mention can be made of the information for NHTSA, ANPRM notice 1, and GM's "Case-by-case analysis of side impact accident files" (5) (6).

NHTSA made a survey in NCSS and concluded that while 65% of the accidents are multi-vehicle accidents the side impact collision requirements should be based on car-to-car collision tests. Thereafter, much work was devoted to identification of the types of accidents, in the form of angles between vehicles and their speed at the moment of collision. Suggestions and evaluations have been made for a relatively complicated test method with angled tracks.

GM states in a recent report that "a subsystem test strategy offers distinct advantages over the more complex full-scale testing". GM makes a close analysis of their side impact collision information and draws the conclusion that the concept of side impact collisions includes a large number of different types of accidents and injury mechanisms and that, therefore, a test method should include a number of different component tests, and perhaps full-scale testing, in order to cover the range of types of injury.

Our information has been classified and structured so that it is suitable for an analysis intended to give a relevant laboratory description of traffic environments.

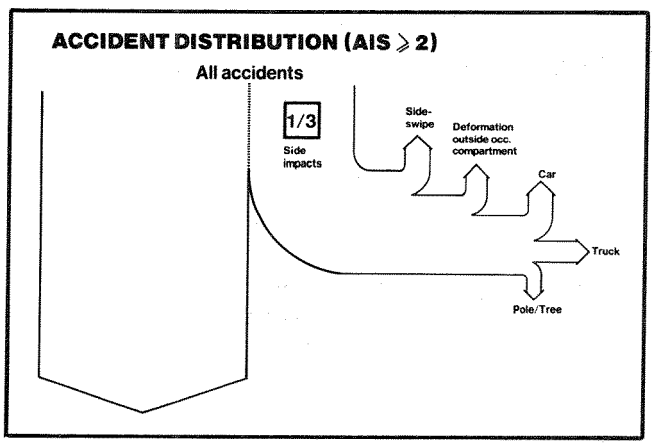


Figure 12. Distribution of side impact accidents.

We have also limited our work to occupants who receive injuries ≥ AIS 2.

We are interested in establishing a basis for transfer of the traffic environment concerned in side impact collisions into the laboratory. It is then misleading to look only at injuries of severity AIS ≥ 4 as the step between severe (AIS 3) and serious (AIS 4) injuries may be small and may depend upon factors which cannot be simulated in the laboratory.

The AIS scale has the characteristics that certain injuries, for example injuries to the extremities, very seldom are recorded as in excess of AIS 3. We consider that we are, therefore, justified in continuing to work with groups AIS 2-6. In this way we see the picture as a whole and obtain more material, to give more accurate assessments.

It is possible to distinguish the principal types of injury mechanism.

1. Injuries resulting from an intruding structure, or from direct contact with the deformed side. These injuries are caused to near-side occupants (except in the case of extreme depth of deformation) when the collision object impacts with part of the passenger space.
2. Injuries resulting from impact against the interior. These are injuries caused to occupants beyond the deformation zone—off-side occupants in collisions against the passenger space and all occupants in collisions to the front and rear of the passenger space.
3. Injuries resulting from the person being thrown out of the car.

The injury mechanisms 2 and 3 above, depend on the design of the interior, the properties of the doors and windows and the use of seat belts by the occupants. There is no reason to try to reconstruct all the complicated sequences of events which result in the occupants impacting against the interior, or being thrown out. Safety requirements for all internal fittings and strength requirements for door fastenings and window fastenings increase safety in the same way as obligatory use of seat belts.

Injury mechanism 1 is related to the ability of the vehicle to resist violent impact against the passenger space. Any test method which has the object of reducing injuries resulting from this cause must be able to reproduce the impact in some relevant and reproducible way.

We are only too well aware that the violent impact may be applied in innumerable ways. Which should be selected as a means of reproducing the true traffic situation, in a test method?

Since we are concerned here with the injuries produced by direct violence on the near-side occupant of the car, we should use the spectrum of injuries suffered by these occupants as the starting point, rather than the frequency of the various types of side impact collision.

The most frequently injured part of the body is the chest. In all accidents (AIS ≥ 2) the frequency of chest injuries is 61%. Chest injuries occur at all angles and with all collision objects. Examination of the objects with which the car collides shows that 48% of chest injuries result from side collisions with other cars.

A test method in which deformation of the passenger compartment is caused by a simulated car front should cover 48% of all the chest injuries. The remaining chest injuries occur in 42% in collisions with trucks. The de-

formation which then occurs at chest height on the door is not unlike that caused by a car under similar collision circumstances. It could, therefore, be assumed that if a car front were used in the laboratory to cause deformation, this would also, to a certain extent, simulate collisions with trucks.

If we look at the specific injury picture in the case of car-to-car collisions, we find that chest injuries are clearly predominant.

The chest injury frequency is 63%. It is thus mainly this type of injury that will occur when a car front is causing the deformation.

It is important to simulate not only the final position of the deformed door but also the dynamic process, i.e., the acceleration of the door in relation to the occupant.

Naturally, it is of most importance that the testing device used in the test has the ability to measure violence to the thorax.

If we go back to Table 7 which shows occupant injuries, classified according to object of collision, we see that the type of testing spoken of above, has a potential of reproducing impact situations which together cause about 90% of all chest injuries. In Table 5, where proportion of injuries to various parts of the body are shown, the chest injuries constitute 34% of all injuries (AIS $\geq$ 2). The Abdominal injuries constitute 11%. Corresponding figures for the AIS $\geq$ 4 injuries are 44% and 24% respectively. The injuries to the abdomen are often associated with injuries to the chest and it is reasonable to believe that a test method that can give about a reduction of chest injuries also will affect the abdominal injuries.

What is the effect of a car-to-car test method on the injuries to other parts of the body?

Table 6 shows that the head injury frequency is a lot higher in accidents involving trucks or poles than in car-to-car accidents. According to Table 7 only 25% of the head injuries appear in accidents where a car has been the collision object. A laboratory simulation of this accident type will probably not reduce head injuries in any major extent. The head injuries appear mostly in accidents where the roof zone is deformed. There is not much written about the simulation of collisions against objects that cause deformations on the roof zone.

It is important that there is work being done with the aim of mapping the injury mechanism behind the head injuries.

Injuries to the extremities are very common in collisions with poles, where the leg area is reduced. It is mainly injuries to the lower extremities, mostly the thigh. There is, as of today, no dummy-related measuring device that measures this kind of injury.

On the basis of the discussion above it seems probable that various kinds of component testing will be required, while the injuries to the head and to the extremities are caused by several different kinds of deformations.

CONCLUSION

* It is important that there is a system to follow up accidents which by its size and method of selection can give a representative picture of the traffic accident situation and which by in-depth studies of accidents can give good information on the causes of individual personal injuries.

* Collisions against the side of the vehicle comprise a large proportion of all accidents which cause personal injury. When development work is done on making cars safer, a large proportion of this work should be devoted towards the question of side impacts.

* Side collisions are however not one homogeneous group of accidents which cause injuries. Where and how on the vehicle side the impact occurs and the object causing it have a large influence on the resulting personal injuries.

* Of all the more serious personal injuries, chest injuries comprise the largest group with approx. one-third.

* A car-to-car test method probably reproduces the great majority of collision situations in which chest injury occurs.

* More research is needed on the occurrence of head and (lower) extremity injuries in side impacts, plus work to permit reproduction at some future date of these injuries in a laboratory environment.

* Volvo will concentrate a proportion of future traffic accident research on a continued programme of side impact studies, with particular emphasis on investigating how various typical injuries occur. In addition, various important parameters which have not been discussed in this report, will be taken up. Some of these are the mutual relationships of direction of force to direction of impact, collision speed—ΔV—door speed—injuries.

REFERENCES

1. Collision Deformation Classification—Technical Report—SAE J 224b.
2. The Abbreviated Injury Scale—presented on Eighteenth Conference of the American Association for Automotive Medicine.
3. Frontal crash protection in a modern car concept. R. Almqvist, H. Mellander, M. Koch, presented at 9th ESV Conference in Kyoto, Nov. 1982.
4. Status of the NHTSA research and rulemaking activities for upgrading side impact protection, A. Burgett, J. R. Hackney.
5. NHTSA—ANPRM docket 79-04 notice 1, Dec. 79.
6. Side Impact Insight from General Motors' Field Accident Data Base. By R. Mehta et al., presented at Eighth International Technical Conference on Experimental Safety Vehicles, in Wolfsburg, October 1980.

A Study on the Methodology to Evaluate Lateral Impact and Occupant Protection Measures

S. MORITA, K. MATSUSHITA,
M. YAMAGUCHI AND K. SOBAJIMA
Nissan Motor Co., Ltd.

ABSTRACT

In order to study the occupant protection functions of vehicles in side collisions, an analysis was made on protection countermeasures and their effects. The synthetic evaluation primarily used vehicle crash tests which included static sled experiments.

Practical and concrete solutions to the countermeasures were obtained from the fundamental experiments, which were used to develop an experimental NRV-II.

Further, various parameters of the striking cars, such as impact energy, impact point, etc. were examined to determine their influence in order to clarify methods for evaluating the side-impact occupant safety of vehicles.

INTRODUCTION

Types and Purposes of Tests

The types of tests are outlined in Tables 1 through 5.

(1) The body structures of the struck cars were a small 4-door, passenger car and a small 5-door, passenger car.

(2) A small 4-door passenger car was used as the striking car in most cases. A deformable moving barrier was substituted in some cases.

(3) HSRI side-impact dummies were used throughout all the series of tests.

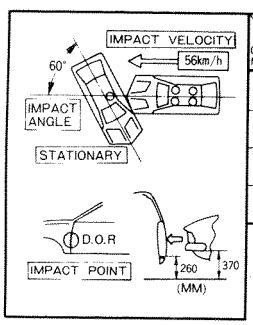
(4) As regards the seating conditions of the dummies, the seat slide and seat back angle were in the neutral position.

Program I. An outline of the impact conditions is given in Table 1. The striking cars were modified incrementally to examine the effects of the respective modifications on body deformation and dummy injury levels.

Program II. A static crash load element that can simulate the mode of side-crash door deformation in static sled tests was developed, and its correspondence with dynamic impact tests was examined.

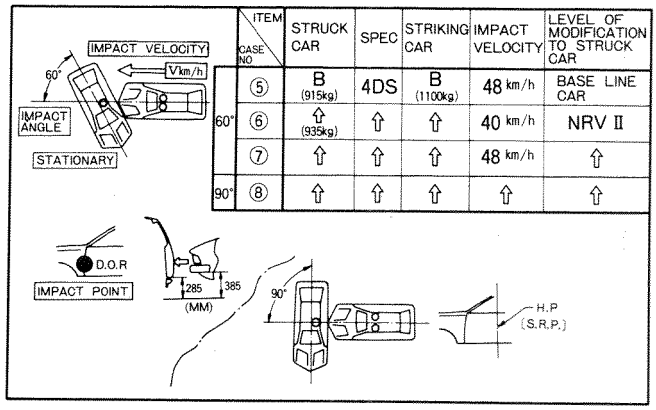
Program III. An outline of the impact conditions is given in Table 2. A practical, concrete solution to the countermeasure was investigated. Through the development of an experimental NRV-II car, a study was made to determine a more effective countermeasure for the body.

Table 1. Program I.



CASE NO \ ITEM	STRUCK CAR	SPEC	STRIKING CAR	LEVEL OF MODIFICATION TO STRUCK CAR
①	A (1030kg)	5D H/B	E_1 (1635kg)	BASE LINE CAR
②	⇧	⇧	⇧	MODIFICATION I
③	⇧	⇧	⇧	MODIFICATION II
④	⇧	⇧	⇧	MODIFICATION III

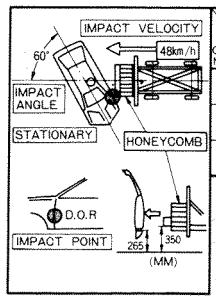
Table 2. Program III.



CASE NO \ ITEM		STRUCK CAR	SPEC	STRIKING CAR	IMPACT VELOCITY	LEVEL OF MODIFICATION TO STRUCK CAR
60°	⑤	B (915kg)	4DS	B (1100kg)	48 km/h	BASE LINE CAR
	⑥	⇧ (935kg)	⇧	⇧	40 km/h	NRV II
	⑦	⇧	⇧	⇧	48 km/h	⇧
90°	⑧	⇧	⇧	⇧	⇧	⇧

Program IV. An outline of the impact conditions is given in Table 3. The aggressiveness of the striking car in lateral impact was examined by using a deformable moving barrier and controlling the stiffness of the honeycomb.

Table 3. Program IV.

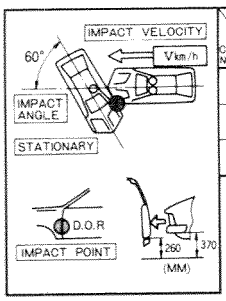


CASE NO \ ITEM	STRUCK CAR	SPEC	STRIKING CAR	HONEYCOMB STIFFNESS	LEVEL OF MODIFICATION TO STRUCK CAR
⑨	B (915kg)	4DS	M/B (1100kg)	3.16 kgf/cm²	BASE LINE CAR
⑩	⇧	⇧	⇧	2.5 kgf/cm²	⇧
⑪	⇧	⇧	⇧	1.3 kgf/cm²	⇧

Program V. An outline of the impact conditions is given in Table 4. The effect of impact velocity and weight, which are particularly important factors in lateral impact, were examined under various impact energy levels.

Program VI. An outline of the impact conditions is

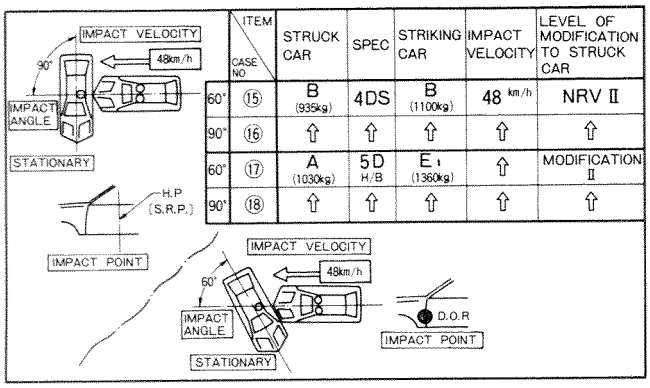
Table 4. Program V.



CASE NO / ITEM	STRUCK CAR	SPEC	STRIKING CAR	IMPACT VELOCITY	LEVEL OF MODIFICATION TO STRUCK CAR
⑫	A (1030kg)	5D H/B	E₁ (1100kg)	40 km/h	BASE LINE CAR
⑬	⇧	⇧	⇧ (1360kg)	48 km/h	⇧
⑭	⇧	⇧	⇧ (1630kg)	56 km/h	⇧

given in Table 5. The effect of the angle of impact was examined at the impact angles of 60° and 90°, typical angles for lateral impacts.

Table 5. Program VI.



CASE NO	ITEM	STRUCK CAR	SPEC	STRIKING CAR	IMPACT VELOCITY	LEVEL OF MODIFICATION TO STRUCK CAR
60°	⑮	B (935kg)	4DS	B (1100kg)	48 km/h	NRV II
90°	⑯	⇧	⇧	⇧	⇧	⇧
60°	⑰	A (1030kg)	5D H/B	E₁ (1360kg)	⇧	MODIFICATION II
90°	⑱	⇧	⇧	⇧	⇧	⇧

PROGRAM I

The struck cars were modified incrementally. The injury levels of dummy in the driver's seat and the state of deformation of the struck cars were compared under the same impact conditions in order to clarify the effects of the respective modifications.

For the impact conditions, reference was made to the NHTSA proposal. For repeatability, however, the struck car was kept stationary, the impact angle was 60°, and the impact velocity was the somewhat high speed of 56 km/h (35 mph). The struck cars were modified in three steps, based on a small 5-door, passenger car.

Levels of modifications
(a) Base line car
(b) Modification I
(c) Modification II
(d) Modification III

The modified parts included the door, sill, A pillar, B pillar, floor, seat, etc., and the total weight required for the modifications amounted to 50 kg. Further, the specifications of the modifications were those devised as countermeasures for a 60° lateral impact and did not take production design into consideration.

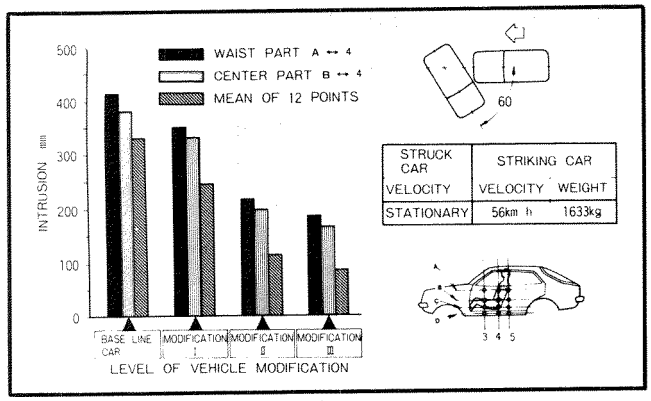


Figure 1. Relationship between car modification level and intrusion of door inner panel into compartment.

Test Results

Relationship between Intrusion of Door Inner Panel into Compartment and Level of Modification. In our paper presented at the 8th ESV Conference, we pointed out that one of the requirements for lateral impact occupant protection was to keep a survivable space for the occupant, i.e., to examine the strength of the sides of the struck car.

In this study, examination was conducted on the body side strength of the three types of modified cars.

The relationship (static) between the level of modification and the intrusion of the door inner panel into the compartment is shown in Figure 1. As seen from the figure, modifying the foregoing parts of the car can reduce their intrusion into the compartment. This is not very practical and will cause many problems during production.

The average intrusion into the compartment, measured at 12 points of the door inner panel covering the dummy chest, showed a reduction from 28 to 76 percent compared to the base line car's. A reduction of 16 to 31 percent was observed at the upper door which is closest to the upper ribs of the dummy. While body deformation in area near the shoulder must be prevented as much as possible to reduce the chest injury level, a deformable area to absorb impact energy must be provided in the portions that do not contact the occupants. This would be an excellent subject for a future study to find out the proper balance between these contradictory requirements.

From the analytical study of deformation of the struck cars, the following items require examination on the part of the struck car in lateral impact.

Items Requiring Examination

(1) The sturdiness of the door that undergoes a direct hit from the striking car.

(2) Distribution of external force exerted on the door to the sill, A pillar, and B pillar.

(3) Sharing external force with the floor, roof, and seat and padding.

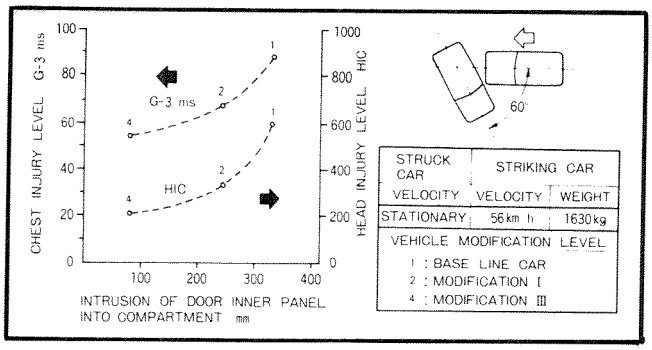


Figure 2. Relationship between intrusion of door inner panel into compartment and dummy injury level (comparison with modification level).

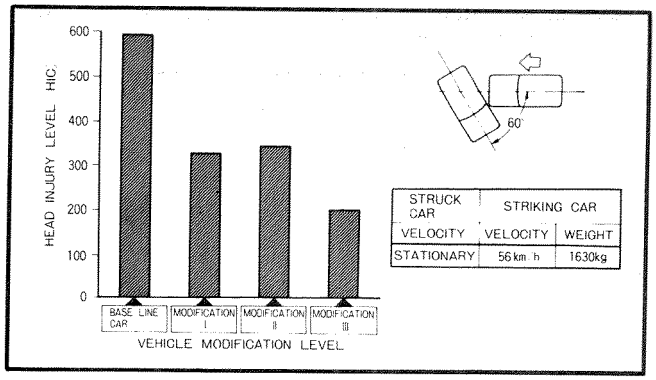


Figure 3. Relationship between countermeasure weight and dummy head injury level.

In the base line car, a characteristic of the deformation mode is that the lower end of the door separates from the sill during the initial stage of collision. This is an important phenomenon which requires a lateral impact countermeasure as mentioned in item (2) above. Photo 1 shows a whole view of a lateral impact car.

Relationship between Level of Modification and Dummy Injury Level. Figure 3 shows the relationship between the level of modification and the head injury level. Figure 4 shows the relationship between the level of modification and the chest injury level.

In the base line car, the head injury level HIC is 600, which is lower than the objective level (HIC: 1,000), however, the chest injury level 88 G-3ms is far greater than the objective level (40 G-3ms).

The chest injury level was reduced by 20 to 38 percent, depending on the level of modification. This is less than the foregoing reduction range of intrusion of the door inner panel into the compartment.

This phenomenon implies that the countermeasure of keeping a survivable space can be obtained by modifying the sides of the vehicle. However, despite a slight reduction in the injury level, the rate of the reduction is small relative to the weight increase required for the modification.

That is to say, modifications to the struck car alone are limited in improving lateral impact occupant safety. It follows that it is necessary to study a wide range of occupant protection countermeasures, including interior padding, seat structure, improvement in the aggressiveness of the striking car, etc.

PROGRAM II

In order to efficiently pursue occupant protection in lateral impacts, impact tests must be conducted paralleling static tests (including simulation analysis). Prior to carrying out the programs of this series, some tasks were planned along the flow shown in Table 6, by which the development of an NRV-II was advanced.

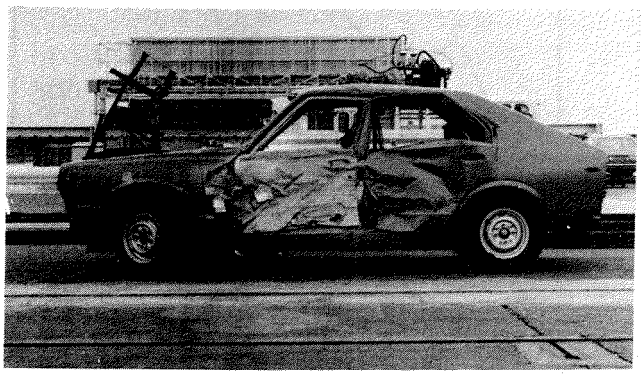


Photo 1. Condition of modified Car III after impact.

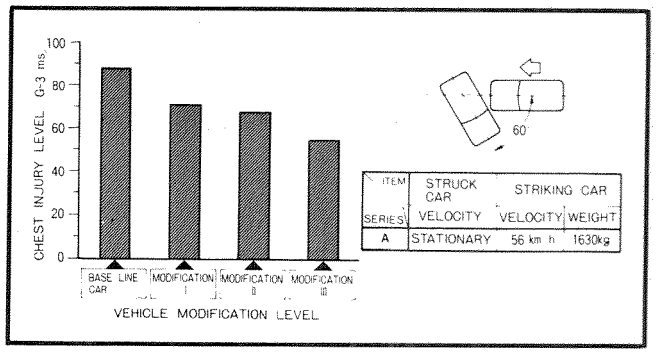
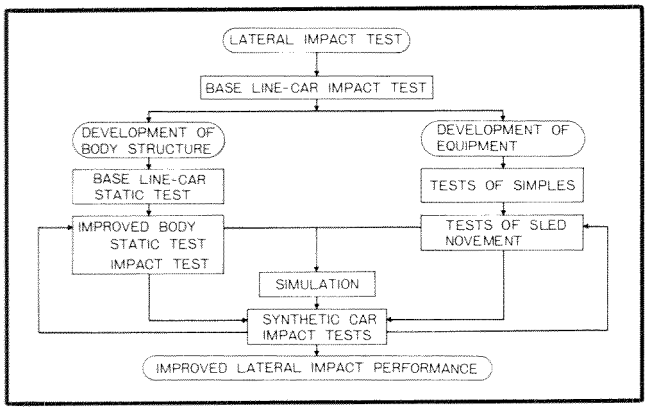


Figure 4. Relationship between car modification level and chest injury level.

Table 6. An example of approach to lateral-impact countermeasures.



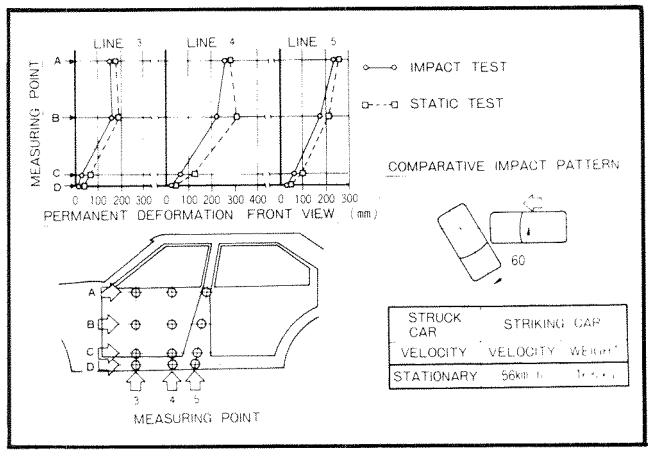


Figure 6. Permanent deformation modes in impact and static tests.

An Example of Body Development by Static Test

A method of simulating the impact of a single car with a pole is specified in item 214 of the F.M.V.S.S. Because stimulation covering all crash conditions cannot be achieved in lateral impacts, it will be necessary to study only typical cases of collisions.

In this program, typical cases were selected from the crash conditions of a series of impact tests: the impact angle was 60 degrees, impact point was D.O.R., the struck car was stationary, and impact velocity was 56 km/h (35 mph).

In static tests the shape of the loading device and the loading point were important factors. As regards the shape of the loading device, the average, permanent deformation of the struck car's door was obtained from several cases of impact tests conducted under the foregoing conditions. An examination was made on how this deformation mode should be simulated.

Figure 5 shows the shapes of newly-developed loading device. Further, Figure 6 shows a comparison of the door deformation modes that occurred in static tests and impact tests. In addition, predicting the amount of deformation that might occur in an impact test was attempted from the results of static tests using the loading device.

Figure 7 shows an example of prediction method. From the data of load-loading device displacement and load-door inner panel displacement in the static tests, the maximum compartment deformation in an actual car impact was predicted by the following procedure.

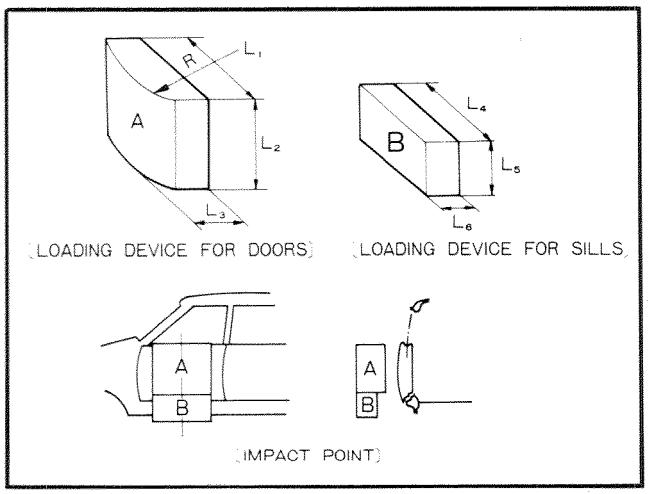


Figure 5. Shapes of loading device and impact points.

Procedure for Prediction

(1) The first step is to obtain energy (E_1) required to produce the deformation (X_0) in an impact of the base line car.

(2) The second step is to predict the maximum compartment deformation (X_1) of a modified car by obtaining the energy (E_2) corresponding to (E_1) with the load-displacement characteristics of the modified car.

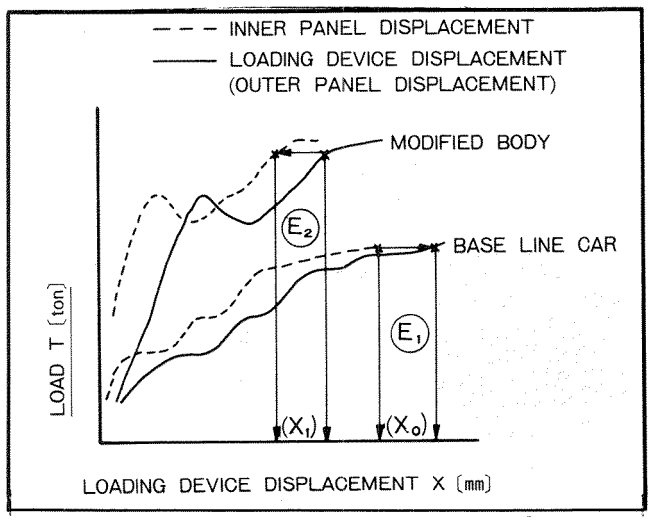


Figure 7. An example of prediction of impact deformation by static test.

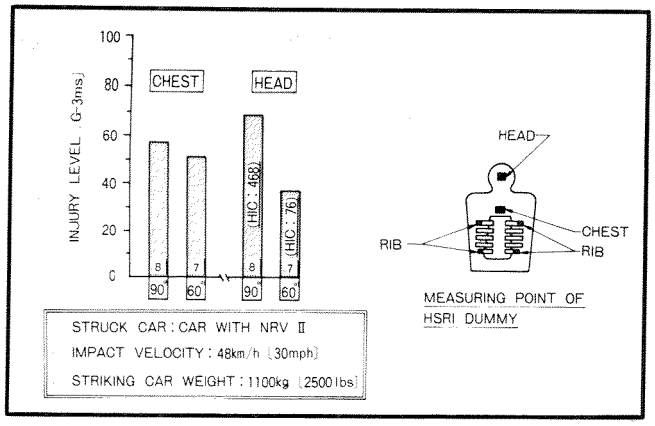


Figure 8. Impact test results of NRV-II (injury level).

The degree of contribution of each modification and modified part as countermeasures can be examined by a detailed analysis of the load-displacement characteristics data. Single part data are obtained by a similar test method. These techniques were used in the modification of each program.

PROGRAM III

Various effective countermeasures, or incremental modifications to the base line car, were examined in program I; each of which was accompanied by a considerable weight increase. Also, because they were not investigated from the standpoints of production and practicality, there remains a number of unsettled problems.

In program III, the development of an NRV-II was attempted by selecting countermeasures that seemed very effective and also allowed a weight reduction.

The actual struck car was small 4-door, passenger car, which was modified as described below. The specifications of the modifications were intended for a 60° crash.

Modified parts and details of modifications:

The evaluation conditions were established as described below.

The objective impact velocity was 48 km/h (30 mph), however, some of the tests were carried out at different velocities. The impact angles were 60° and 90°, typical side-impact patterns. The weight of the striking car was 1,100 kg (2,500 lb) which corresponds to the weight of the moving barrier employed by ECE, ISO, etc.

Further, for improved repeatability, the impact tests were performed on the base line car with the stationary struck car, and the striking car of the same model.

Figure 8 shows the dummy injury levels produced in a series of tests in conjunction with the development of an NRV-II.

A comparison of the results of Case No. (5) and Case No. (7), which were conducted at a 48 km/h impact speed and at a 60° impact angle, discloses that the NRV-II exhibited a 42 percent reduction in chest injury level (G-3ms) as compared to the base line car. This is good evidence that the NRV-II is effective in its well-balanced countermeasures.

On the other hand, in Case No. (8) at a 90° impact angle, higher levels of injury to the head and chest were produced than in the 60° impact tests.

In programs I, II, and III, concrete solutions to lateral impact occupant protection countermeasures have been pursued under limited conditions. If the various phenomena surrounding the occupants in lateral impacts are taken into consideration, it can be understood that there are many factors that influence injuries to the occupants. Analysis of these phenomena will be useful as a reference for the future development of lateral impact countermeasures.

The following three themes, which are particularly important for occupant safety, were selected for analysis this time.

Part	Details of modification
Door	* To restrain deformation in portions that come into contact with the occupant, a) A guard bar was installed near the bumper of striking car. b) The portion where the guard bar was attached was reinforced. c) A joint was installed between the door and sill.
Door ~ Sill	* To restrain door deformation by scattering an impact load which is exerted on the door, a) A joint was installed between the door and sill.
Sill	* To restrain deformation that is caused by an impact load transferred from the door, front pillar, and center pillar, a) The sill section was reinforced.
Center pillar	* To restrain deformation that is caused by an impact load transferred from the door and by a collision of a striking car, a) The center pillar was reinforced. * To restrain deformation that is caused by a collision of a striking car and by an impact load transferred from the door, a) The front pillar was reinforced. b) A transverse member was installed between the pillars.
Second cross-member	* To restrain the deformation of the sill and door that is caused by a collision of a striking car with the sill and by an impact transferred from the door, front pillar, and center pillar, a) The second crossmember was increased in size.

1. The aggressiveness of a striking car in a lateral impact
2. Relationship with impact energy
3. Relationship with impact angle

PROGRAM IV

As already stated in program I, lateral impact occupant protection requires not only countermeasures for the striking car, but also a synthetic examination of the safety performance of both vehicles, including an improvement in the aggressiveness on the part of the striking car.

The side structure of a vehicle has a small area in which the energy from a collision is absorbed most by the front and rear structure, and yet the sides are the portions closest to the occupant. Therefore, the front-end stiffness of the striking car, i.e., the aggressiveness, seems to have a direct, substantial effect on injuries to the occupants.

In this program a moving barrier was used in place of a striking car to accurately assess the influence of the aggressiveness of the striking car. Furthermore, the impactor used moving barriers whose surfaces were covered with three types of honeycomb, each having different stiffness. The test conditions are given in Table 3.

Incidentally, the shapes of the honeycombs were in accordance with the NHTSA Side Impactor. For reference purposes, the honeycomb used in Case No. (9) simulates the characteristics in Citation's 60° oblique impact.

Figure 9 shows the relationship between the front-end stiffness of the striking car and the head injury level of the dummy. Figure 10 shows the relationship between the stiffness and the chest injury level of the dummy. Both the head and the chest injury levels increase as the front-end of stiffness of the striking car increases and the relationships are almost proportional.

If the reduction in the aggressiveness of the striking car can be achieved at the front end including the bumper,

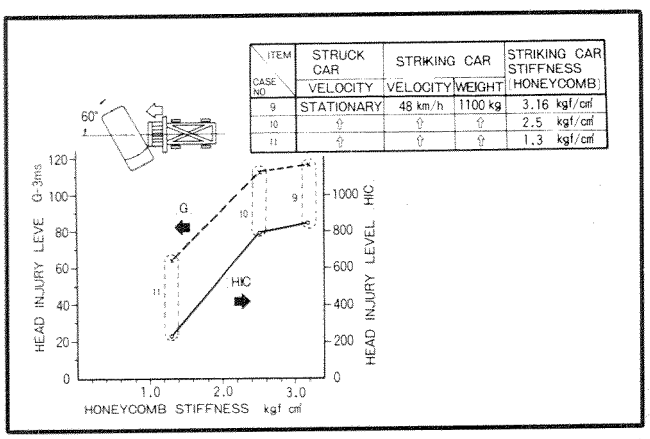


Figure 9. Relationship between striking-car (honeycomb) front-end stiffness and dummy head injury level.

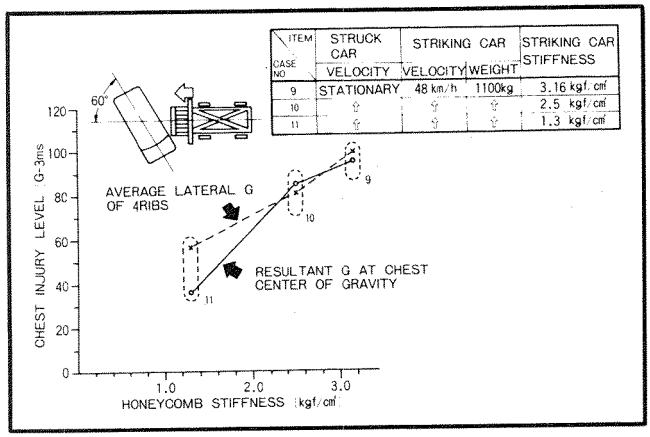


Figure 10. Relationship between striking-car (honeycomb) stiffness and dummy chest injury level.

it will be possible to provide effective occupant protection together with countermeasures for the struck car.

PROGRAM V

The effect of the impact velocity and weight in lateral impacts was examined by controlling impact energy. The struck car used a base line small 4-door, passenger car, and the striking car was a base line small 4-door, passenger car of a different size. Impact patterns were standardized. Three impact conditions were established as shown in Table 4 and the body deformation modes and the injury levels of the dummy in each impact condition were compared.

Results

Relationship between Impact Energy and Intrusion of Door Inner Panel into Compartment. The intrusion of the door inner panel into the compartment naturally increases with an increase of impact energy. Figure 11 shows the amounts of deformation in comparison.

As seen from the respective increasing rates of impact

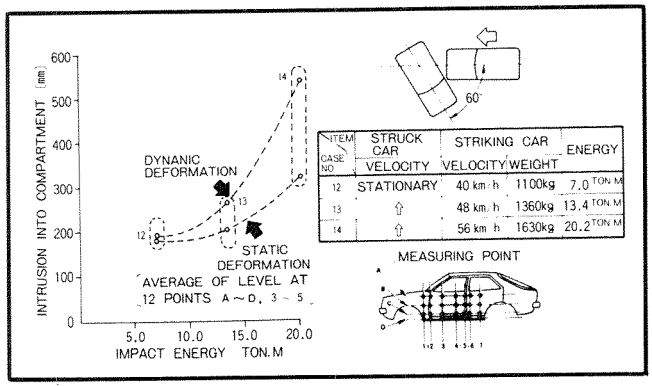


Figure 11. Relationship between impact energy and intrusion of door inner panel into compartment.

energy and intrusion into the compartment, it can be safely said that the conditions under which the evaluation was made in program I [corresponding to Case No. (14) in Fig. 11)] were very severe.

Relationship between Impact Energy and Dummy Injury Level.

On head injuries

As shown in Figure 12, the head injury levels increase both in HIC and in compound G with an increase in impact energy, both of which are below the objective level, HIC: 1,000. Photo 3 shows part of the behavior of the dummies during collision.

Here, let us notice the behavior of the head during collision. In Case No. (14), a high G level was produced, because the side of the head came into contact with a portion of the B pillar.

In Case No. (13), the side of the dummy head, shaken by impact, contacted with the upper part of the shoulder. Case No. (12) indicates that the side of the head did not contact anything, even though it was shaken. The behavior of the dummy changes with the difference in input to the body caused by impact energy, the difference in the relative velocity between the dummy and the door inner panel, etc. The head in particular seems to be greatly affected by this behavioral change.

On chest injuries

Figure 13 shows the relationship between impact energy and the chest injury level. The chest injury level also increases with an increase of impact energy, the same as with the head injury level.

Further, examination was conducted on the relative velocity between the dummy and the door inner panel and on the relationship between the relative velocity and the chest injury level.

The results of these examinations are shown in Figures 14 and 15. From the results of sled impact tests conducted at the same time, it is determined that a strong correlation exists between the impact velocity of the dummy and the chest injury level.

As stated previously, the dummy chest injury level can be correlated with the amount of intrusion of the door inner panel into the compartment, and the dummy impact velocity is related to this.

From the investigation of the effect of the impact energy of the striking car, it has been proven that as described under the heading "Results", the side impact energy affects the intrusion of the door inner panel into the compartment and injuries to dummies very greatly.

Therefore, when conducting an evaluation test, a more detailed analysis of real accidents is needed involving the impact velocity and weight level, and moreover, any de-

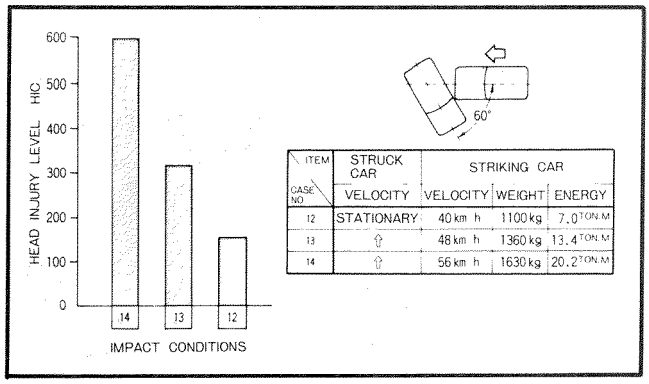


Figure 12. Relationship between impact energy and dummy head injury level.

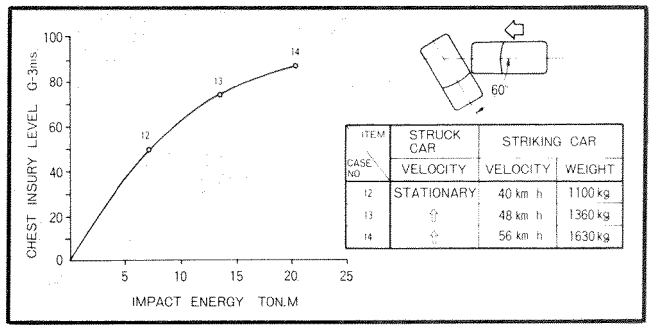


Figure 13. Relationship between impact energy and dummy chest injury level.

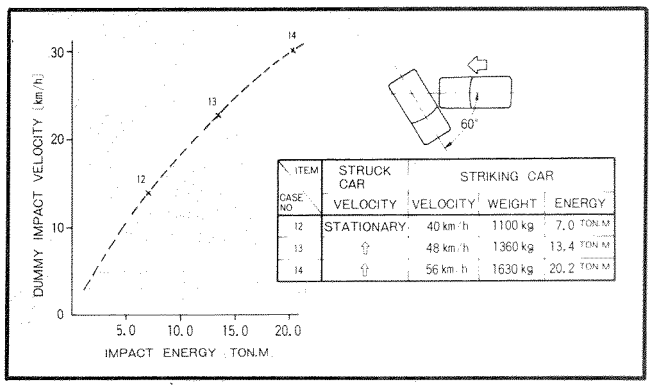


Figure 14. Impact energy and dummy impact velocity (relative velocity).

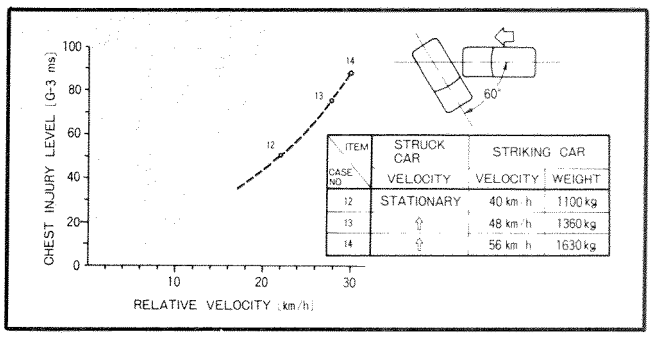
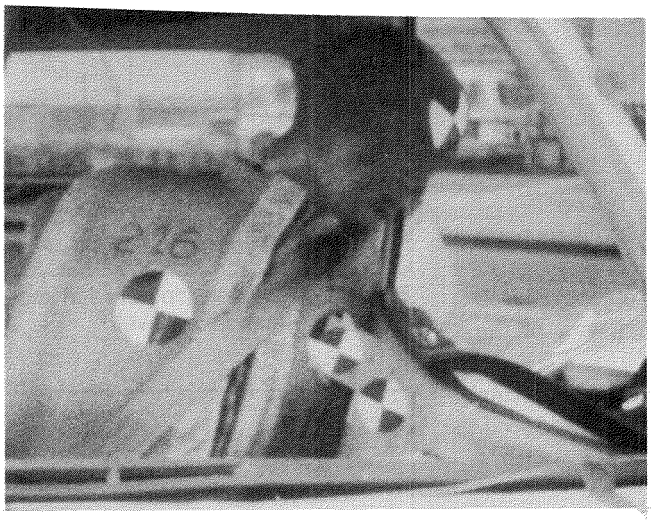
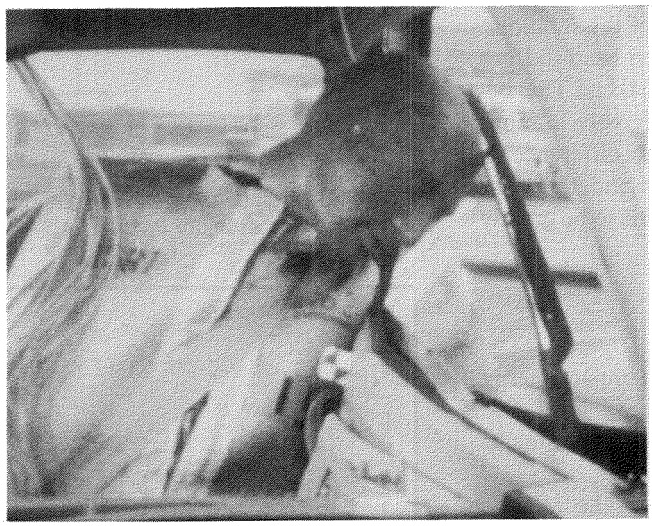


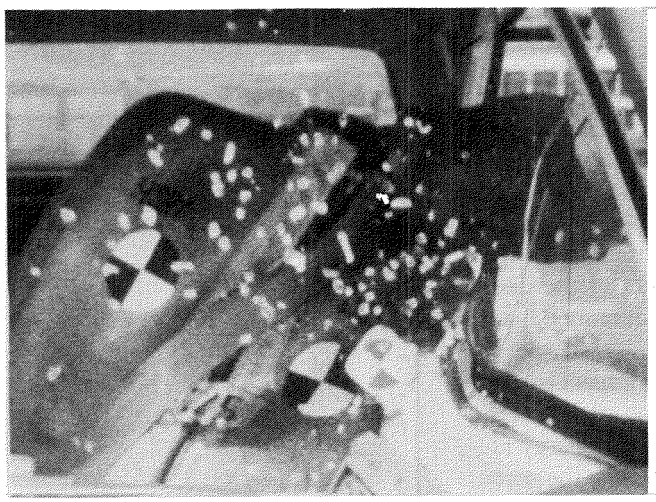
Figure 15. Relationship between dummy impact velocity (relative velocity) and chest injury level.



CASE ⑫



CASE ⑬



CASE ⑭

Photo 3. Dummy behavior after 100 ms in each test.

cisions must be carefully made in consideration of a future trend toward down sizing.

Relationship between Impact Angle and Dummy Injury Level. Because of various traffic conditions in each country, the way of interpreting impact angles in side collisions has not yet been standardized through the analysis of real accident data. Side impact angles range widely from 40° to 100° as seen in the NHTSA analytical results. Typical impact angles of 60° and 90°, which are most commonly used in impact tests, were examined on how they influence the dummy injury level.

Figure 16 shows the results of impact tests performed at different impact angles. Both the head and the chest indicate that higher injury levels were produced in a 90° impact than in a 60° impact. Also, Figure 17 shows the deceleration waveforms produced at the head and chest.

Sled tests were run at the same impact angles to clarify the characteristics of the dummy itself. The results reveal that the damper built in the rib of the HSRI side-impact dummy has directionality, and the function of the damper does not perform normally at impact angles other than 90°.

Therefore, it follows that if side-impact countermeasures are researched for only a certain impact angle, they will not provide effective occupant protection in side impacts occurring at different angles.

In the case of a 60° side impact, injuries to the occupant are considered to be greatly affected by the seating position of each occupant (seat slide position) and the initial impact point of a striking car.

In the case of a 90° side impact, on the other hand, the seating position (seat slide position) seems to have no direct effect on injuries to the occupants, because a wide area in the front of the striking car hits the struck car.

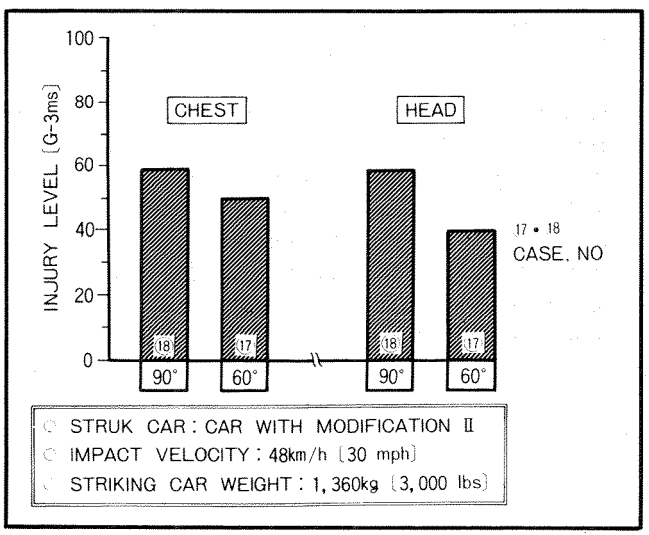


Figure 16. Relationship between impact angle and dummy injury level.

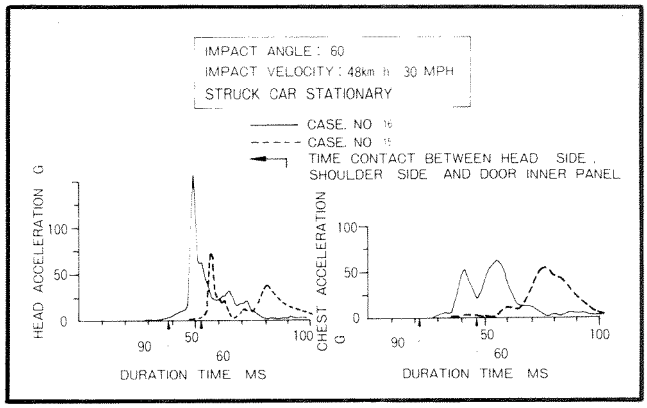


Figure 17. Acceleration curves of dummy head and chest in 90° and 60° lateral impacts.

Finally, this series of programs can roughly be classified into three themes. In the first theme, tests were performed under test conditions close to the NHTSA evaluation method to research a basic solution to side-impact occupant protection. This is relative with programs I and II. In the second theme, studies were made using modified cars which took practicality into account. This is related to program III.

In the first and second themes, occupant protection was examined under limited conditions. In the third theme, however, problems of the evaluation methods were pursued with attention paid to the main items of the respective parameters assumed in side impacts. These are concerned with programs IV, V, and VI.

CONCLUSIONS

(1) A reduction of vehicle deformation keeping occupant survivable space and a means of relieving an impact in an occupant secondary crash seem to be possible countermeasures for the struck car. However, the strengthening of the vehicle body leads to a large increase in weight, resulting in a great sacrifice with respect to practicality. Therefore, side-impact occupant protection is considered to need further examination of the striking car including the aggressiveness as well as the struck car.

(2) The effect of the aggressiveness of the striking car is obvious in impact tests using honeycomb impactors. Considering the repeatability of the evaluation method, a honeycomb used for a striking car yields better results than using a vehicle. However, another problem arises with the use of honeycombs. That is, although certain typical values need to be established in simulating the stiffness and the impact direction, it is difficult to relate them to the aggressiveness of the striking car.

(3) Impact energy (impact velocity and weight) and impact angles are known to exert great influence on

dummy injury levels. Therefore, in order to determine impact energy, more complete analysis of real accident data must be continued and the conformity among the countries must be taken into consideration.

Moreover, the angle of impact covers a wider range in side collisions than in frontal and rear-end collisions. This makes it difficult to include all impact angle conditions in crash tests, and leads us to believe that crash tests may be performed only in certain representative conditions.

Dummy response is closely related to impact angle. An investigation of the relationship between impact direction to the dummy and dummy response reveals that because of the directionality of the damper built in the chest, the HSRI side-impact dummy presents a problem in terms of the adequateness in impacts at other than 90°. It is necessary, therefore, to develop a dummy that simulates human body response.

(4) As described above, a great number of factors are involved in lateral impact occupant protection, each of which exerts important influence on one another. At present, there are a number of difficult problems awaiting solutions before the occupant safety performance of vehicles can be evaluated by dummy injury level under some conditions.

REFERENCES

1. August Burgett, and William Brubaker "The Role of the Side of the Motor Vehicle in Crash Protection" SAE 820245.
2. O. Kitamura, K. Watanabe, and K. Matsushita "An Experimental Study of the Lateral Impact Protection" 8th ESV Conference Wolfsburg, October 1980.
3. C. J. Griswold, R. A. Wilson, and R. Metha "Side Impact Sub-System Test Development" 8th ESV Conference Wolfsburg, October 1980.
4. J. Provensal, and G. Stcherbatcheff "Identification of Compatibility Factors in Side Collision" 8th ESV Conference Wolfsburg, October 1980.
5. A. Burgett and J. R. Hackney "Status of National Highway Traffic Safety Administrations Research and Rulemaking Activities for Upgrading Side Impact Protection" 7th ESV Conference, Paris, June 1979.
6. J. W. Melvin, D. H. Robins, and J. B. Benson "Experimental Application of Advanced Thoracic Instrumentation Techniques to Anthropomorphic Test Devices" 7th ESV Conference Paris, June 1979.
7. E. Franchini, Fiat Technical Presentation "Side Collision" 7th ESV Conference, Paris, June 1979.

The Status of the National Highway Traffic Safety Administration Side Impact Research

WILLIAM T. HOLLOWELL,
JAMES R. HACKNEY,
THOMAS MACLAUGHLIN
National Highway Traffic Safety Administration

ABSTRACT

This paper presents the status of the program for side impact research of the National Highway Traffic Safety Administration. The program consists of four projects: S1 Side Protection—Thoracic Injury, S2 Side Protection—General, S3 Ejection and Roof Protection, and S4 Roof Rail and Pillar Protection. The NHTSA plans to complete the S1 project by mid-year 1983, while the remaining projects shall emphasize problem determination.

INTRODUCTION

In 1977, the National Highway Traffic Safety Administration (NHTSA) established the upgrade of side impact protection as a top priority program in its rulemaking plan. The major emphasis of this program has been focused on the reduction of thoracic injuries resulting from vehicle-to-vehicle accidents. The research areas in support of this objective included accident data analysis, the development of test devices and procedures, the development of potential safety measures in vehicle design, and the determination of the cost and leadtime of implementing these measures. Since its inception, this program has been allocated substantial resources of the Agency and has been widely publicized.

On January 31-February 1, 1980, the NHTSA sponsored a Public Meeting at which technical papers were presented to highlight the activities supporting the aforementioned research areas [1]. Papers have been presented at both the Seventh and Eighth International Technical Conferences on Experimental Safety Vehicles to provide the status of the ongoing research [2-9]. Furthermore, the program has been presented to both the Motor Vehicle Manufacturers Association and the Automobile Importers of America, Incorporated.

Since 1977, a number of factors have developed such that a review of the entire NHTSA crashworthiness programs was undertaken. In particular, five years have elapsed since the NHTSA published a plan for motor vehicle safety research and development. Also, motor vehicles have changed significantly during this time period. Over the past five years, the quantity and quality of the accident data and the vehicle crash performance infor-

mation have increased dramatically. Finally, the policies and resources available for research have changed. As a result of this review, significant adjustments have been made to the Agency research programs. For side impact, this review has resulted in an expanded program. This paper is written to provide the status of the current program for side impact research.

GENERAL

On February 24, 1982, a special session entitled "Priorities and State of Knowledge in Crash Protection" was held at the Society of Automotive Engineers' 1982 International Congress and Exposition. Papers from this session addressed the current planning of the Agency's research programs. In the paper "A Search for Priorities in Crash Protection", Malliaris presented the methodology and results of the analyses from which the priorities of the program for the enhancement of crash protection have been based [10]. For each program resulting from this review, a generalized solution approach has been incorporated. The approach includes the following steps:

1. A problem determination in sufficient detail to allow a meaningful execution of the subsequent steps;
2. A characterization of the vehicle component(s) involved;
3. An examination of the injury potential arising from a collision of a specific body region with specific vehicle components, and an examination of the injury types and severities by the body region;
4. A preliminary evaluation of mitigation concepts;
5. The development of a test surrogate and instrumentation for measurement of injury potential;
6. The development of a test procedure and injury scales;
7. The development of hardware for the leading mitigation concept(s);
8. The test and evaluation of these concepts;
9. The formulation of performance requirements for the affected vehicle components; and
10. The translation of performance criteria (reduction in human harm resulting from vehicle modifications) into benefits and costs.

The expanded side impact program has been developed to utilize this approach. In addition to completing the program for reducing thoracic injuries, the expanded program includes research for the reduction of injuries to the other body regions—the head, the upper and lower extremities, the abdomen, and the pelvis. The vehicle component characteristics to be explored include those of both the striking vehicle and the struck vehicle. To accomplish this program, the effort has been divided into four projects. These include: (1) S1—Side Protection: Thoracic Injury, (2) S2—Side Protection: General, (3) S3—Ejection and Roof Protection, and (4) S4—Roof Header and Pillar Protection.

S1 SIDE IMPACT PROTECTION—THORACIC INJURY

As mentioned, the side impact program pursued by the Agency over the past five years has concentrated primarily on reducing thoracic injuries resulting from vehicle-to-vehicle accidents. The S1 project shall complete this effort by mid-year 1983. Shown in Figure 1 is the flowchart of the remaining tasks. As can be seen, these follow the approach established by Malliaris.

To date, the studies for Problem Determination have shown that thoracic injuries account for the majority of serious injuries (AIS $\geq$ 3) in side impacts. It has been found that structural integrity and the interior padding of present vehicles do not provide adequate protection. The studies reported to date by the Agency for defining the conditions from which the injuries occur have been based on the incomplete versions of the accident data files obtained from the National Crash Severity Study. A final analysis of the completed files is under way. A final report for the Problem Determination is due by November, 1982.

The second task is the vehicle component characteristics. The approach for mitigating the thoracic injuries in the program has been to examine the effect of vehicle size and weight class; the interior padding; and the stiffnesses of the door, door beam, the A and B posts, the rocker panels, and the seat structures. A report for summarizing these shall be completed by April, 1983.

The third task is the human loading and tolerance. For S1, the effort has been concentrated for establishing continuous injury predictors for thoracic loadings. The approach has been to translate mechanical responses measured from cadaver testing (sled and pendulum) into accurate predictors of the observed cadaver trauma. Testing being conducted at the Heidelberg University is providing data to supplement the existing Biomechanics data base. Additionally, a cooperative effort has been established with the Organisme National de Securitè Routière (ONSER) to provide data from vehicle crash tests. The predictors are updated quarterly by the staff of the Biomechanics group. The latest predictor (July, 1982) was reported to be:

$$AIS = 0.768\ \Delta V + .053\ AGE - 1.89$$

where ΔV is the peak relative velocity between the left and right ribs. This equation is depicted graphically in Figure 2. The technique for computing the ΔV is based on the work of Eppinger and Chan [11]. The final report for this task is due April, 1983.

The fourth task is the analysis of the mitigation concepts. The analysis is to include the review of the padding and improved structure. The report for this task is to be completed in April, 1983.

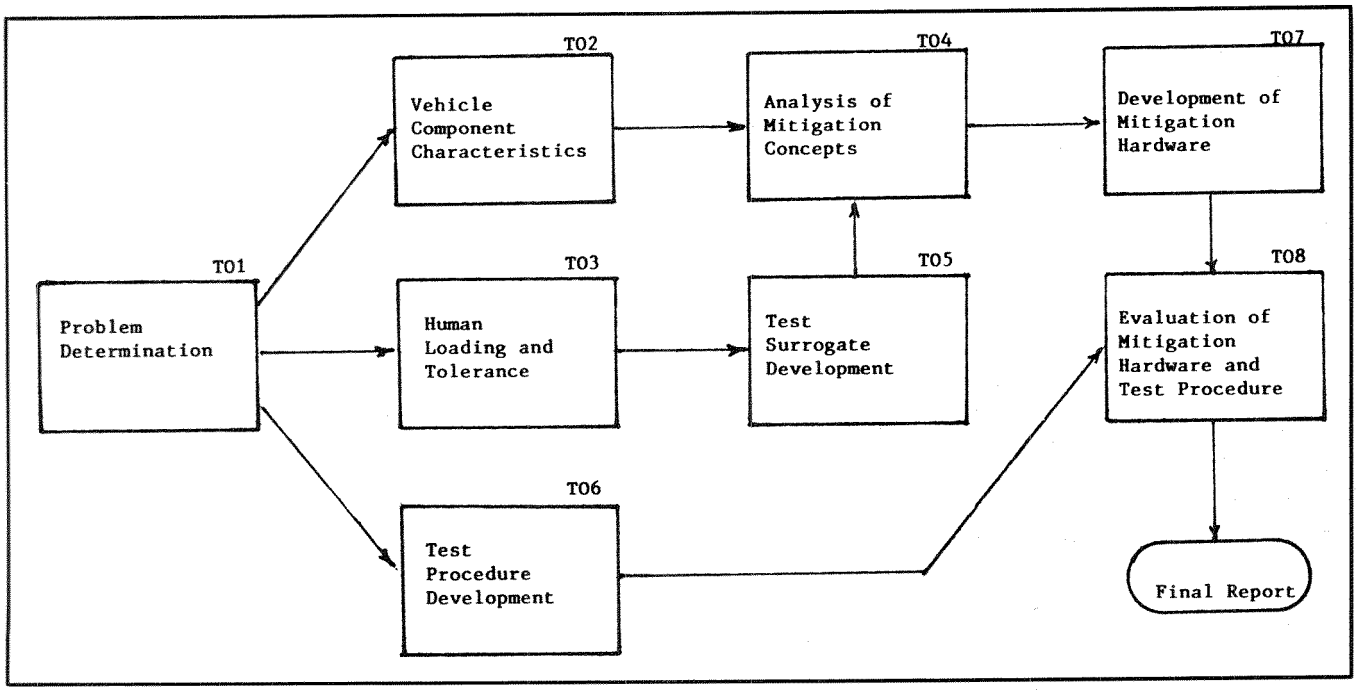


Figure 1. Project S1 side protection—thoracic injury.

The fifth task involves the development of the test surrogate. In this program, two side impact dummies have been extensively assessed—the dummy developed by the Highway Safety Research Institute of the University of Michigan and the dummy developed by the Association Peugeot-Renault of France. The biomechanical characteristics of these devices have been developed utilizing results from cadaver tests. The HSRI dummy was designed to mimic the dynamic responses observed from cadavers in pendulum and sled testing. The APR dummy was designed to characterize the force-deflection properties of cadavers measured in drop tests. Each dummy has undergone considerable evaluation testing in identical sled environments to which the cadavers were tested. Shown in Figure 3 is the HSRI dummy in a sled environment. The head, neck, and lower body are essentially the same as the Part 572 dummy. Shown in Figure 4 is the interior design of the thorax. The damper mechanism, the ribs, and the distribution of masses are clearly visible. The thorax is instrumented with twelve accelerometers. Shown in Figure 5 is the APR dummy in a pre-test condition which is being used as a calibration test to verify the response characteristics before full systems or sled

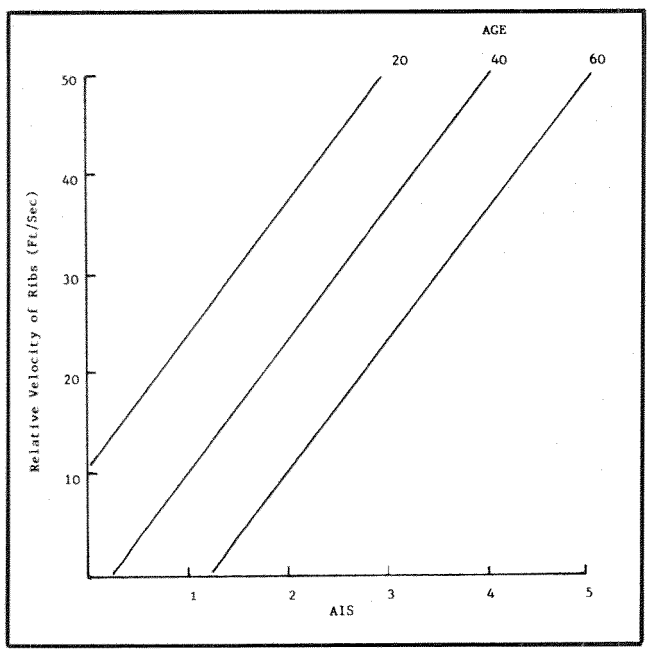


Figure 2. Side impact injury criteria (July 1982).

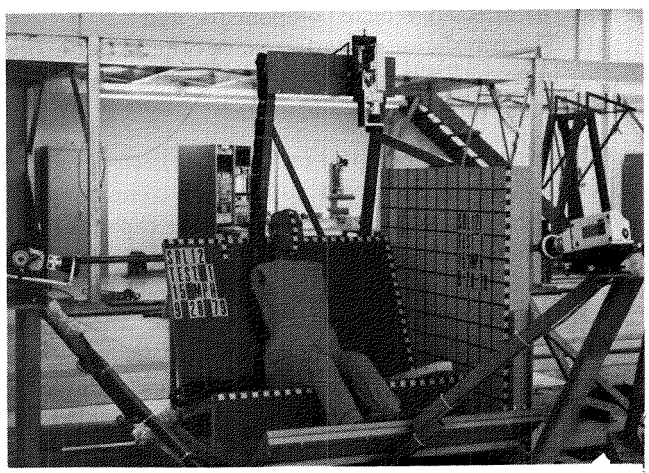


Figure 3. HSRI side impact dummy in sled test environment.

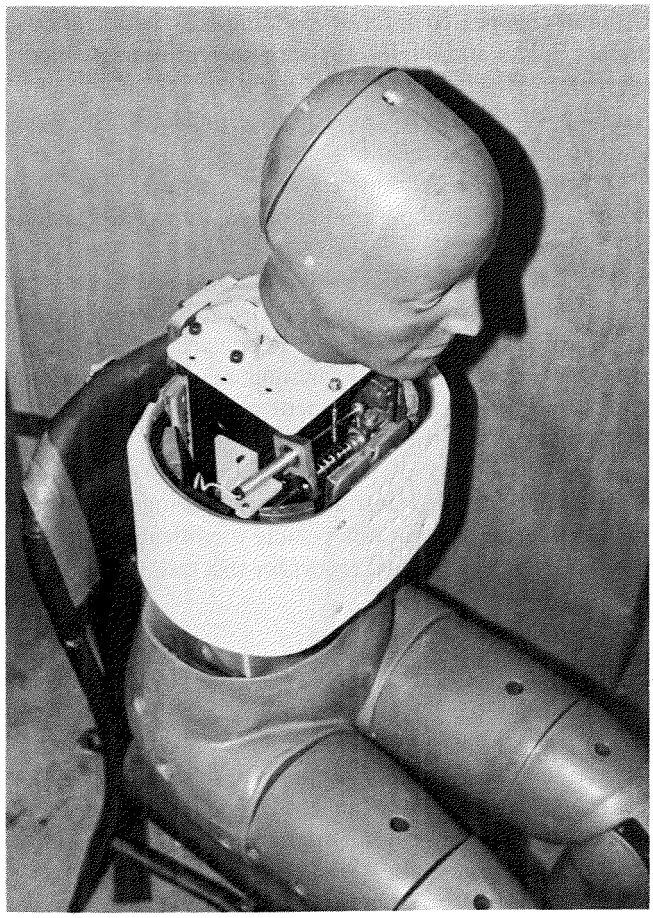


Figure 4. Interior view of HSRI side impact dummy thorax.

testing. The HSRI dummy has been selected for the completion of the S1 project. While both dummies have demonstrated their biofidelity, the HSRI dummy was selected due to its immediate availability for the remaining project tasks. The latest modifications to the HSRI dummy included an improved connection of the ribs to the spine to retard the deterioration of leather attachment from repeated use. Also, a cable support has been incorporated to prevent the ribcage from sagging. A final report summarizing the dummy development shall be available May, 1983.

The sixth task is the development of the test procedure. The effort of this task is concentrated on finalizing the characteristics of the side impact barrier and in specifying the test procedure. The present version of the moving barrier impactor is constructed with a deformable aluminum honeycomb face mounted to a framework carriage. The most important characteristics of the impactor include the weight, the frontal geometry, and the force-deflection properties of the honeycomb face. Previous studies established the weight of the impactor at 3,450 pounds. The studies were based on the accident data and the probability of collision. The weight corresponded to the 85th percentile of the 1985 projected new car sales weight plus 300 pounds inertial weight in the vehicle. It was estimated that this weight represents the 1985 median level of striking vehicle weights which results in severe side impact injuries. A recently concluded study has revised the weight projection to total 3,000 pounds. The geometry of the face was based on data for 1978-1980 model vehicles. The minimum and maximum bumper heights corresponds to the 50th percentile values of 1979 two-door sedans weighted by vehicle sales. The other dimensions were selected from direct measurements of high sales volume cars. The lower and upper bumper heights are 13 and 21 inches, respectfully. The honeycomb core is 22 inches in height, 15 inches deep (19 at the bumper), and 66 inches wide. The bottom of the core is 11 inches from the ground. The stiffness characteristics for the face were determined from an analytical study and from data collected from load cell moving barrier tests of 1979 and 1980 production cars. In comparing the characteristics of the honeycomb face to a Chevrolet Citation, it can be seen that the load deflection character-

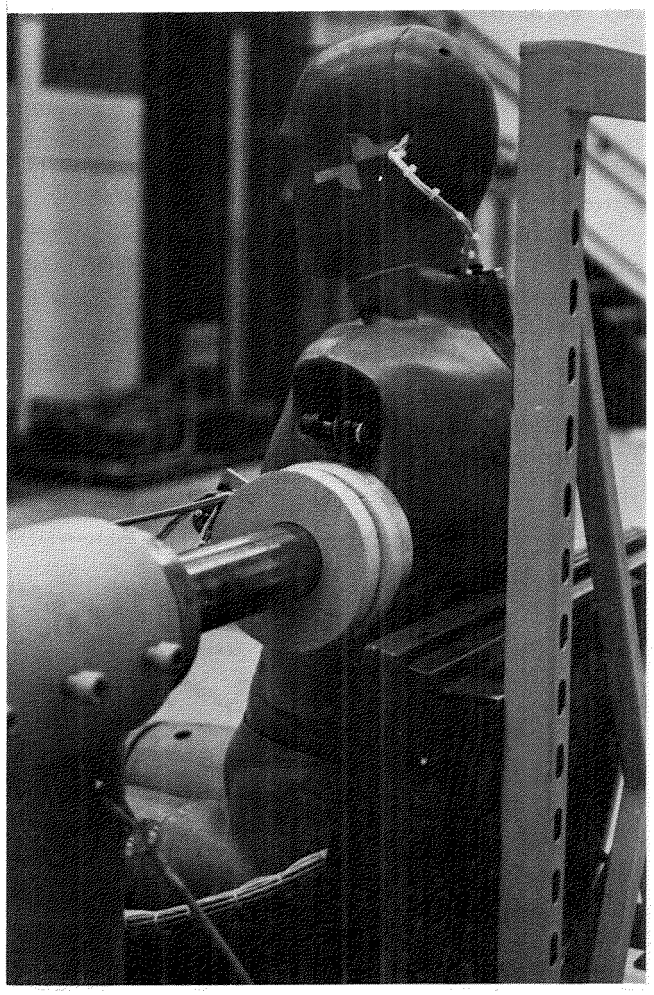


Figure 5. APR side impact dummy pendulum test for calibration.

istics for a 30 degree impact match very well through ten inches of deflection. (See Figure 6.) It should be noted that the maximum crush of striking vehicles in side impacts is typically under ten inches.

An extensive test series is planned to evaluate the impactor and test procedure for its realism and repeatability. This test series includes moving vehicle-to-moving vehicle crash tests as well as crabbed side impactor tests to simulate the moving-moving collisions. The test series' parameters include the striking vehicle (Chevrolet Citation and side impactor), impact angle (60 and 90 degrees), impact speed (40/20 and 26/13 mph—striking vehicle speed/struck vehicle speed), and struck vehicle (Chevrolet Citation and VW Rabbit). The test series has been designed such that the main effects and the various two-way interactions of the cited parameters may be determined from statistical analyses. The final report for this task is due May, 1983.

The seventh task is the development of mitigation hardware. For this project, structural modifications have been developed under contracts by the Budd Company, Minicars, and Volkswagenwerk AG. Additionally, padding studies were undertaken by Dynamic Science and the NHTSA Safety Research Laboratory. A final report summarizing these activities is due May, 1983.

The eighth and final task for the completion of S1 is the evaluation of the mitigation hardware. The evaluation includes controlled crash testing, reconstructed accidents, subsystems testing, and the cost assessment for the improved performance.

To date, a considerable number of crash tests have been conducted for the development of the test devices and vehicle modifications. These have not been evaluation tests. With the test devices now developed, the planned effort is to assess the potential safety levels of baseline and modified vehicles and to determine the sensitivity of the test devices to varying crash environments. Crash tests are scheduled for the following conditions: (1) with and without changes to interior padding, (2) with various impact points and angles, (3) with several impact velocities, and (4) using car-to-car, barrier-to-car, and car-to-fixed object testing. Again, a part of the series has been designed for a statistical analysis.

In this case, the parameters are the structural configuration, interior padding configuration, impact angle, and impact speed.

Accident reconstructions are also scheduled to provide additional data for evaluating the relationship of crash testing to real world accidents. Reconstructed accidents also provide important information relative to accident injury mechanisms, establishment of injury criteria, and the accuracy of our accident data files.

The final activity of this task is to perform the cost assessments. Detailed cost analyses are being performed for introducing the various vehicle modifications to the production line. The final report for this task is due May, 1983.

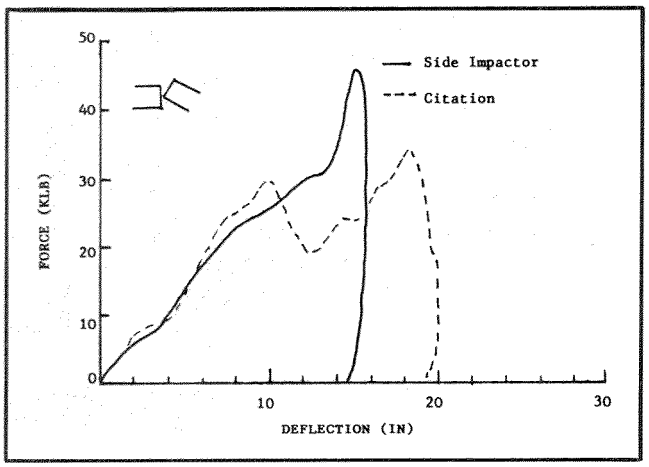


Figure 6. Comparison of force vs crush (side impactor versus citation).

S2 SIDE PROTECTION—GENERAL

The second project for the expanded program emphasizes a new look at the side impact problem. While the S1 project concentrated on the mitigation of thoracic injuries through improvements to the struck vehicle, the S2 project examines the parameters for both the striking and struck vehicles. Additionally, all injury categories are considered. The planned tasks for this project are shown in Figure 7. As can be seen, the major emphasis shall be placed on problem determination. The information required for this activity shall be generated through accident data analysis, computer simulations, and baseline testing.

In the accident data analysis, a rigorous effort is planned for determining the effects of both accident and vehicle parameters. The accident parameters include the weights of the striking and struck vehicles, the impact speeds, the impact points, and the impact angles. The vehicle parameters to be examined are quite extensive. These include the bumper height, door configuration, seat configuration, door stiffness, striking vehicle profile and

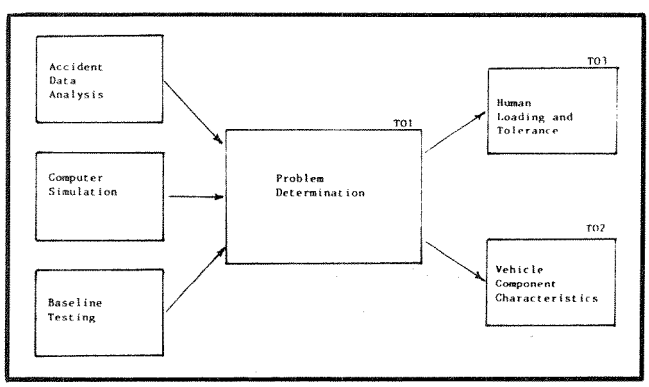


Figure 7. Project S2 side protection—general.

stiffness, etc. While the NCSS file was utilized as the primary source of accident data for the S1 project, the NCSS, the Fatal Accident Reporting System (FARS) and the National Accident Sampling System (NASS) shall be used for the S2 project. The primary emphasis shall be placed on the NASS data.

Computer simulations are planned to supplement the information obtained from the accident data analysis. The objective is to better define the occupant kinematics and contacts that occur during side impact collisions. Parametric studies of the vehicle characteristics shall be investigated to determine their effect on occupant response. Lumped mass computer models shall be employed to simulate vehicle characteristics and response. The Crash Victim Simulator (CVS) shall be used for the occupant simulations.

Another activity to support the problem determination is baseline testing. Limitations of the accident data and computer simulation can be minimized through a judicious choice of crash test conditions. Crash testing also provides for the evaluation of potential problems arising from the use of prototype test surrogates. The final report for the Problem Determination task is due September, 1983.

A variety of activities supporting the task for Human Loading and Tolerance is under way. Cadaver tests are being conducted at Heidelberg University to supplement the data base for the development of response characteristics and injury criteria associated with the thorax. Tests are being conducted at Wayne State University to provide data for the knee, femur, and pelvis. Other activities have been planned. One includes addressing the injury mechanisms for the abdominal viscera. Cadaver tests are to be conducted with objects (such as arm rests) to simulate a penetrating abdominal injury. Another activity is planned to conduct tests for supplementing the data base of head injuries resulting from lateral impacts. The existing data base consists largely of frontal impact tests in which the injuries resulted from blunt, short duration impacts. Finally, an activity is planned for examining head-neck kinematics and injuries. The final report for Human Loading and Tolerance is due April, 1984.

S3 EJECTION AND ROOF PROTECTION

The third project for the expanded side impact program emphasizes protection from injuries resulting from ejection and roof contacts. The planned tasks for this project are shown in Figure 8. As in the S2 project, the major emphasis for S3 shall be placed on problem determination. The information required for this activity shall also be generated through accident data analysis, computer simulations, and baseline testing.

In the accident data analysis, both accident and vehicle parameters shall be analyzed. The accident parameters include the weights of the striking and struck vehicles,

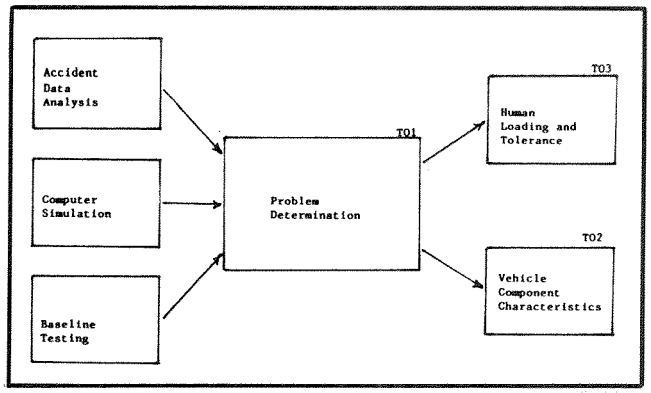


Figure 8. Project S3 ejection and roof protection.

the impact speeds, the impact points, the impact angles, and the accident mode and location. The vehicle parameters include the latch and hinge failures, column stiffness, siderail flexibility, windshield retention, glazing, etc. The NCSS, FARS, and NASS data files shall be utilized for these studies.

Computer simulations are planned to supplement the information obtained from the accident data analysis. Again, the primary objective is to better define the occupant kinematics and contacts that occur in accidents involving ejection and/or roof contacts. This objective is particularly important since accident field data are extremely limited in terms of defining the gross occupant motions associated with this accident environment. For the vehicle simulations, the Highway Vehicle Object Simulation Model (HVOSM) shall be used. The Crash Victim Simulator shall be used for the occupant simulations.

The third activity supporting the Problem Determination is baseline testing. Again, the limitations of the accident field data and computer simulations may be minimized by selecting crash conditions that mimic the accident environment. In particular, the crash tests shall be conducted such that a thorough analysis of ejection routes and roof interior contacts can be made. The final report for the Problem Determination is due November, 1983.

S4 ROOF RAIL AND PILLAR PROTECTION

The fourth and final project for the expanded side impact program emphasizes protection from injuries resulting from roof rail and pillar contacts. The planned tasks for this project are shown in Figure 9. Here, too, the major emphasis shall be on problem determination. Again, the information required for the problem determination shall be generated through accident data analysis, computer simulations, and baseline testing.

The accident data analysis shall include both accident and vehicle parameters. The accident parameters include the weights of the striking and struck vehicles, the impact speeds, the impact points, and the impact angles. The vehicle parameters include the geometry, stiffness, and

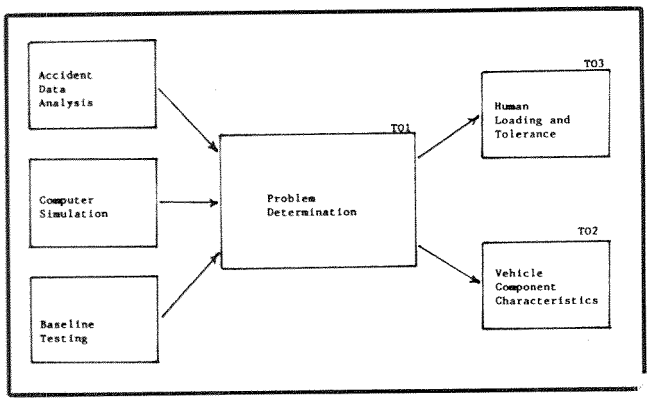


Figure 9. Project S4 roof header and pillar protection.

padding on the roof rail and pillars. The NCSS, FARS, and NASS data files shall be utilized for these studies.

Computer simulations are planned for parameter studies involving head impacts into the roof rail and pillars. Head-neck interactions and contact speeds are two areas in which special emphasis shall be placed. The CVS model shall be used for the analysis.

The final activity shall be baseline testing. The tests shall be conducted using the head impactor. Tests shall be conducted at various speeds, angles, and impact points. The final report for this task is due October, 1983.

SUMMARY

The program for side impact research will continue to receive emphasis in the Agency research program. An extensive effort is planned to complete the work on thoracic injury during the next year. The new projects emphasize problem determination and shall be concerned with both the striking and struck vehicles involved in the side impact accident. Special attention shall be made to each body region and the associated injuries.

REFERENCES

1. *Proceedings of the Public Meeting for Side Impact Protection Upgrade*, National Highway Traffic Safety Administration, U.S. Department of Transportation, DOT-HS-805 614, January 1980.
2. Eppinger, "Considerations in Side Impact Dummy Development," *Proceedings of the Seventh International Technical Conference on Experimental Safety Vehicles*, National Highway Traffic Safety Administration, U.S. Department of Transportation, DOT-HS-805 199, December 1979.
3. Burgett and Hackney, "Status of the National Highway Traffic Safety Administration Research and Rulemaking Activities for Upgrading Side Impact Protection," *Proceedings of the Seventh International Technical Conference on Experimental Safety Vehicles*, National Highway Traffic Safety Administration, U.S. Department of Transportation, DOT-HS-805 199, December 1979.
4. Eppinger and Partyka, "Estimating Fatality Reductions Associated with Safety Improvements," *Proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles*, National Highway Traffic Safety Administration, U.S. Department of Transportation, DOT-HS-805 555, October 1981.
5. Morgan and Waters, "Comparison of Two Promising Side Impact Dummies," *Proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles*, National Highway Traffic Safety Administration, U.S. Department of Transportation, DOT-HS-805 555, October 1981.
6. Hollowell and Pavlick, "Status of the Development of Improved Vehicle Side Structures for the Upgrade of FMVSS 214," *Proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles*, National Highway Traffic Safety Administration, U.S. Department of Transportation, DOT-HS-805 555, October 1981.
7. Shaw and Clark, "Side Impact Restraint Development and Evaluation Techniques," *Proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles*, National Highway Traffic Safety Administration, U.S. Department of Transportation, DOT-HS-805 555, October 1981.
8. Davis and Ragland, "Development of a Deformable Side Impact Moving Barrier," *Proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles*, National Highway Traffic Safety Administration, U.S. Department of Transportation, DOT-HS-805 555, October 1981.
9. Burgett, "Status of Program for Improving Side Impact Crash Protection," *Proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles*, National Highway Traffic Safety Administration, U.S. Department of Transportation, DOT-HS-805 555, October 1981.
10. Malliaris, Hitchcock, and Hedlund, "A Search for Priorities in Crash Protection," Society of Automotive Engineers 1982 International Congress and Exposition, SAE 820242, February 1982.
11. Eppinger and Chan, "Thoracic Injury Prediction via Digital Convolution Theory," Twenty-Fifth Stapp Car Crash Conference, SAE 811010, September 1981.

A Force Measuring Mechanical Test Device for Estimating and Comparing the Energy Absorbing Characteristics of Vehicle Interior Side Panels

ROGER P. DANIEL, MAX S. KOGA, PRIYA PRASAD, and CARL D. YOST
Ford Motor Company

ABSTRACT

A laboratory mechanical test device for estimating the relative energy absorbing and, to some extent, the force distributing characteristics of vehicle interior lateral components is being designed with the objective of generating data that will provide meaningful comparisons of such components. The device consists of upper, middle, and lower sections.

The upper section is a one-piece, padded semi-circular damped spring-mass system. Lateral force, displacement and acceleration will be measured. The middle section consists of a solidly supported semi-circular foam insert. Indentation in the foam will be measured. The lower section consists of a wooden form and a hinged contoured metal bar with provision for measuring acceleration of the wooden form and force between the wooden form and the metal bar. These three sections are intended for mounting in a test fixture such that the relative locations of the upper, middle, and lower sections will approximate the relative locations of the chest, abdomen, and hip of a 50 percentile male dummy.

The device is being designed to be used with only slight modifications on either a pendulum, a linear propulsion device, or the Hyge Sled with a body buck or component, providing a laboratory simulation of a 90 degree side impact test.

The test device, if successfully developed, may permit comparative assessments of vehicle components early in the design process.

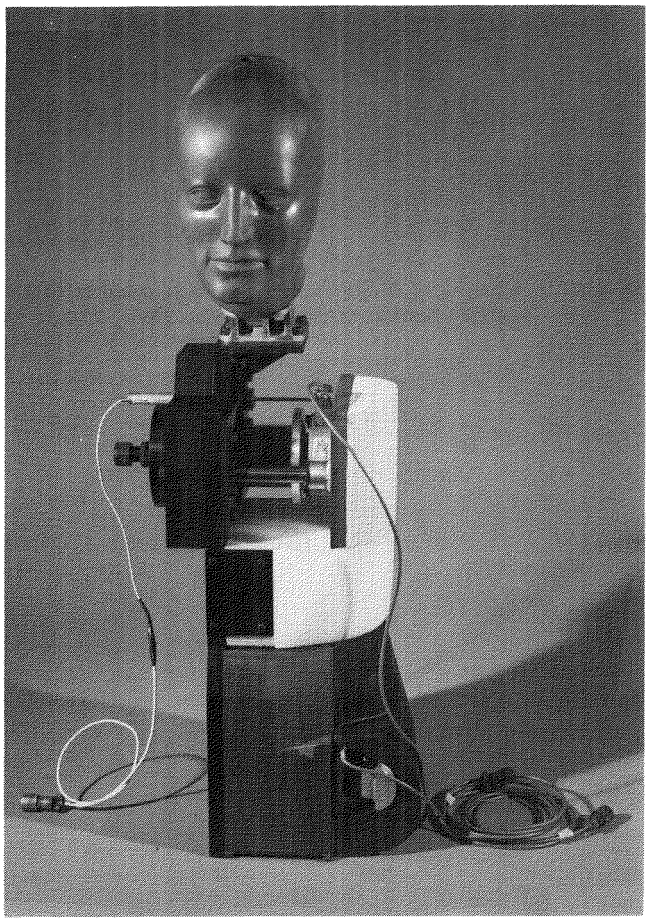


Figure 1. Side impact test device shown in front view with optional head and neck.

INTRODUCTION

An experimental impact test device is being developed by Ford Motor Company to help determine the energy absorbing and load-distribution characteristics of vehicle lateral interior components in the 90 degree impact configuration. The device has approximate biomechanical equivalence to male cadaver load-deflection data in the simulated areas of the rib cage, abdomen, and pelvis. The device may be propelled into the vehicle component to be tested by being swung as a pendulum, by linear guided or free flight devices, or by use of the Hyge Sled.

OVERALL DESCRIPTION

The 45 kg test device (Figures 1–2) consists of a one piece, non-articulated steel back-up structure (see Figure 5) to which are attached three subsystems—a "chest" unit (Figures 3, 4), an "abdominal" unit (Figure 5), and a "pelvic" unit (Figure 6). Provision also has been made to attach an optional dummy head and neck to the steel backing structure as seen in Figures 1 and 2. This adds 6.9 kg to the mass of the test device. Both a flat and a 25 degree angled piece of slippery plastic (to approximate the seat back angle) are available for the bottom of the test device if the test calls for the device to slide on a "seat" surface during the test.

THE CHEST UNIT

The 18.9 kg simulated chest unit (Figures 3, 4) consists of a laterally guided, padded 4.6 kg moveable mass po-

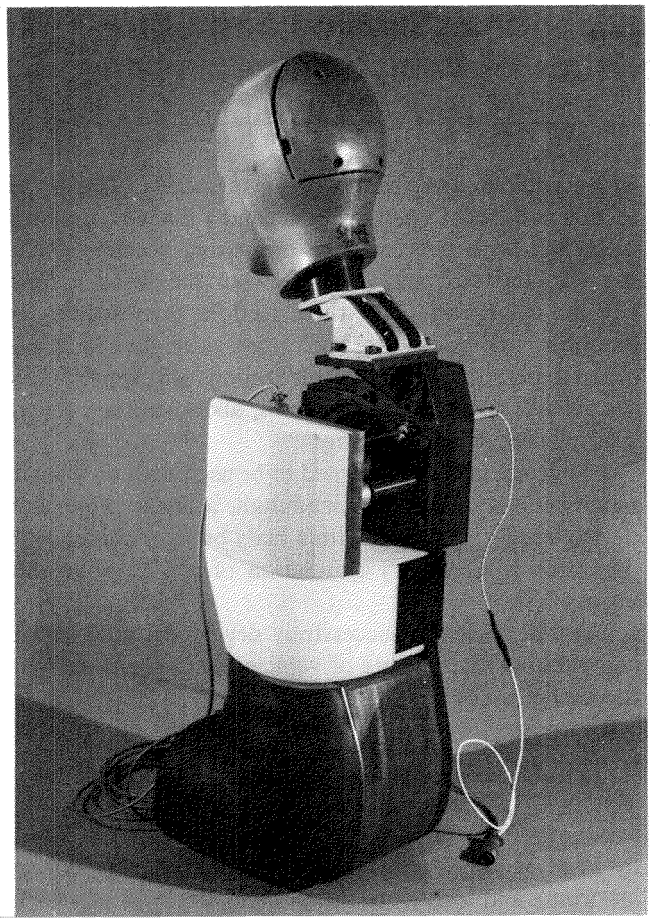


Figure 2. Side impact test device shown in ¾ rear view.

sitioned to represent the lateral chest wall (rib cage) of a dummy. Inward movement of the simulated chest wall is resisted by a 75 mm diameter by 150 mm long natural rubber cylindrical spring/damper. The rubber cylinder acts against a 22 kN load cell mounted as part of the moveable section. Pre-compression of the rubber spring/damper is provided by an adjustable steel plate at the backing plate end of the cylinder.

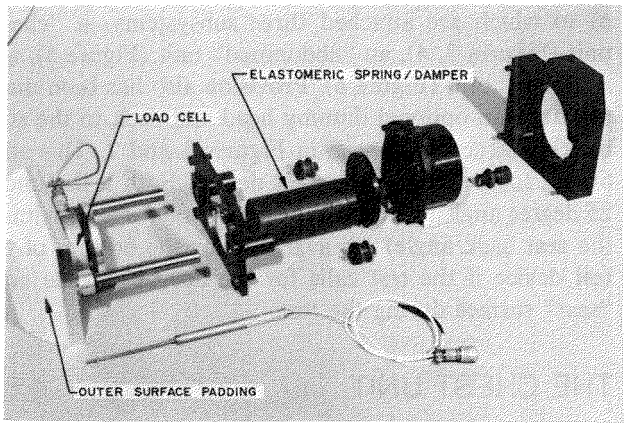


Figure 3. Exploded view of chest unit which mounts to upper portion of the steel backing plate.

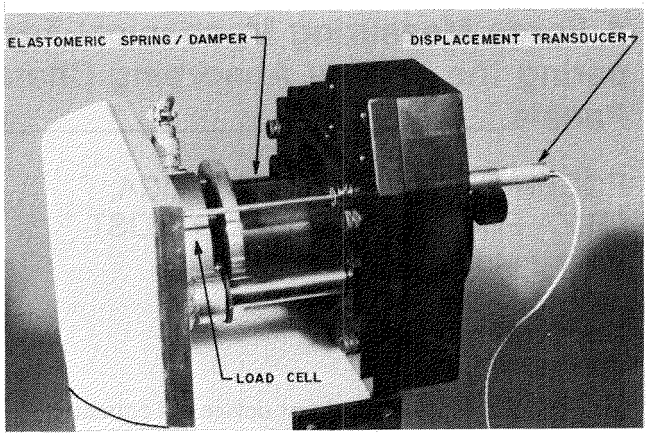


Figure 4. Chest unit assembled to backing plate.

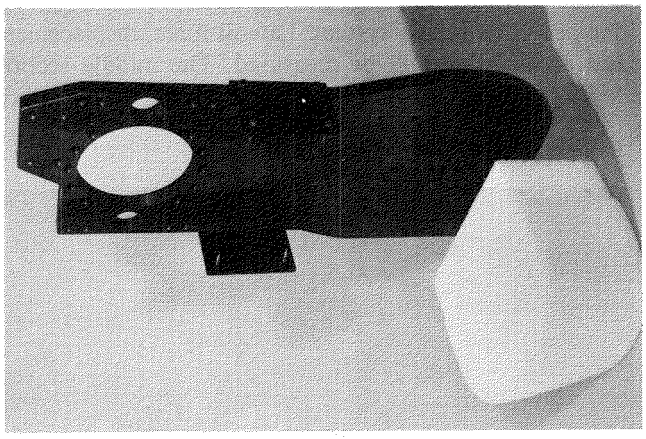


Figure 5. Styrofoam abdominal unit which mounts to the central portion of the backing plate.

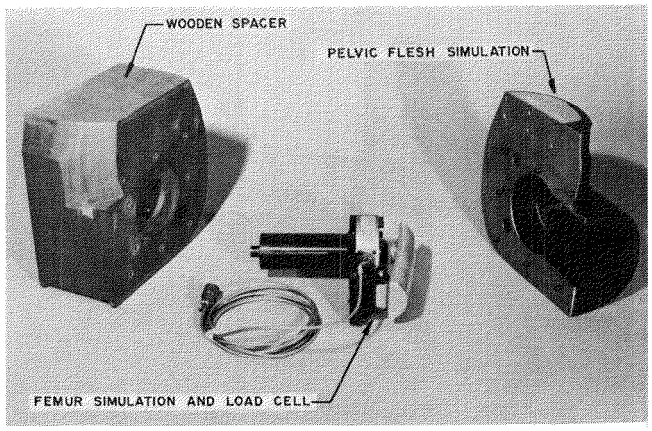


Figure 6. Exploded view of the pelvic unit which mounts to the lower portion of the backing plate.

Instrumentation for the chest unit is the load cell described above, a linear potentiometer to measure moving mass displacement, and two accelerometers; one on the back-up plate and one on the moveable mass.

SPRING/DAMPER/PADDING DEVELOPMENT

Dynamic biomechanical data for human cadaver chest wall lateral stiffness from tests conducted at Association Peugeot-Renault (APR) (1) were utilized in the development of this test device. Cadavers were dropped laterally against padded load cells positioned in line with the rib cage. The resulting load-deflection band from a number of these cadaver tests is plotted in Figure 7. A spring/damper for the mechanical test device was sought that would bring the chest unit within the APR load-deflection band when the inertia of the moving mass was also taken into account, would deform repeatedly without damage up to 75 mm, and would fit within the confines of the design concept. After studying various metal spring systems and pneumatic and hydraulic damper units, an elastomeric device was chosen as most closely meeting design and performance objectives.

The CRUSH-II math model was employed to blend the characteristics for the spring/damper and the external "flesh" simulation (padding) for a minimum 3.6 kg inertial mass at an impact speed of 28–32 km/h. The model predicted that the chest outer surface padding would have a considerable effect on the results, even though the padding only absorbed a small amount of the total energy. This effect is seen in Figure 8 which is a typical plot of impact tests performed on several paddings with the same elastomeric spring/damper, as described below.

The model predictions were evaluated on a horizontal mini-sled. A 25 kg moving mass, to which was mounted the rubber spring/damper cylinder and a padded plate,

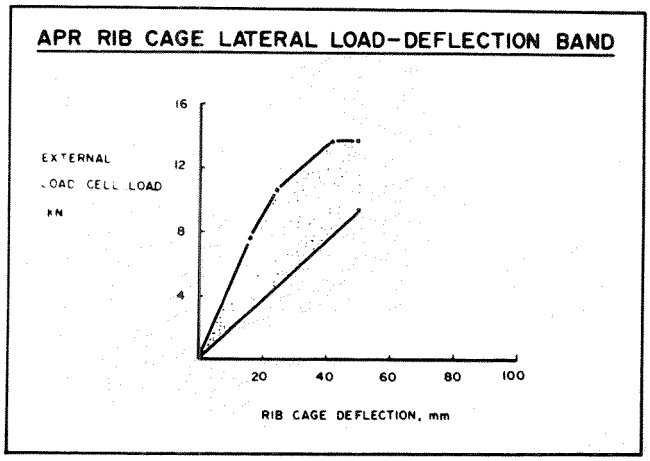


Figure 7. The resulting load-deflection band from cadaver tests.

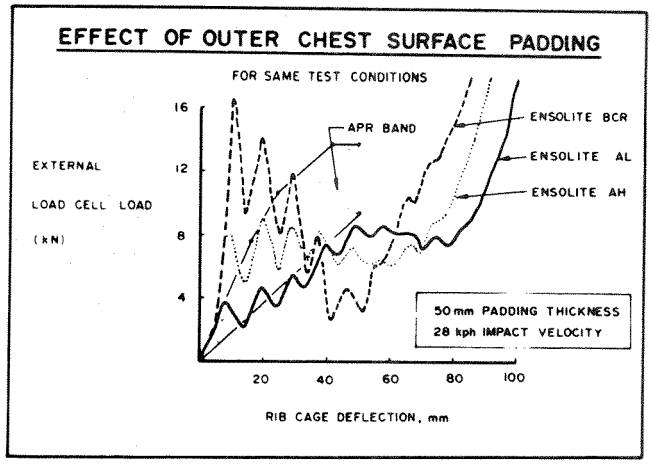


Figure 8. Typical plot of impact tests performed on several paddings.

struck a stationary load cell at speeds up to 32 km/h. The test set up is shown in Figure 9. A comparison between the test results and the CRUSH-II model results for the final design is shown in Figure 10.

THE ABDOMINAL UNIT

The 4.5 kg simulated abdominal unit (Figure 5) consists of a shaped section of Dow Styrofoam DB (TM), backed up by the central portion of the steel backing structure, and held in place by pointed screws through side plates (Figure 11). The Styrofoam is kept from shattering by a brushed-on elastomeric film. The Styrofoam has a minimum dynamic resistance of about 170 kPa, probably a low value for abdominal penetration. Penetration into the foam surface is the only measured criterion.

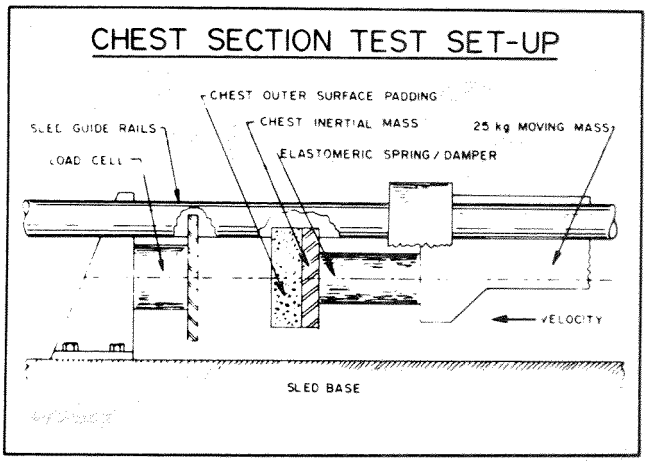


Figure 9. Test set up for Crush-II model.

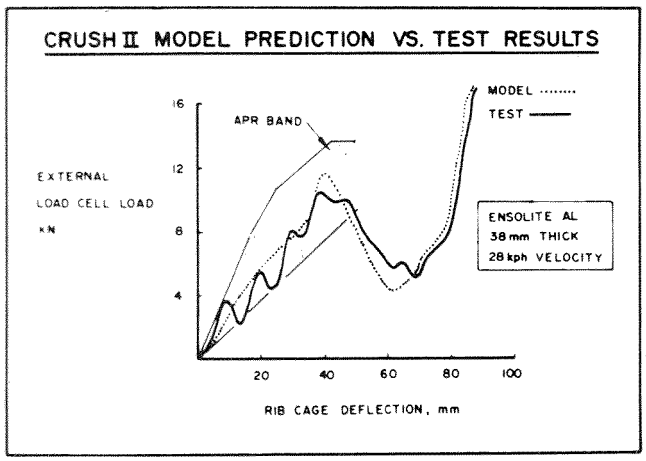


Figure 10. Comparison between test results and Crush-II model results for the final design.

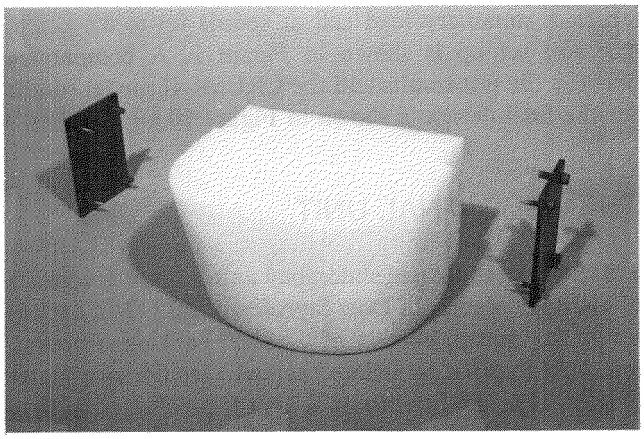


Figure 11. Close-up of abdominal insert and retaining screws.

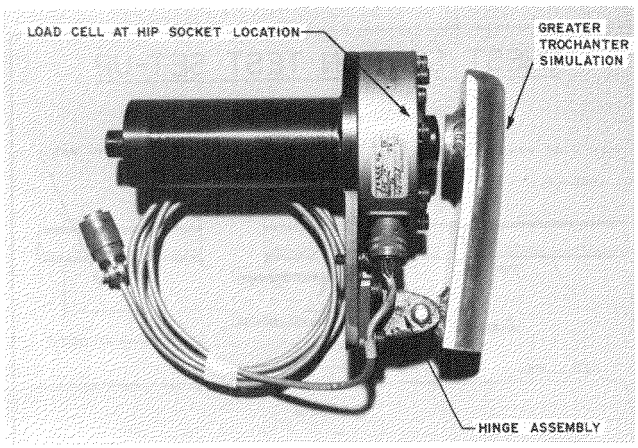


Figure 12. Close-up of the pelvic unit femur simulation and hip socket load cell.

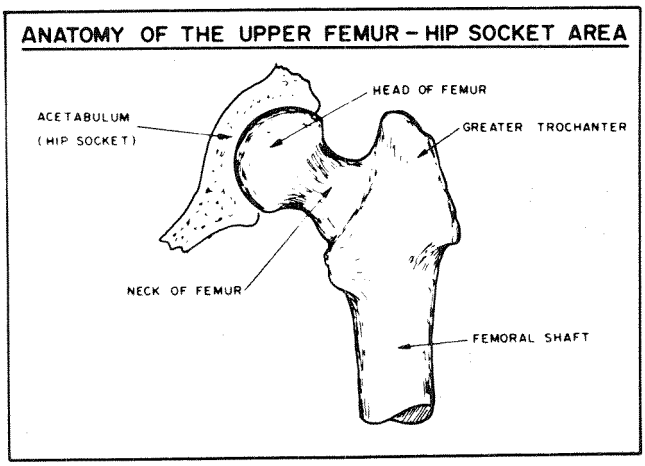


Figure 13. Lateral load applied to the femur foward of the trochanter.

THE PELVIC UNIT

The 21.6 kg simulated pelvic unit (Figure 6) consists of a wooden spacer, backed up by the lower portion of the steel back plate, to which spacer is bolted a hollowed out cold molded "Blak-Tufy" (2) rubber section shaped to the outer lateral contour of the Part 572 dummy pelvis. A 22 kN load cell, located in three dimensional space at the anatomical location of the dummy acetabulum (hip socket), is loaded through a hinged femur simulation (Figure 12).

When a lateral load is applied to the femur forward of the greater trochanter location (Figure 13), the femur tends to simply move out of the way with reduced likelihood of serious damage to the pelvic structure. Therefore, it was believed that only loads on or very near the greater trochanter would create the possibility of fracture of the acetabulum or of the femur head or neck. Thus, only those loads transmitted directly into the acetabulum area are measured by this test device.

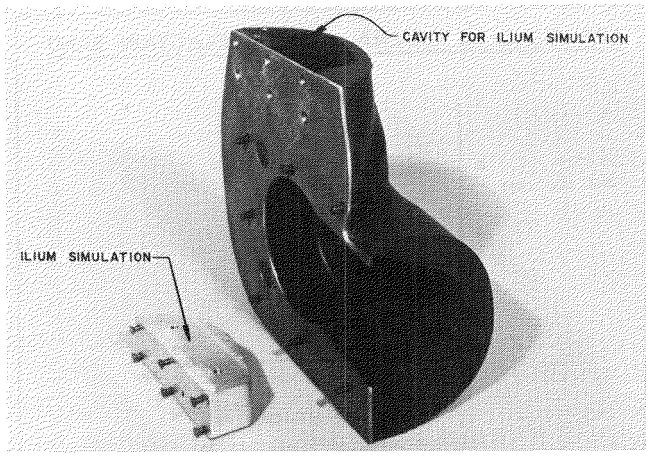


Figure 14. Ilium simulation which is inserted into the upper portion of the pelvic unit flesh simulation.

The upper flared out portion of the ilium, i.e., that upper portion of the hip bone that can be felt just below the waist, is simulated by a shaped, replaceable metal section (Figure 14) protruding laterally outward from the wooden spacer in a cavity in the rubber flesh simulation. This metal section, which is currently bolted to the wooden spacer, was designed so that at a later date it can be mounted to the spacer by one or two load cells if measurement of load into the upper ilium is desired.

REFERENCES

1. R. L. Stalnaker, C. Tarrière, et al., "Modification of Part 572 Dummy for Lateral Impact according to Biomechanical Data," pg. 841, Proceedings of the 23rd Stapp Car Crash Conference.
2. Blak-Tufy Cold Molding Compound, The Perma-Flex Mold Company, 1919 E. Livington Ave., Columbus, Ohio, 43209.

Evaluation of Improved Protection and Dummy Biofidelity in Side Impact

DOMINIQUE CESARI
Organisme National de Securité Routière
Laboratoire des Chocs et de Biomecanique

ARNOLD K. JOHNSON
National Highway Traffic Safety Administration

ABSTRACT

A series of tests has been conducted in which unmodified and modified Volkswagen Rabbits have been laterally impacted in a simulation of a real world lateral crash. The modified Rabbits had reinforced side structures and additional padding to help mitigate impact injury severity. Unembalmed cadavers were used as test subjects. Each was seated in the driver's position, and impact occurred in the region of the driver. These impact tests are replicas of earlier tests conducted at a different test facility with two differently designed side impact dummies. These tests showed that the modified Rabbit mitigated injury severity compared to the unmodified Rabbit. The tests also compared the responses of the corresponding laterally oriented accelerometers mounted to the chest of the dummies and cadavers in the two impact environments, that of the modified and that of the unmodified Rabbits.

INTRODUCTION

A series of tests has been conducted in which unmodified and modified Volkswagen Rabbits have been laterally impacted in a simulation of a real world lateral crash. The simulated crash was equivalent to an Oldsmobile Cutlass impacting the driver's side of a Rabbit. The modified Rabbits had reinforced side structures and additional padding to help mitigate injury severity in side impacts. Although the simulated crash remained nominally unchanged (same impact angle, velocity, etc. . . .) for the series of tests, the modified and unmodified Rabbits provided, of course, different impact environments for the test subjects.

Unembalmed cadavers were used as test subjects. Each was seated in the driver's position, and impact occurred in the region of the driver. These impact tests are replicas of earlier tests conducted at Dynamic Science, Inc. (DSI)*, with two differently designed side impact dummies. One dummy (SID) was developed by the Highway Safety Research Institute (HSRI) described in (1), and the other was developed by the Association of Peugeot-Renault (APR) described in (2). Each dummy was impacted once in an unmodified Rabbit.

Table 1 summarizes the impact tests conducted with cadavers at the Organisme National de Securité Routière (ONSER) and with dummies at DSI.

Table 1. List of test conducted together with test identification number.

		Rabbit	
Laboratory	Surrogate	Unmodified	Modified
DSI	APR	6.1	6.2
	SID	6.4	6.3
ONSER	CADAVER 1	BMD 01	
	CADAVER 2		BMD 02
	CADAVER 3		BMD 03

The cadavers were instrumented with an array of linear accelerometers mounted to the chest (Figure 1). Both dummies had a similar array of accelerometers mounted at anatomically equivalent locations on the chest. The dummies were designed so that the responses of their laterally oriented accelerometers matched fairly closely the corresponding responses of laterally oriented accelerometers mounted to the cadavers in lateral impacts (1). At least for the impact environments like those reported

* These earlier tests were performed under Contract DOT-HS-8-0193 between Dynamic Science, Inc. and the National Highway Traffic Safety Administration.

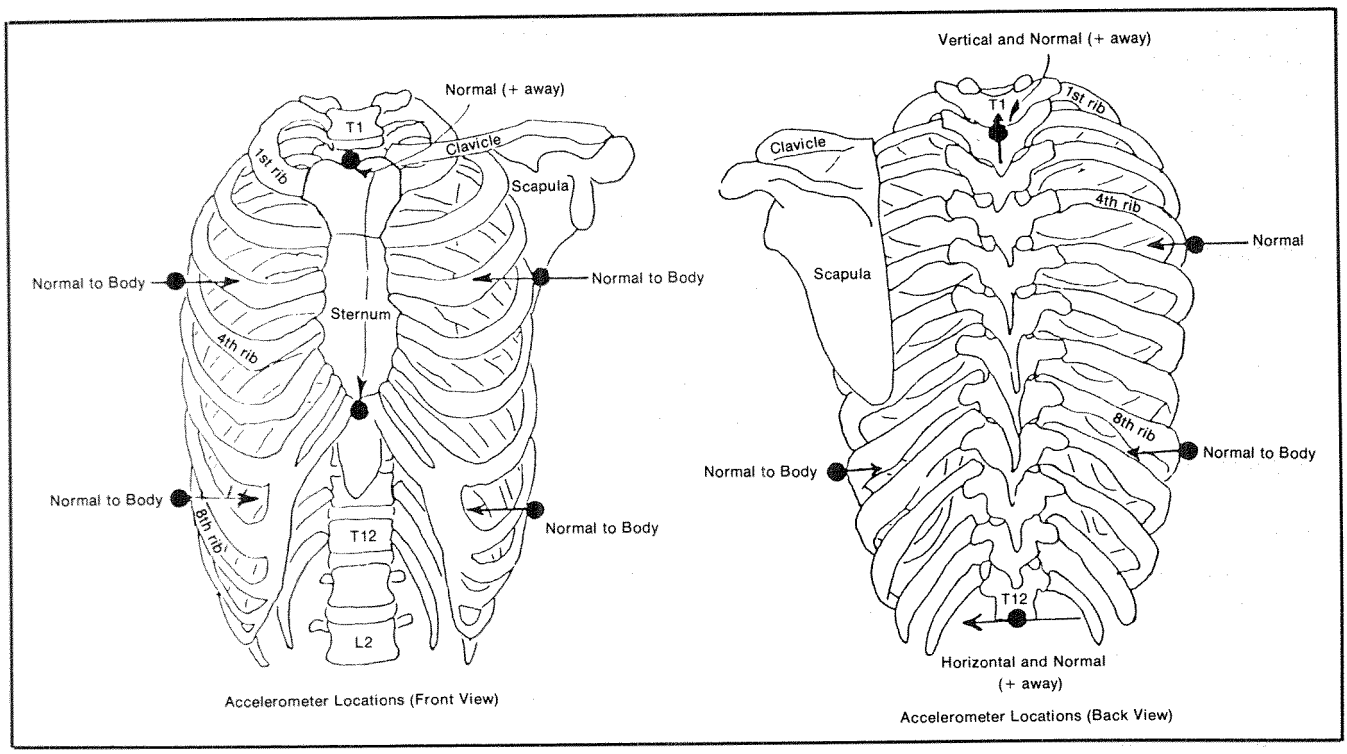


Figure 1. Location of thoracic accelerometers.

in (1), the mechanical responses of the dummies appeared to mimic those of the cadavers. To that extent at least, the dummies had biofidelity. Since in this present paper at least one cadaver was tested in the same impact environment as the dummies, a similar comparison of responses can be made. However, these two impact environments, especially that of the unmodified Rabbit, were closer to real world crash environments than in the earlier impact tests of (1) conducted on a sled. Thus, these cadaver tests help to establish the dummys' biofidelity in real world crash environments.

Since cadavers can be injured, they indicate directly impact injury severity. Their injury severity is reported for each of the two impact environments, that of the modified and that of the unmodified Rabbits.

OBJECTIVES

The objectives in conducting the series of impact tests with cadavers were as follows:

(1) To establish the degree of improved capabilities of the modified Rabbit to mitigate injury severity compared to the unmodified Rabbit as assessed by the injury severity to the cadavers.

(2) To compare the responses of the corresponding laterally oriented accelerometers mounted to the chest of the dummies and cadavers in the two impact environments.

DESCRIPTION OF THE CRASH CONFIGURATION

As already discussed, a real world side impact crash was simulated with a modified and an unmodified Volkswagen Rabbit being impacted in the region near the driver. The impacting "bullet" vehicle was a specially designed side impactor whose crush characteristics were such that its impact was equivalent to an Oldsmobile Cutlass impacting an unmodified Rabbit. Its development is described in (3).

A schematic of the impactor is shown in Figure 2. At the right of this figure is a 72 inch wide crushable impacting barrier designed to exert a controlled force during impact. However, for the tests being reported, an impacting barrier with different crush characteristics was used. The size and shape of this barrier is shown in Figure 3. Some limited data on its dynamic crush characteristics when mounted to the side impactor are given in (3).

Simple schematics of the crash configuration are shown in Figures 4 and 5. For the convenience of having the target Rabbit stationary, the real world configuration in Figure 4 was modified to that shown in Figure 5. The velocity of the impactor has been changed and its wheels turned at an angle (crabbing). Except for some changes in the friction exerted by the surfaces on the tires of the two vehicles, the two impact configurations in Figures 4 and 5 are mechanically equivalent. The change in the frictional forces can be assumed to be small compared to

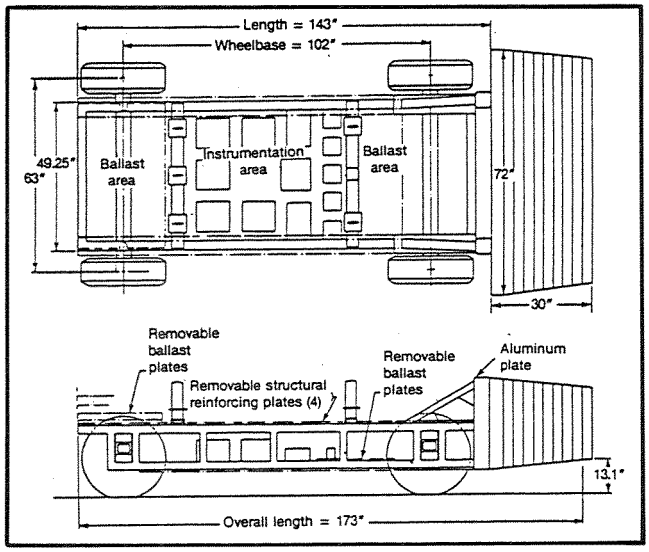


Figure 2. NHTSA side impactor configuration (4 wheeled) vehicle simulator (reproduced from (3)).

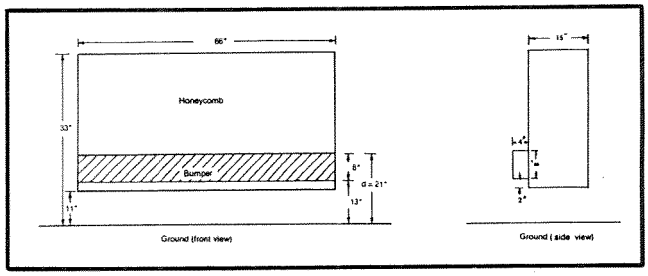


Figure 3. Dimensions of side impactor honeycomb face.

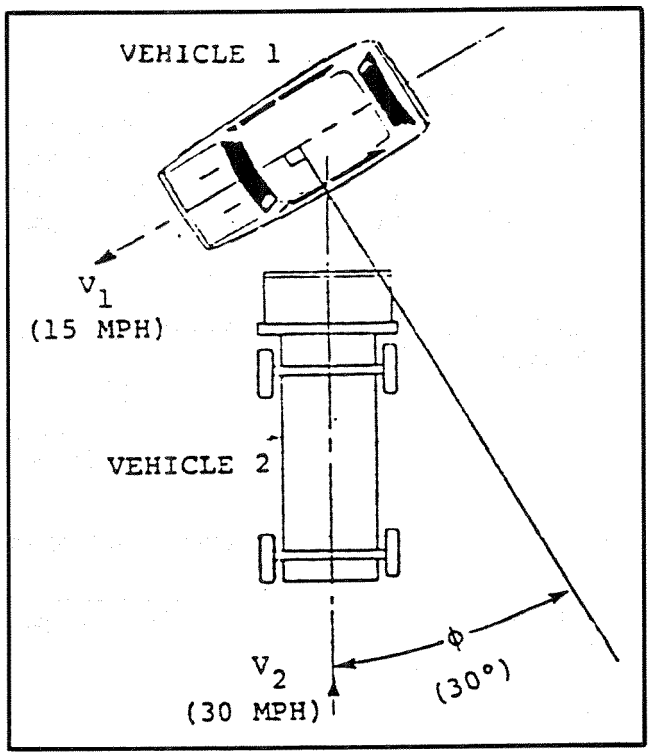


Figure 4. Collision to be simulated.

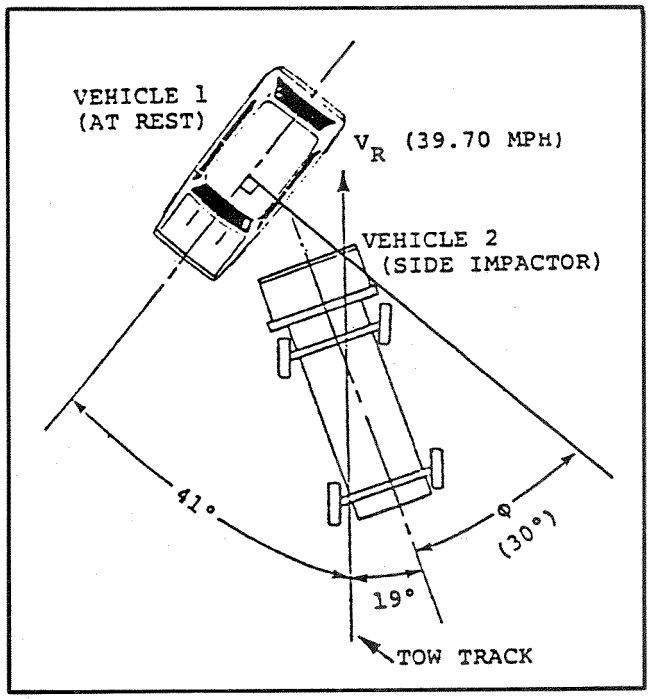


Figure 5. Crabbed side impactor-to-car 60° impact simulation.

the overall crash forces. The crush measurements of an unmodified Rabbit for the crash configuration, shown in greater detail in Figure 6, with the side impactor were comparable to the crush measurements of an unmodified Rabbit for the real world crash configuration in Figure 4 with an Oldsmobile Cutlass. This is the basis for saying that the crash simulated the Rabbits' being impacted by an Oldsmobile Cutlass.

INJURY ASSESSMENT OF THE CADAVERS

Three cadaver tests were conducted: two with a modified Rabbit and one with an unmodified Rabbit (baseline). The three cadavers were selected carefully according to their medical history, the cause of death, their age and their anthropometry. The characteristics of these three cadavers are listed in Table 2.

The comparison of characteristics of the three cadavers shows that the Test BMD 01 cadaver was smaller than the two others; but the detailed anthropometry indicates that its torso has about the same length as the two others; this means that relative to the vehicle, the pelvis, the thorax, the shoulder and the head were all approximately at the same height. The cadavers were prepared before the test with a special liquid injected through the carotids into the brain. The liquid permits identifying brain injuries by post-test dissections of the brain.

The injuries were recorded during an autopsy made a few days after the test. The severity of these injuries found during the autopsy are listed in Table 3.

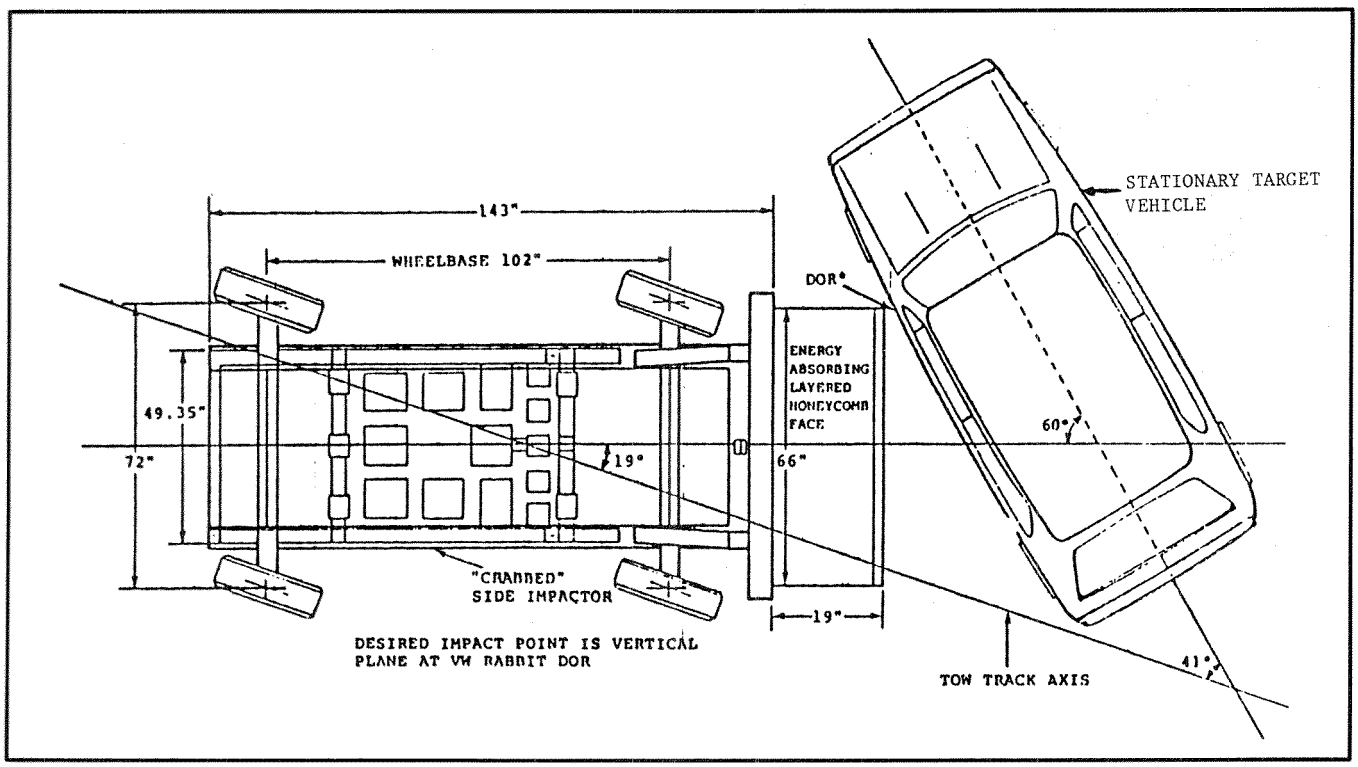


Figure 6. Test configuration in greater detail.

Analysis of injuries sustained by the three cadavers during side impact tests allows us to make the following remarks:

(1) Only one cadaver sustained a minor head injury which was a temporal wound (AIS 1). There was no evidence of brain injury for the three cadavers, and the dissecting of the injected brains did not show any hemorrhage.
(2) The cadaver which was in the unmodified Rabbit baseline sustained pelvic fractures (AIS 3) and a middle shaft fracture of the left femur (AIS 3). The other cadavers did not sustain any injury to the pelvis or to the lower limbs. This can be related to the combined protection provided by the padding and the reinforced side structure.
(3) All the cadavers showed abdominal injuries to the spleen and/or to the liver. However, how well these injuries would compare to the living is uncertain.
(4) All the cadavers sustained a large number of fractured ribs: 2 to 4 on right side and 10 to 14 on the left side. The difference in AIS values depends on the presence of a flail chest or not. It has to be pointed out that the AIS scale is not very sensitive to the severity of thoracic injuries.

The protection provided by the modifications to reduce thoracic injury severity is not as beneficial as for the pelvis. However, it should be noted that the modifications to the Rabbit decreased the severity of thoracic injuries from AIS 4 to AIS 2 for cadavers of approximately the same age (Tests BMD 01 and 02). The value of AIS 4, found in Test BMD 03, could be due to the cadaver's greater age.

DISCUSSION OF THE DAMAGE TO EACH CRASHED VEHICLE

The results of seven tests are analysed in this study: three tests with an unmodified VW Rabbit (one for each

Table 2. Type of rabbit and cadavers characteristics.

ONSER Test Number	BMD 01	BMD 02	BMD 03
Type of rabbit	Unmodified	Modified	Modified
Age (yrs)	40	43	55
Sex (M or F)	F	M	M
Weight (kg)	59	70	74
Height (m)	1.67	1.75	1.74
Torso length (cm)	87	85	84

Table 3. Body segment AIS values (reference to 1980 AIS (4)).

Test number	BMD 01	BMD 02	BMD 03
Head	0	1	0
Thorax	4	2	4
Abdomen	4	3	3
Pelvis	3	0	0
Lower limbs	3	0	0

human surrogate) and four tests with a modified VW Rabbit (two cadaver tests and one with each dummy type).

For all the tests the car deformations and the impacting moving barrier deformations have been recorded with similar procedures.

The deformations are recorded by measuring the position of self-adhesive targets before and after tests. These targets are placed at four levels as indicated on Figure 7. These four levels are distributed from the lower window level (level A) to the bottom of the doors (level D). Level A corresponds approximately to the location of the shoulder and the upper thorax of the driver in the struck car; level B corresponds to the lower thorax and level C corresponds to the pelvis. Curves of the crush of the cars are presented for each of these four levels. Measurements were made at each target location.

For the deformation of the moving barrier we have used the same general procedure except that the deformations were recorded at only three levels, which are at the top of the stack, at the mid point of the stack and at the bumper level.

If we consider the deformations of unmodified (baseline) cars, two of them (Test BMD 01 and Test 6.1 as specified in Table 1) sustained similar deformations in terms of shape and of amount of crush, as shown by Figure 8. For the third unmodified Rabbit (Test 6.4) the depth of the crush was about 25% higher at the levels A and B (thoracic level) than for the Tests BMD 01 and 6.1. The difference was not so great at the pelvic level.

In the vertical distribution of the deformations, the minimum value is found at the lower level D for which the side beam stiffens the cars' sides; the maximum crush occurred at level C, which is the pelvic level of the driver of the struck car. The depth of the crush at the levels of the thorax and the shoulder is approximately 20% lower than the value recorded at the pelvic level. It is also noticeable that for the three upper levels the maximum deformation recorded is to front of the driver. The deformation to the front of the impacting moving barrier is not too extensive when impacting the unmodified Rabbits. The deformation is similar for two tests (BMD 01 and 6.1).

For Test 6.1 a "negative" deformation was recorded; in fact, this corresponds to a swinging out process of the left side of the deformable element of the barrier due to the asymmetry of the impact on the barrier.

The deformations of the four modified cars are similar as indicated by Figure 9; with this car the test seems very repeatable. The amount of crush is lower at the bottom and is in the same order of magnitude at the three other levels. This means that in front of the driver, the crush of the struck car was about the same magnitude from the shoulder level to the pelvis level.

The deformations of the barrier front end decrease from the bumper level to the top of the stack. The deformations of the barrier are similar for the four tests except to the left corner point for which a skidding process could explain this slight difference.

If we compare the deformations of a modified Rabbit and of a baseline Rabbit, differences appear clearly as indicated by Figure 10. The modifications of structures on the Rabbit decreased the amount of crush at the 4 levels at which the deformations were recorded, and then increased the protection given to the occupants (5).

The most important effect in crush reduction is found at level C, which is the level of the pelvis. For this level the reduction of maximum crush is about 40%. This can be related to the reduction of pelvic injury severity.

THE CHEST MOUNTED LINEAR ACCELEROMETERS

Figure 1 establishes on a human skeleton the location and orientation of each of the linear accelerometers of the array mounted to the chest of the cadavers. This array of accelerometers has been used in other programs (6). A similar array was mounted to the chest of the two dummies at anatomically equivalent locations.* Since the impacts were all lateral, it was the responses of the laterally oriented accelerometers that were of interest.

COMPARISON OF ACCELEROMETER RESPONSES

As stated, the tests conducted with cadavers at ONSER were replicas of tests conducted earlier at DSI with dummies. ONSER constructed a replica of the side impactor used at DSI and the crushable fronts at both test facilities were from the same manufacturer lot. The time zero event at both facilities was the closing of a switch by the impactor as it struck the Rabbit. It was felt, however, that this time zero event could vary a few milliseconds between the two facilities. Thus, the comparison of the accelerometer responses between the cadavers, which were tested at ONSER, and the dummies, which were tested at DSI,

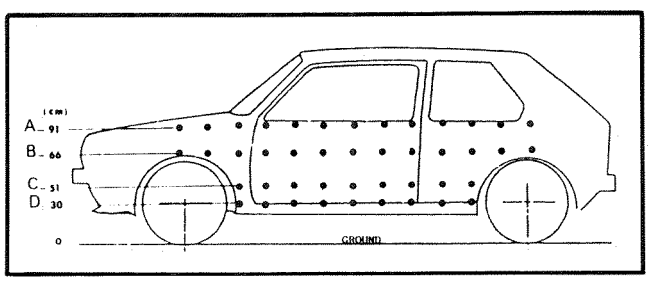


Figure 7. Target locations on side of tested Rabbits.

*The linear accelerometers used on both the dummies and cadavers were Endevco 2264-2000.

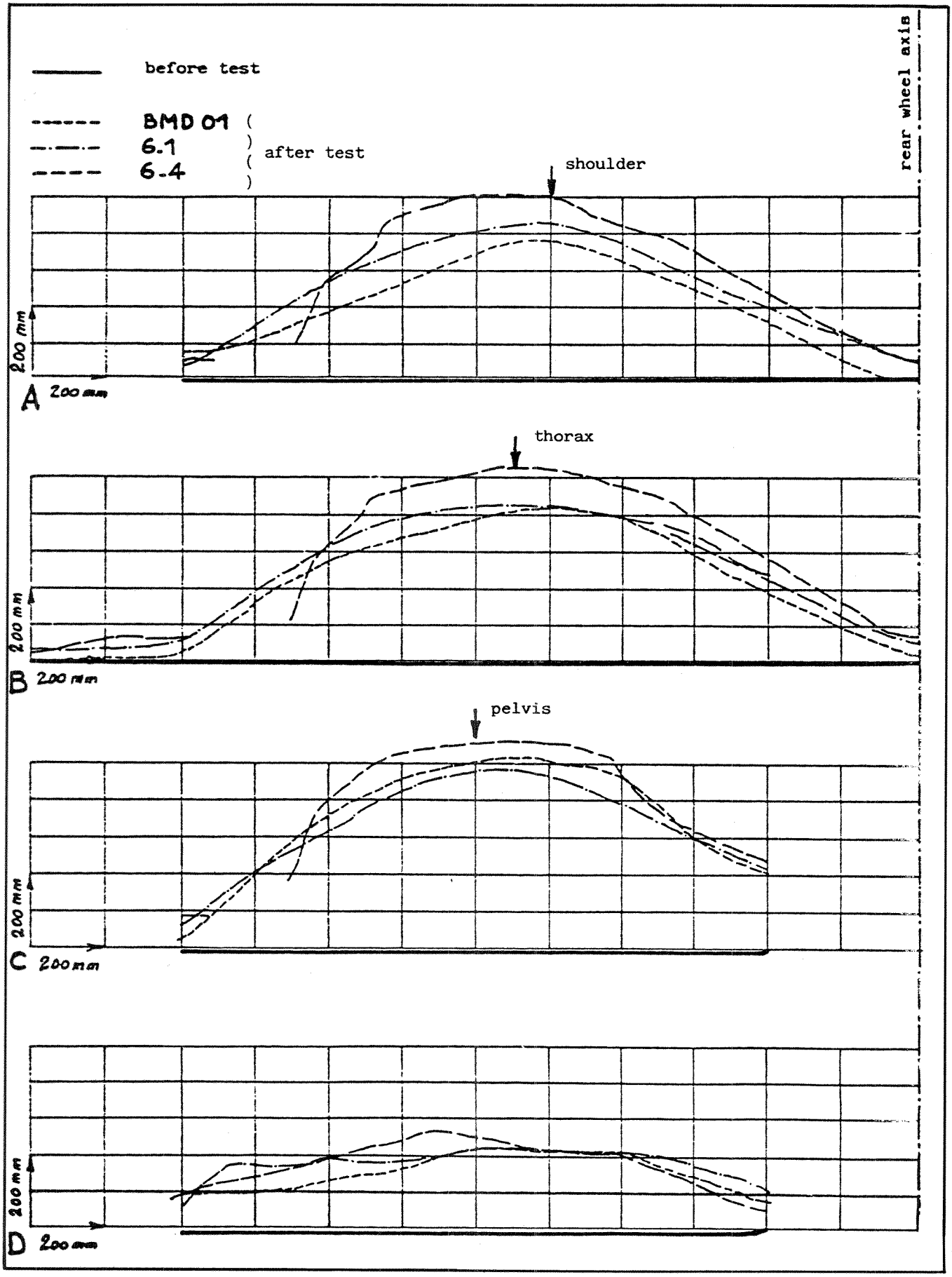


Figure 8. Unmodified Rabbit side deformations.

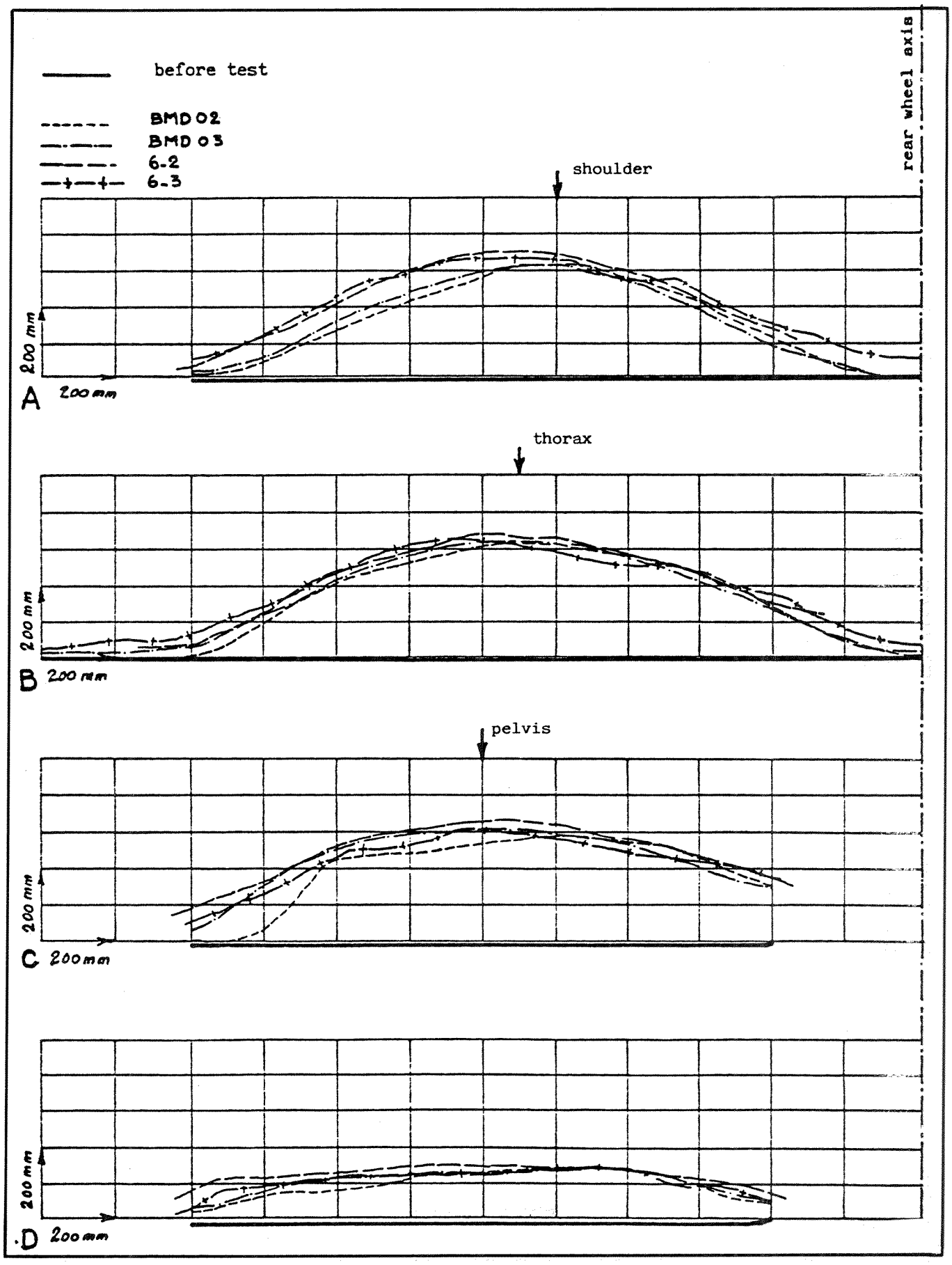


Figure 9. Modified Rabbit side deformations.

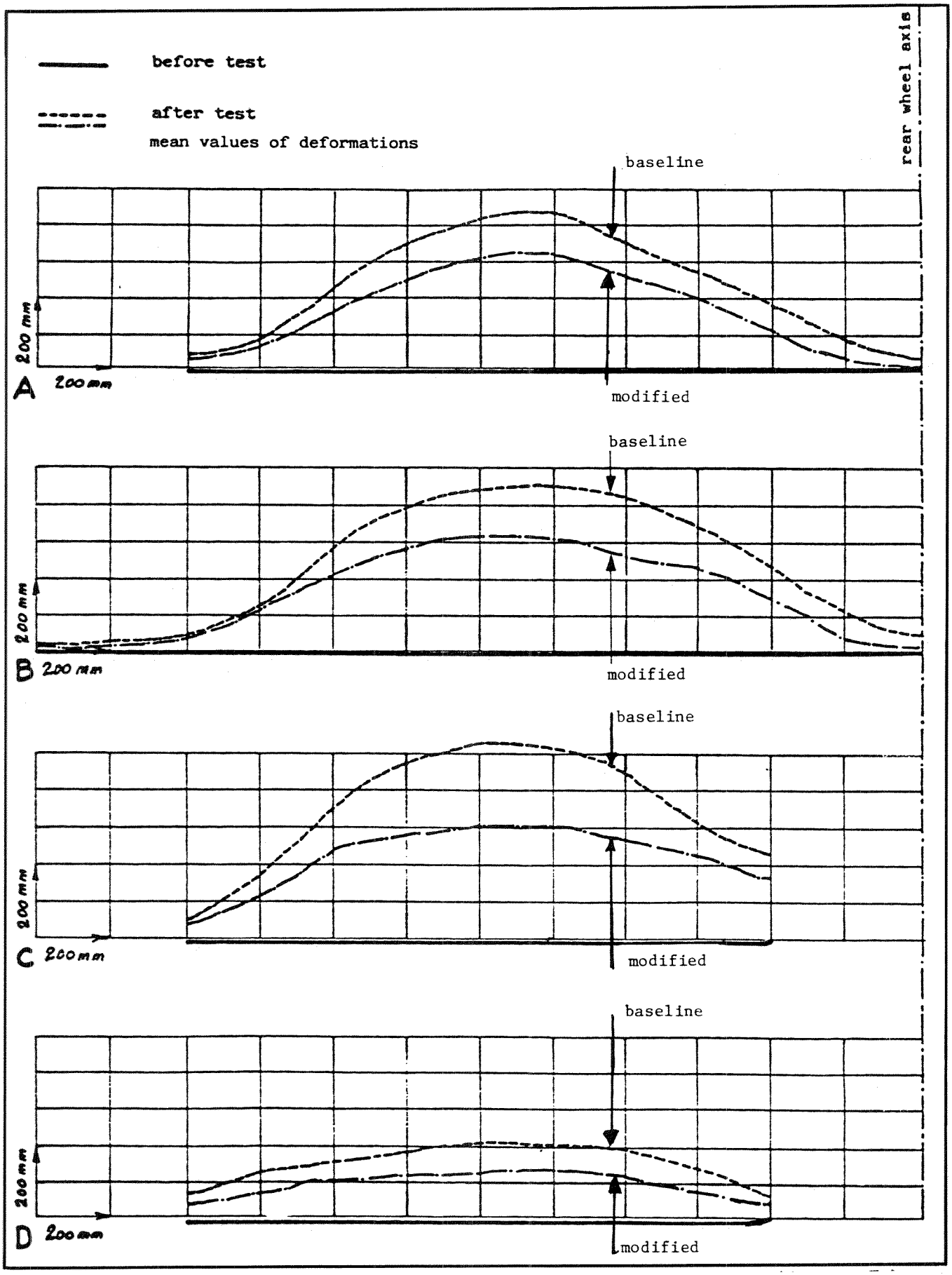


Figure 10. Unmodified and modified Rabbits side average deformations.

was accomplished by having the peak of each response curve aligned at the same instant of time. This procedure eliminated the effect of possible variation in the location of a cadaver response curve relative to the location of a dummy curve. By this procedure the curves could more accurately and meaningfully be compared.

However, when comparing only cadaver response curves such a procedure was not required, because all the cadaver tests were conducted at ONSER with the same impactor for all the tests. Furthermore, it was important to compare cadaver responses relative to a common time zero event. The time at which a response initiated relative to time zero was different depending on whether the subject was in a modified Rabbit in contact with padding prior to impact or in an unmodified Rabbit approximately six inches from the door. Such differences in response initiation times are important in analyzing the injury potential of the two crash environments.

CADAVER ACCELEROMETER RESPONSE IN THE MODIFIED AND UNMODIFIED RABBITS

Figures 11 through 17 are a series of overlays of the responses of the laterally oriented accelerometers mounted to the chest of the three cadavers. The differences among these curves will be discussed in this section.

Reference is made to Tables 2 and 3 which give information about the cadaver subjects and the assessment of injury severity in terms of AIS (4). Table 1 identified that Test BMD 01 was with an unmodified Rabbit and that Tests BMD 02 and BMD 03 were nominally identical impact environments. Differences in accelerometer responses and injury severity for these Tests BMD 02 and BMD 03 have to be attributed to differences in the cadavers.

Table 4 summarizes the peak accelerometer response for all three cadaver tests. Except for the lower spine, the peaks are in the descending order of BMD 01, BMD 03, BMD 02. This is the same descending order as the AIS injury severities recorded in Table 3. Peak accelerometer responses for similar impact environments generally correlate with injury severity as it does for these tests.

For Tests BMD 02 and BMD 03 with modified Rabbits, the cadavers were in contact with padding prior to impact. For Test BMD 01 with an unmodified Rabbit, the cadaver was about six inches from the side of the door. As would be expected, for the cadavers in contact with the padding their response curves begin earlier than the BMD 01 curve with the unmodified Rabbit. Also for the modified Rabbits the curves generally rise to a low level before later rising to a peak response which then rapidly declines. These peaks are significantly lower than for the unmodified Rabbit, except for the right lower rib (Figure 14). It should also be noted that padding distributes the crash

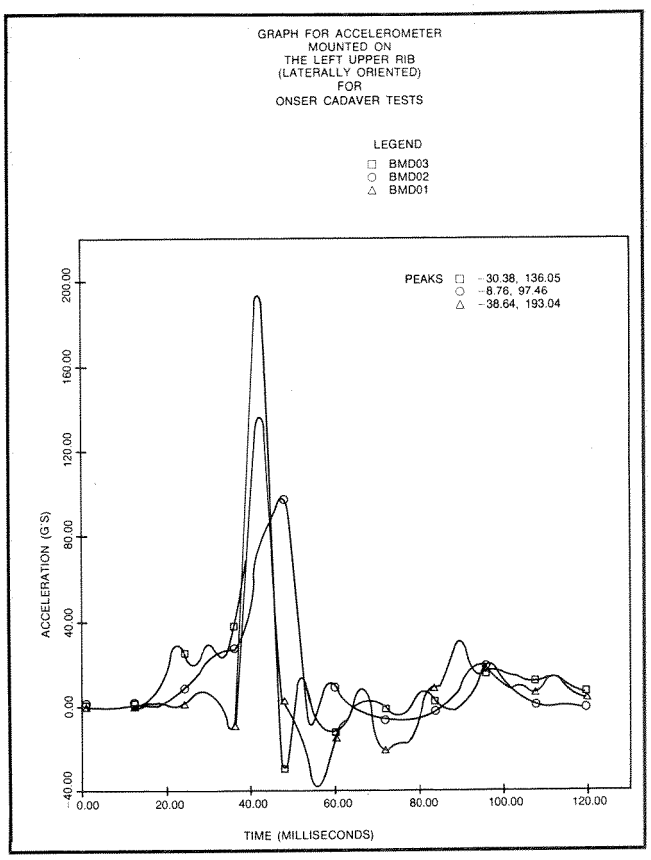


Figure 11.

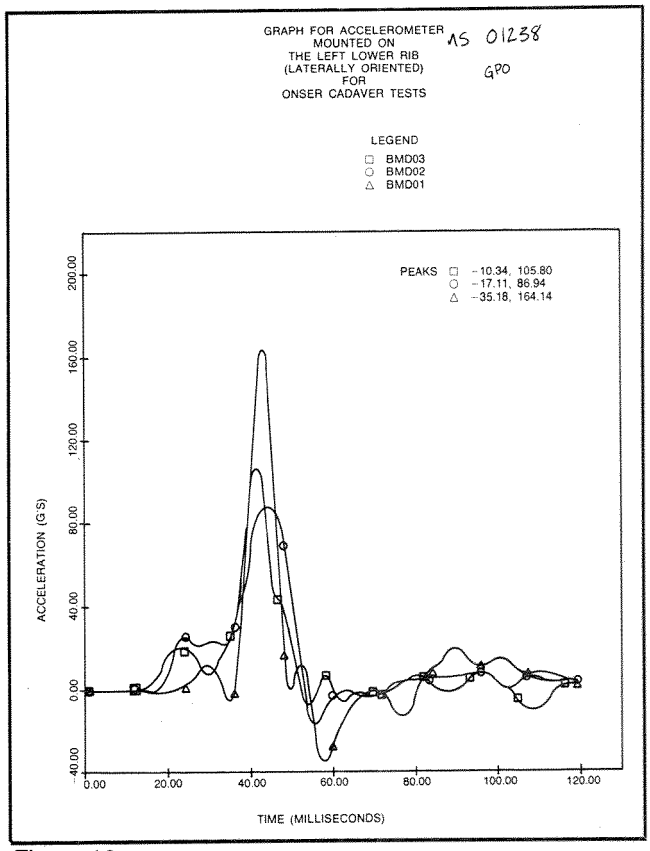


Figure 12.

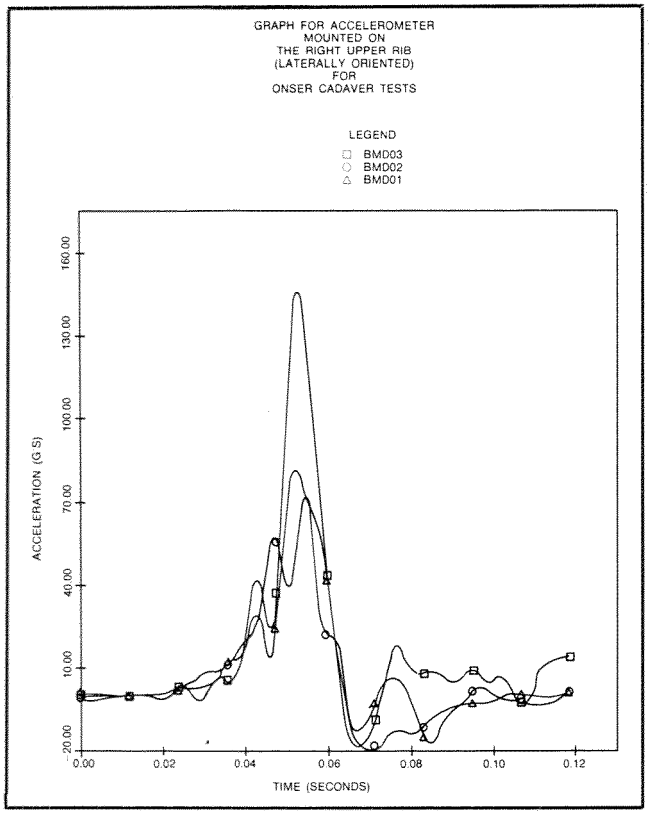


Figure 13.

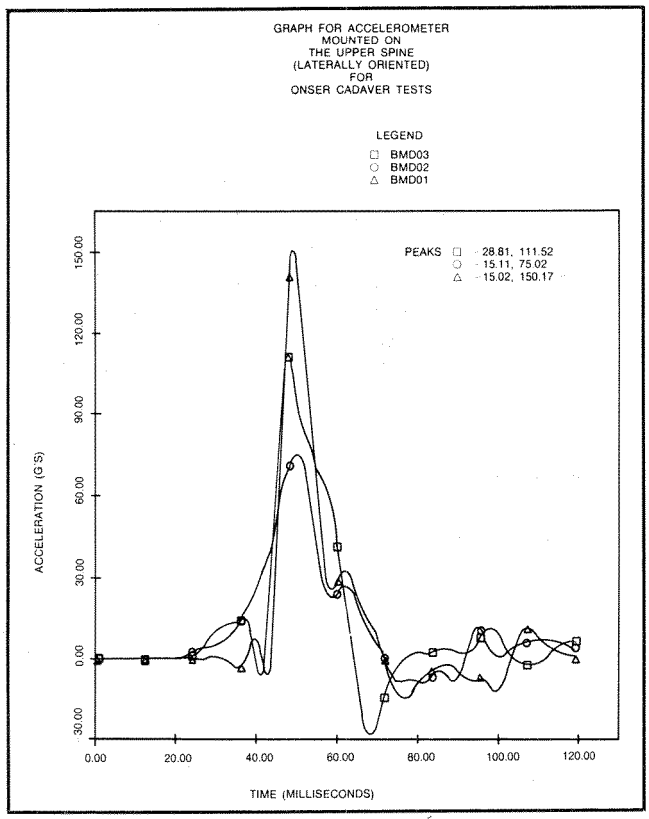


Figure 15.

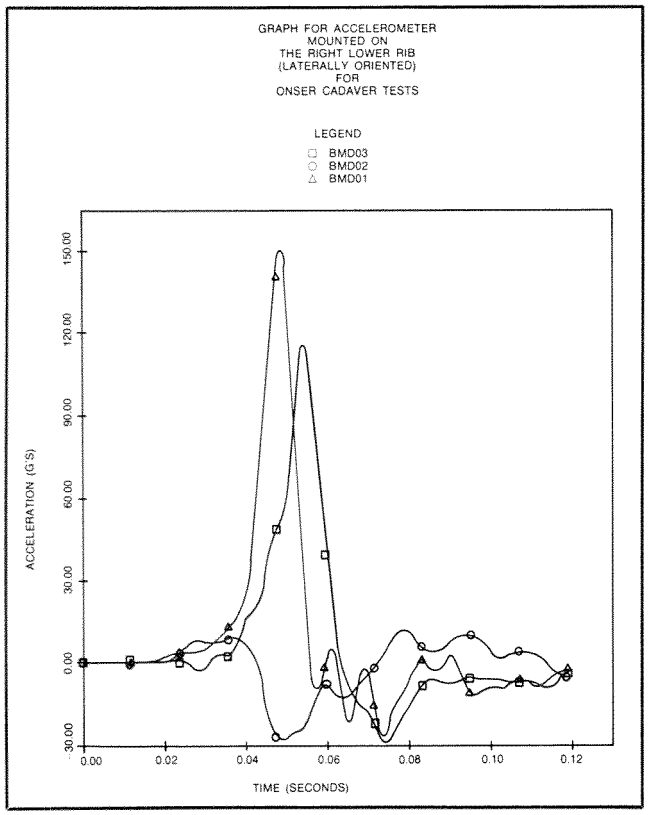


Figure 14.

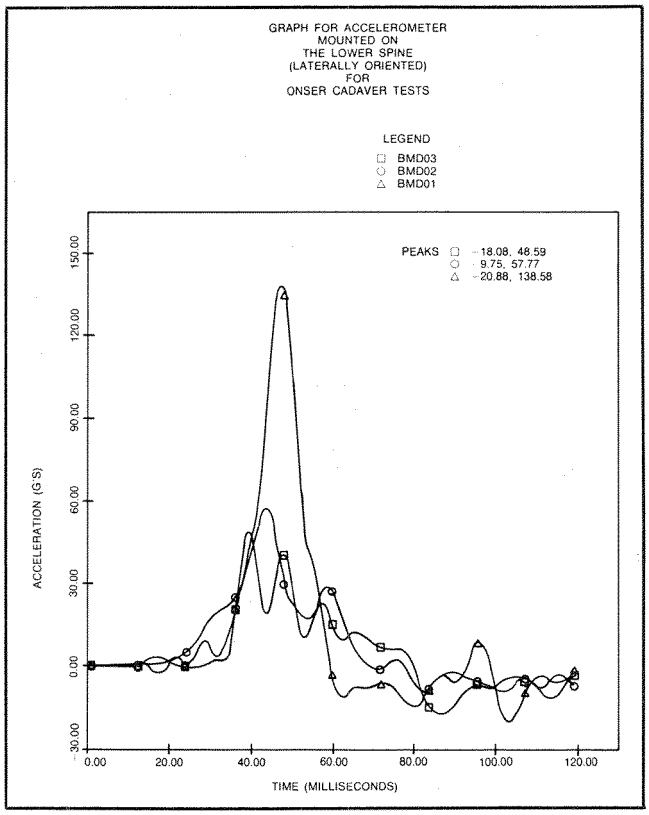


Figure 16.

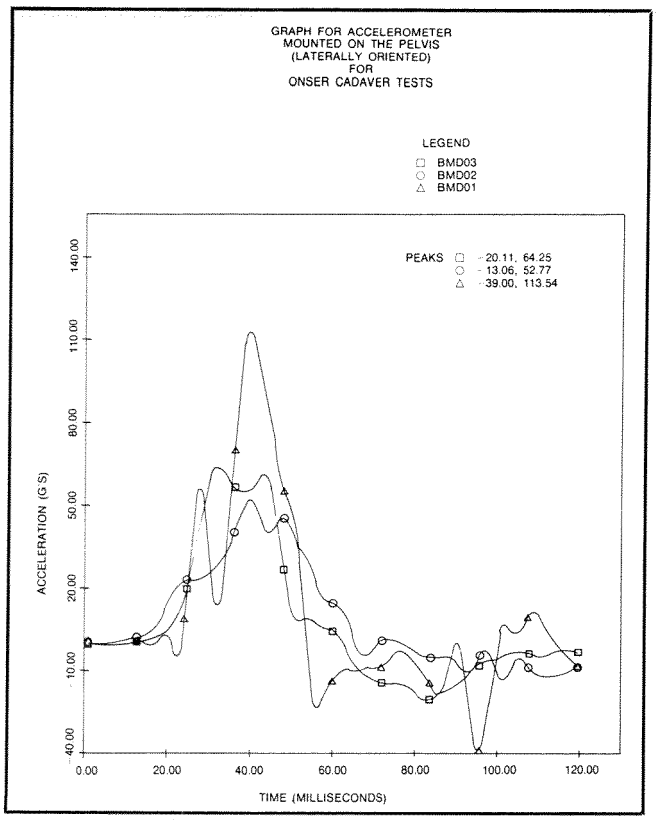


Figure 17.

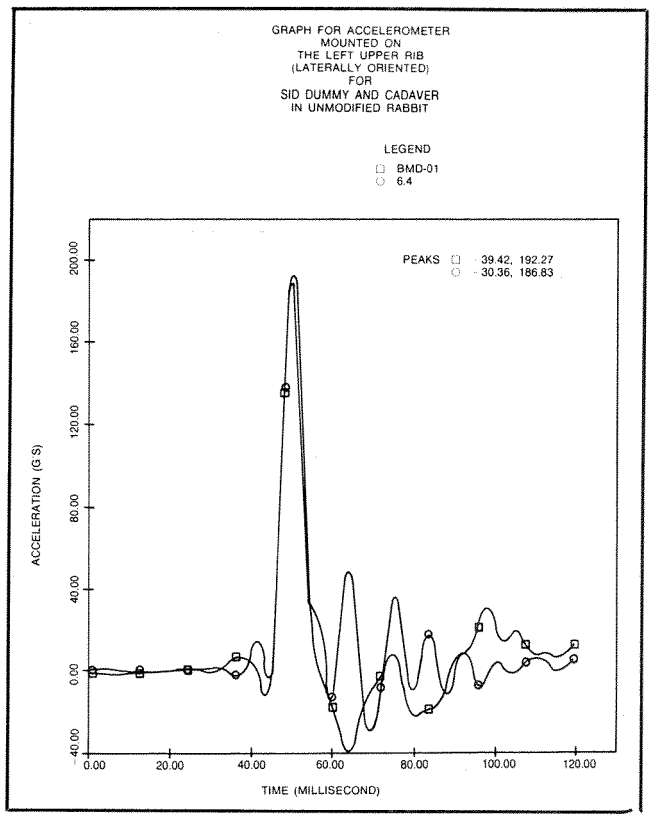


Figure 18.

forces on the cadavers and thereby mitigating the forces' injury potential.

In summary, the modified Rabbit generally lowered the peak accelerometer responses compared to those in the unmodified Rabbit.

COMPARISON OF THE RESPONSES OF THE HSRI DUMMY AND A CADAVER IN UNMODIFIED RABBITS

Reference is made to the set of Figures 18 through 24 which compare the response curves of the HSRI dummy and a cadaver. The anthropometric measurements of the cadaver are those for ONSER Test BMD 01 listed in Table 2.

Table 4. Peak values of G of the laterally oriented accelerometers.

	ONSER test numbers		
Location	BMD 01	BMD 02	BMD 03
Pelvis (center)	114	53	64
Spine (lower)	139	58	49
Spine (upper)	150	75	112
Rib (left-up)	193	98	137
Rib (left-low)	164	87	106
Rib (right-up)	145	70	80
Rib (right-low)	115	bad data	151

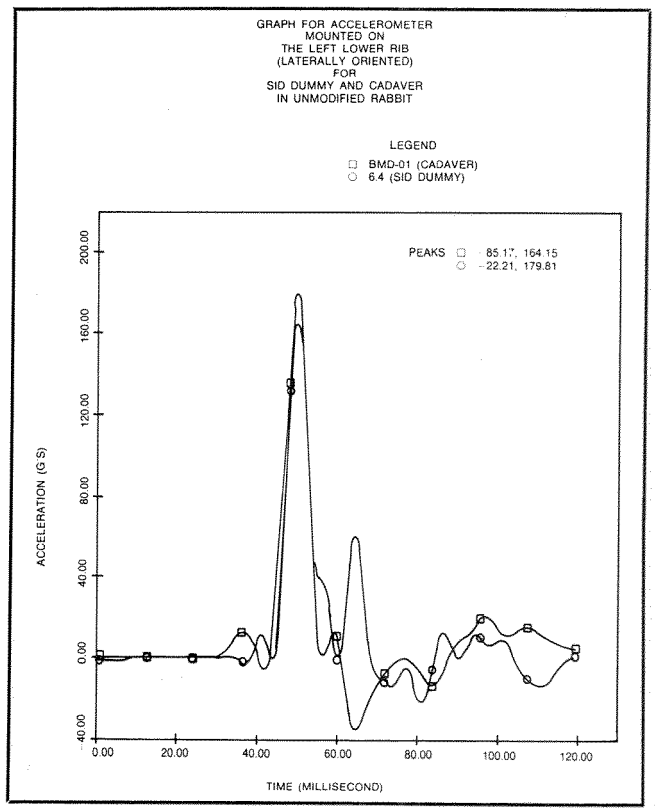


Figure 19.

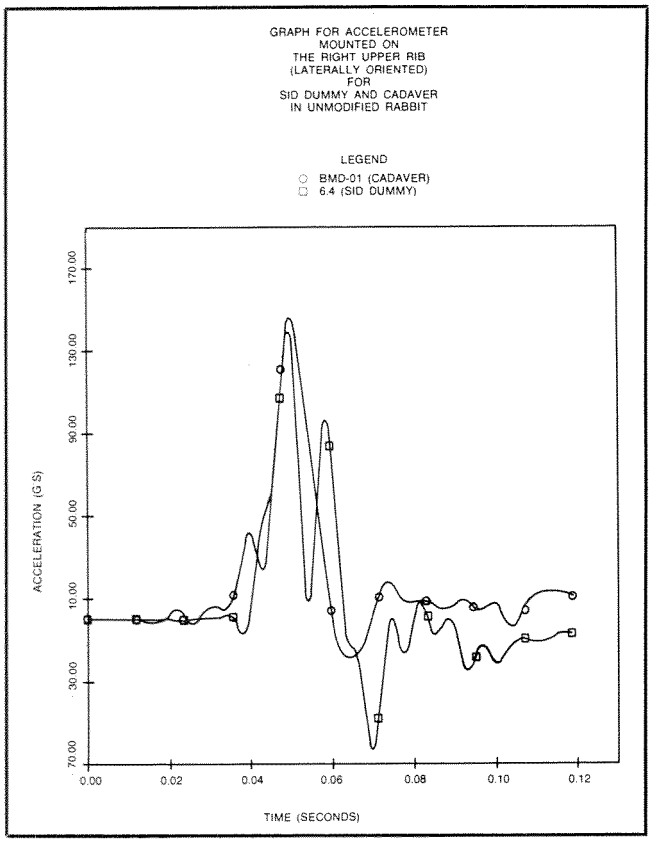


Figure 20.

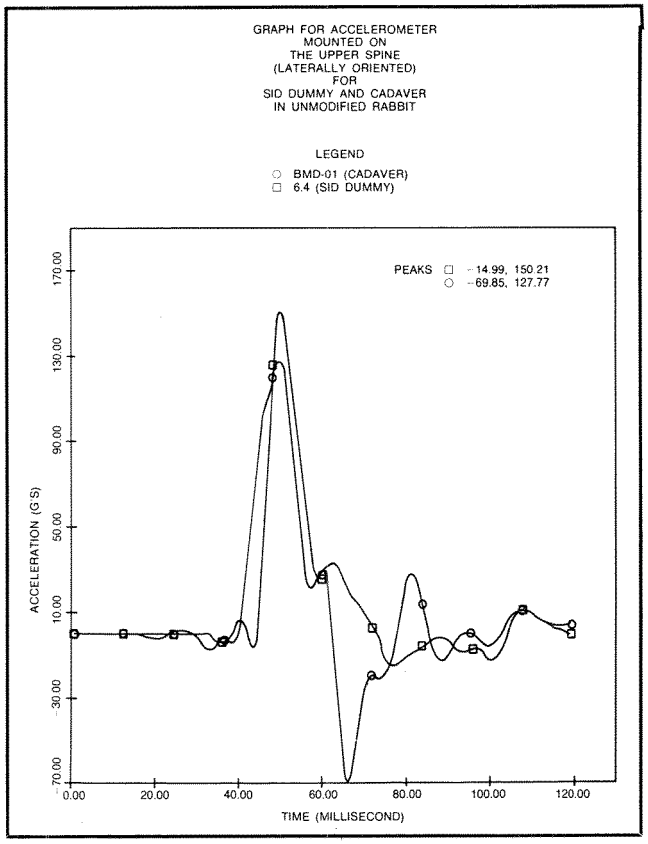


Figure 22.

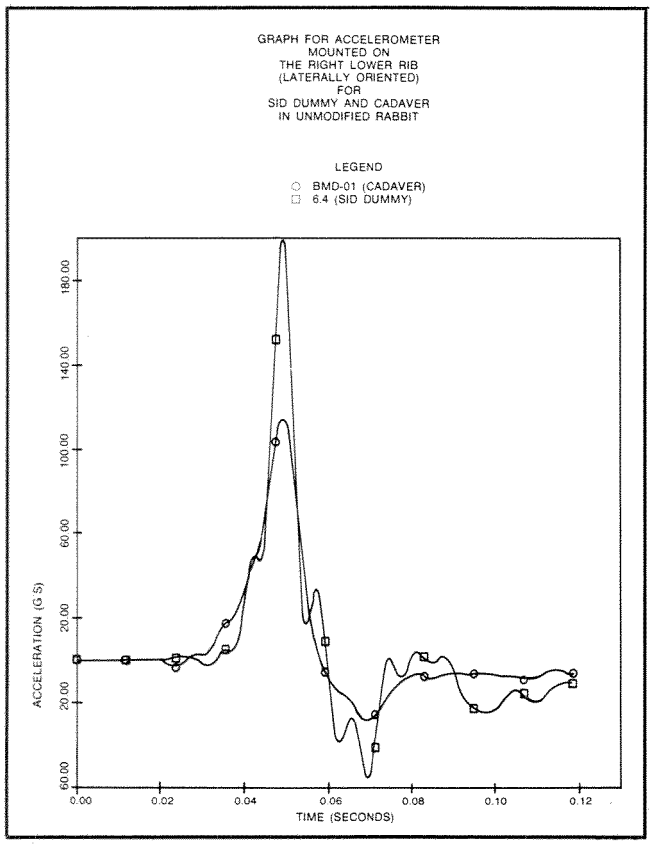


Figure 21.

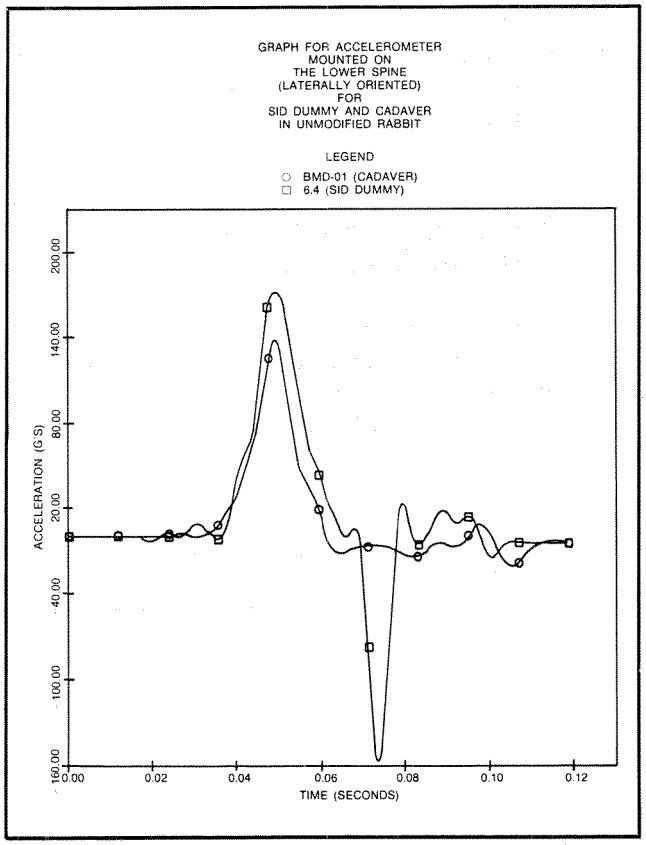


Figure 23.

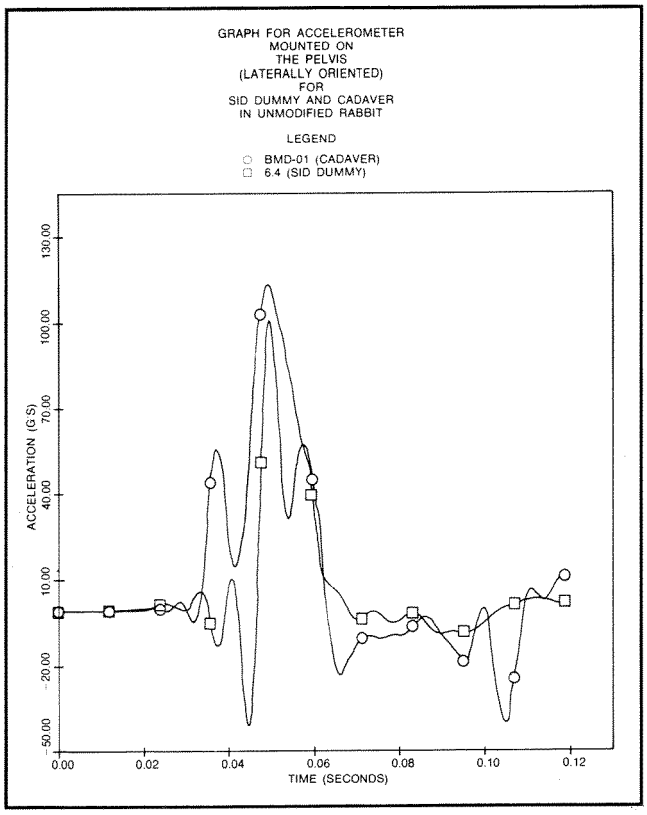


Figure 24.

A review of the above set of figures establishes that the two responses whose curves are in closest agreement are Figures 18 and 19. These are respectively the responses of the left upper rib and the left lower rib. Since both test subjects, the cadaver and dummy, were impacted on the left side by the door, the responses are "driven" by the impacting door. Since each subject was exposed nominally to the same impact environment, it is reasonable that these responses are in close agreement.

The remaining five pairs of response curves of this set are for points which are removed from the region of impact. The degree to which these pairs of curves agree reflects the mechanical equivalence of the dummy to the cadaver. The upper spine and lower spine (Figures 22 and 23 respectively) are the next curves which show the best agreement. However, the curve for the HSRI dummy in Figures 22 and 23 attains a significant negative peak. Since this feature is reflected for both the upper and lower spine, the feature cannot be viewed as an artifact. The HSRI dummy undergoes a ringing not reflected in the cadaver's response.

Of the remaining set of responses, those of the right upper rib in Figure 20 are the next best in agreement in terms of both the duration of the initial pulses and their magnitude. The worst are the pair of curves in Figure 21 for the right lower rib. The duration of the initial pulses is good, but the HSRI dummy has a peak response approximately twice that of the cadaver.

Finally the pelvis response (Figure 24) shows a lot of ringing in both subjects but with good agreement in the peaks. This location for an accelerometer may not be wise because of the ringing.

It should be noted that experience demonstrates that there is a wide scatter in accelerometer responses from one cadaver to the next even for the same impact environment. So far there is only data for one cadaver in an unmodified Rabbit. Another test, however, is to be conducted.

In the next section, the performance for the HSRI dummy is compared against two cadaver tests in the modified Rabbit impact environment.

COMPARISON OF THE RESPONSES OF THE HSRI DUMMY AND TWO CADAVERS IN MODIFIED RABBITS

Reference is made to the set of Figures 25 through 31 which compare the response curves of the HSRI dummy and two cadavers. The anthropometric measurements of the cadavers are listed in Table 2 under Tests BMD 02 and BMD 03.

A review of this set of figures fails to show the close agreement between any of the curves comparable to that of Figures 18 and 19 for the HSRI dummy in the unmodified Rabbit. For all accelerometer locations, except

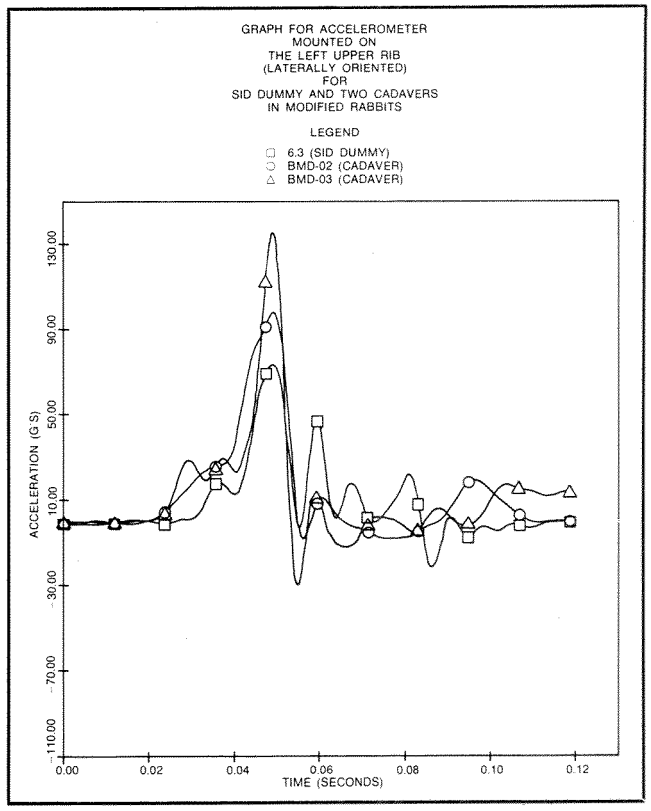


Figure 25.

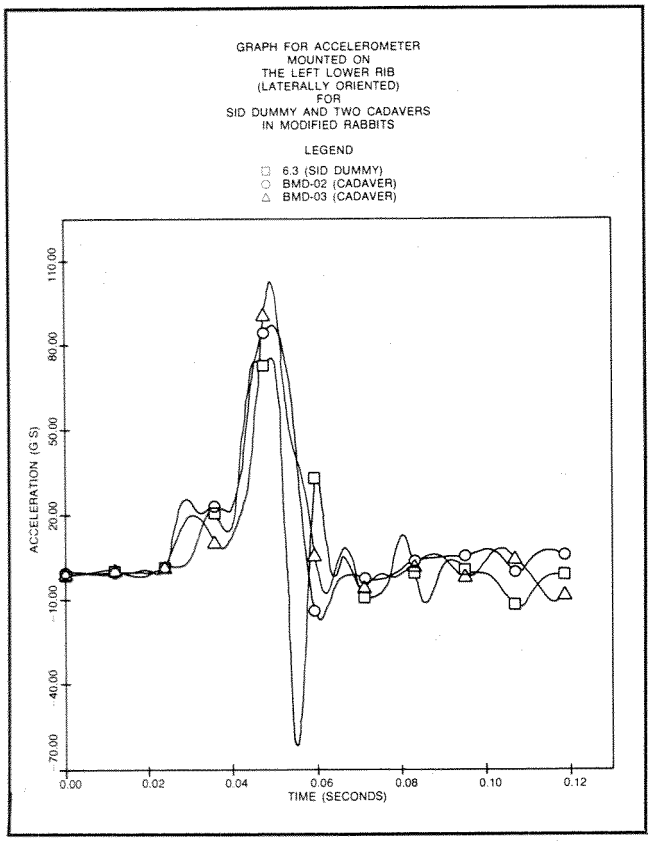


Figure 26.

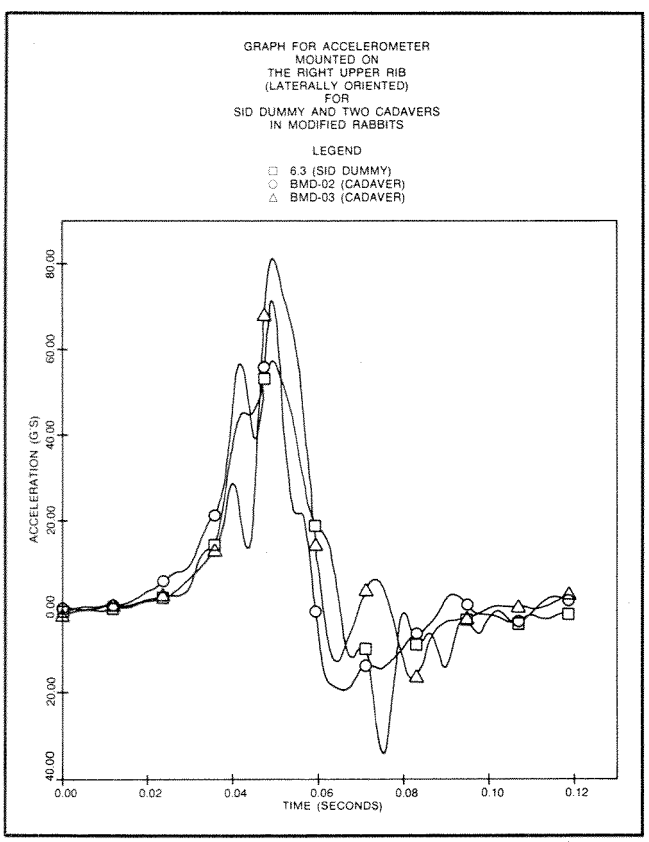


Figure 27.

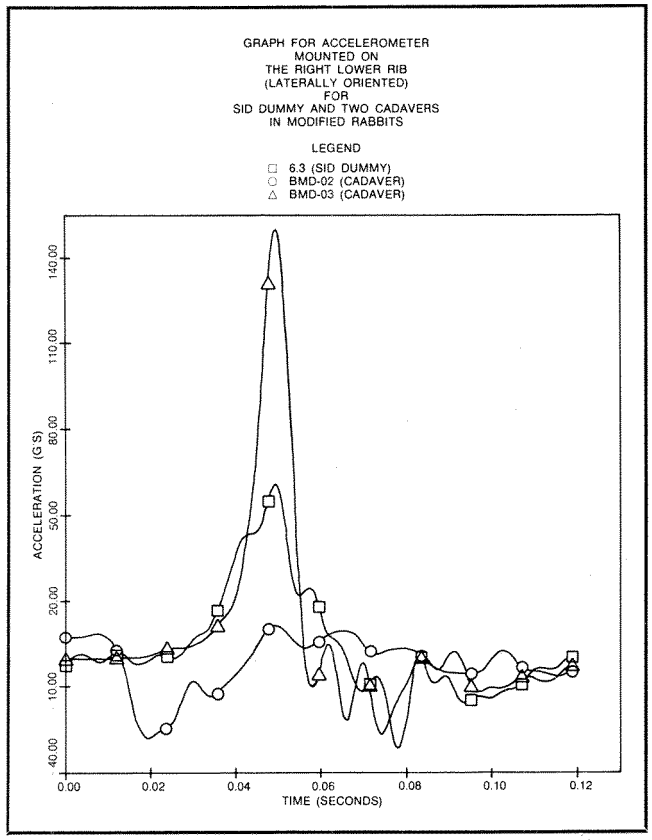


Figure 28.

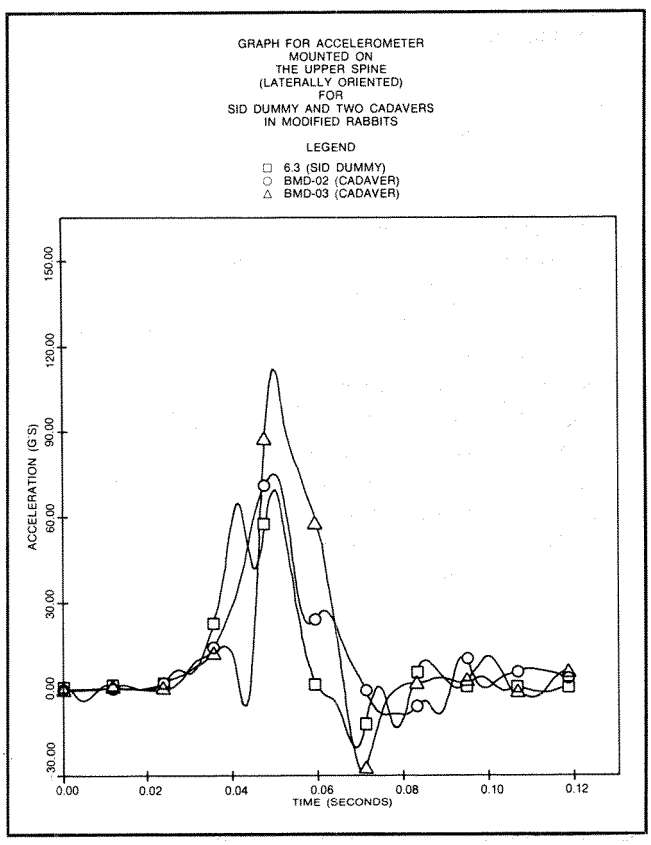


Figure 29.

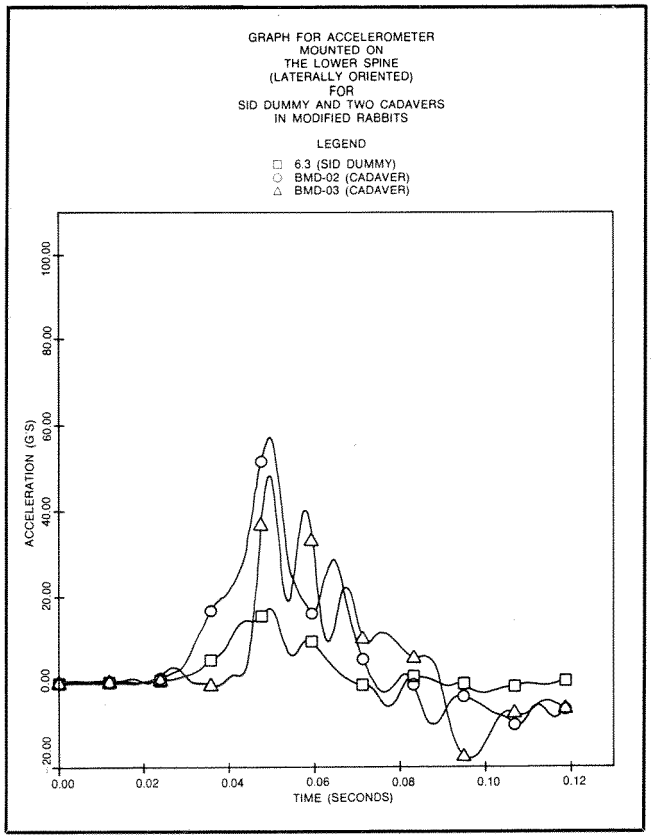


Figure 30.

that of the pelvis, the HSRI dummy had the lowest peak with the cadaver of BMD 03 being the highest. The least variation among the curves are for the left upper and left lower ribs in Figures 25 and 26. Again these are for accelerometers located at the area of direct impact and are "driven" by the impacting surface which for these tests was padded.

The response for the right lower rib for the cadaver of BMD 03 (Figure 28) is much greater than that of the HSRI dummy. The accelerometer for BMD 02 seems to have malfunctioned.

In general, the impact environment of the modified Rabbit caused the accelerometer responses for the three different subjects to have greater variation than that for the unmodified Rabbit.

COMPARISON OF THE RESPONSES OF THE APR DUMMY AND A CADAVER IN AN UNMODIFIED RABBIT

Reference is made to the set of Figures 32 through 36 which compare the response curves of an APR dummy and a cadaver. The anthropometric measurements of the cadaver are listed in Table 2 under ONSER Test BMD 01. This set consists of only five figures instead of the complete set of seven listed in Table 4. The APR dummy had its right lower rib accelerometer oriented in the an-

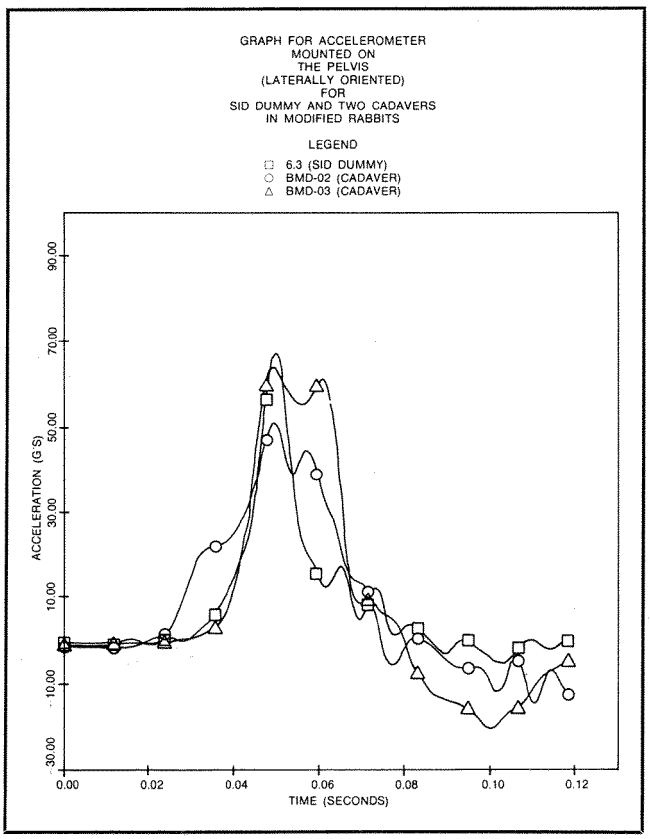


Figure 31.

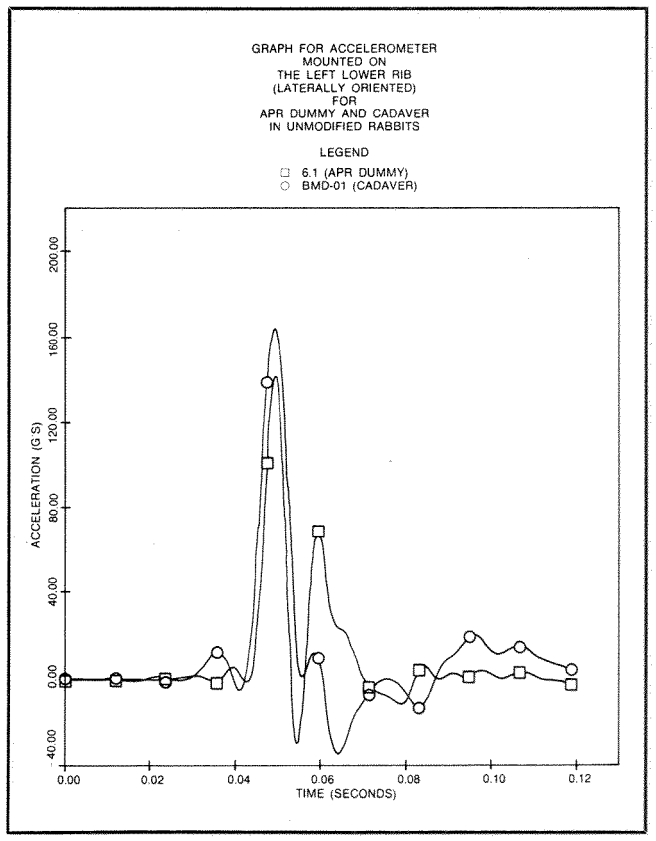


Figure 32.

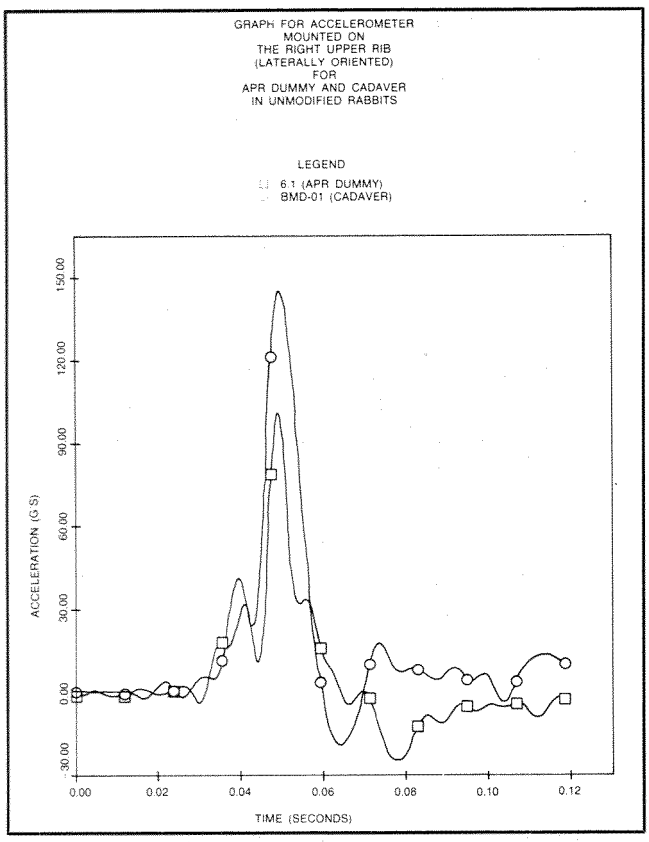


Figure 33.

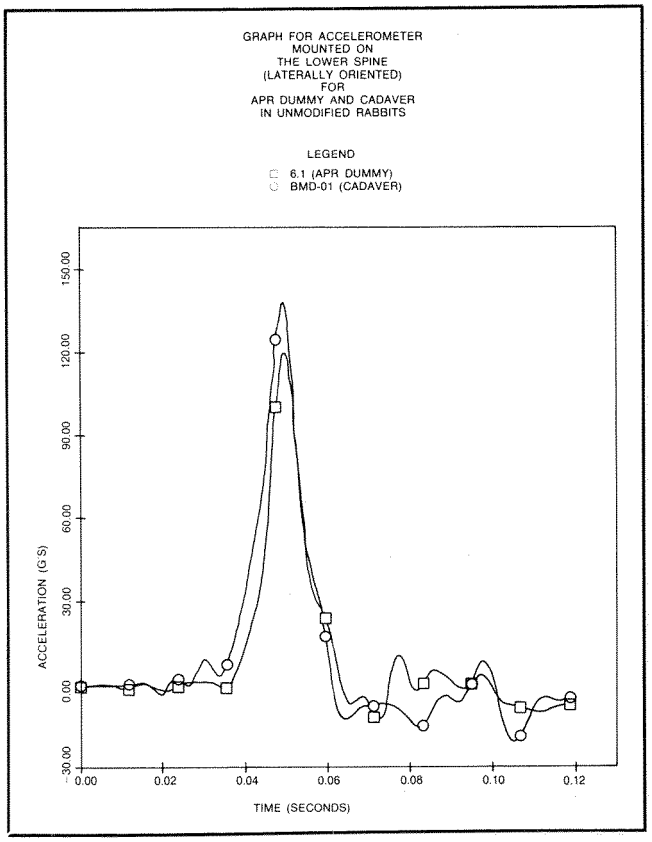


Figure 35.

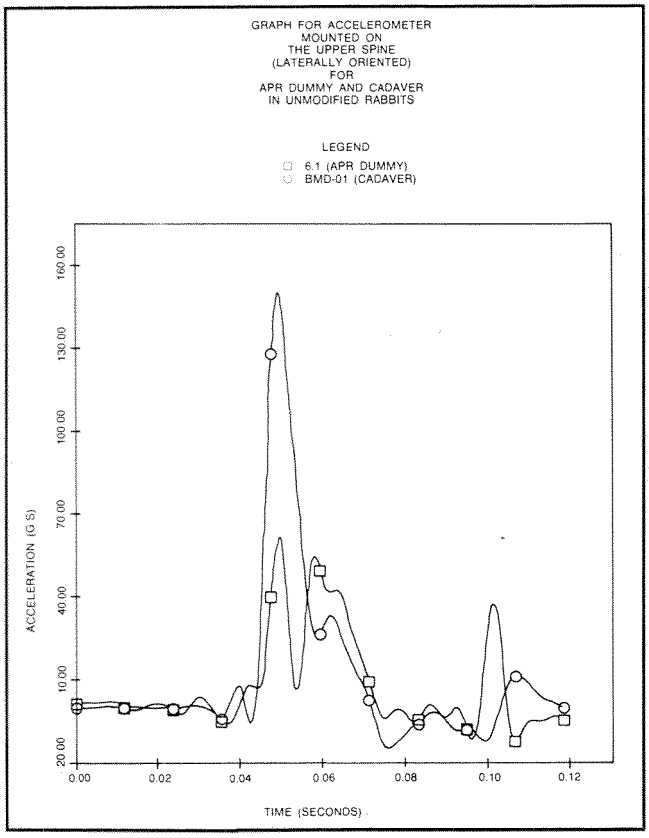


Figure 34.

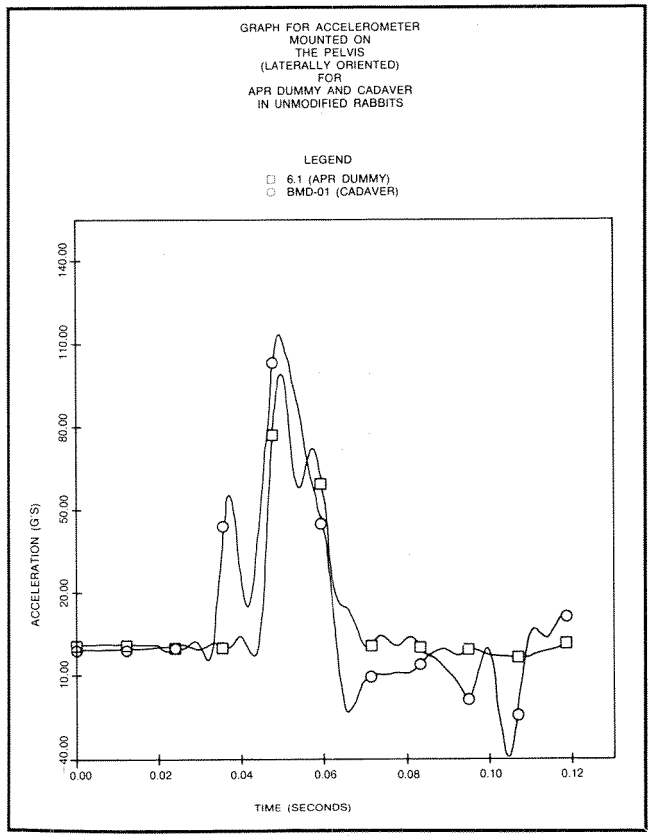


Figure 36.

terior-posterior direction rather than in the lateral direction. In addition, the dummy's left upper rib accelerometer malfunctioned.

A review of this set of figures establishes that the two responses whose curves are in closest agreement are those of the left lower rib and the lower spine (Figures 32 and 35 respectively). Since the two subjects were impacted on the left side, the close agreement of the two curves indicates for the lower spine location mechanical equivalence of the two subjects.

The remaining three pairs of response curves of this set are all for points which are removed from the region of impact. The degree to which these pairs of curves agree, or fail to agree, reflects the mechanical equivalence of the dummy to the particular cadaver for these particular locations. The disagreement is so large between the responses for the upper spine (Figure 34), one has to suspect a malfunction of the dummy's accelerometer.

COMPARISON OF THE RESPONSES OF THE APR DUMMY AND TWO CADAVERS IN MODIFIED RABBITS

Reference is made to the set of Figures 37 through 42 which compare the response curves of an APR dummy and two cadavers. The anthropometric measurements of the cadavers are listed in Table 2 under ONSER Tests

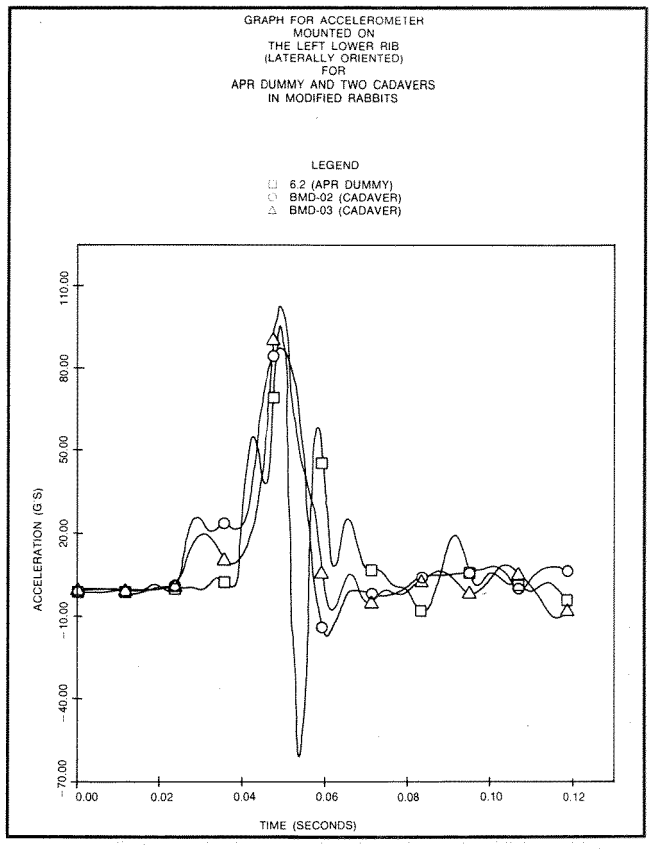


Figure 38.

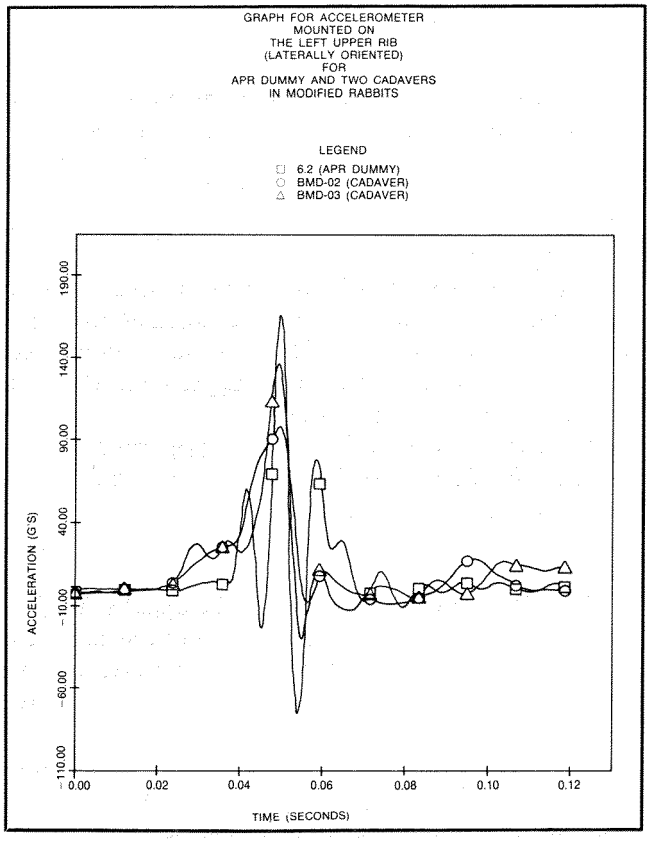


Figure 37.

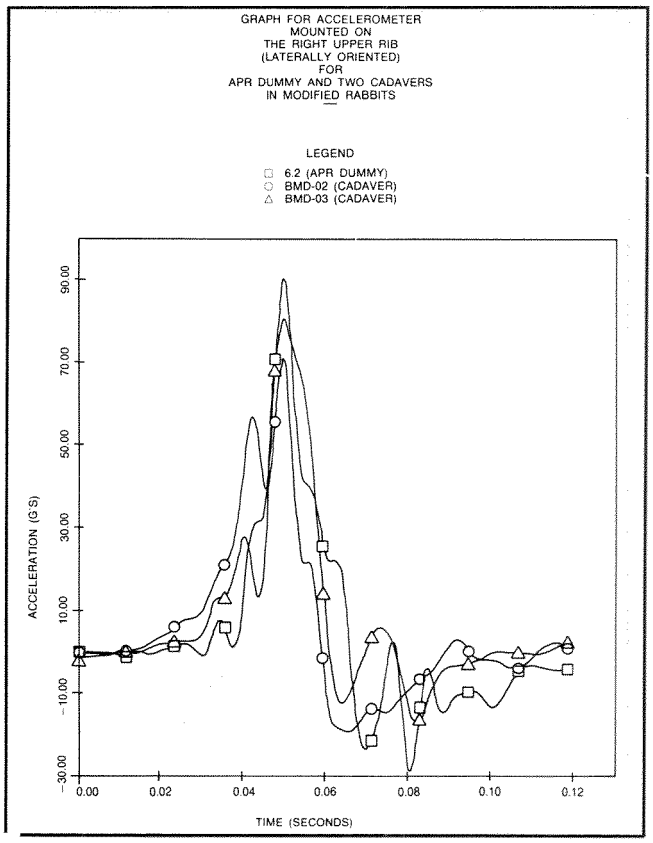


Figure 39.

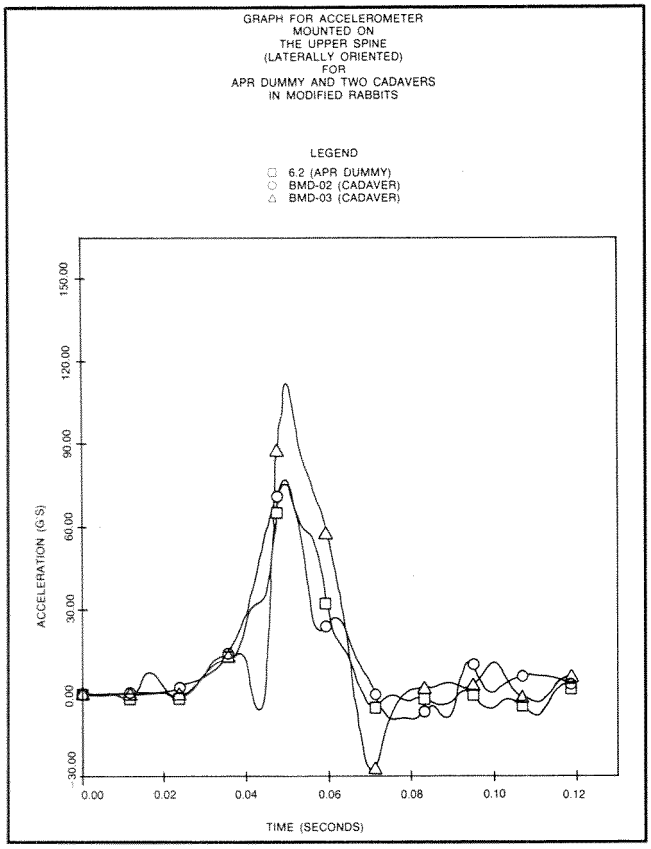


Figure 40.

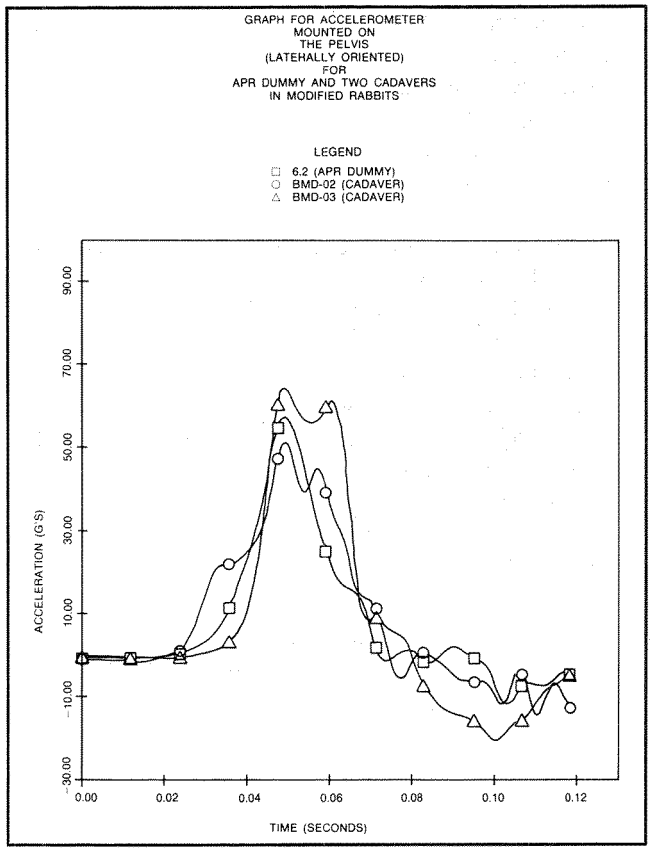


Figure 42.

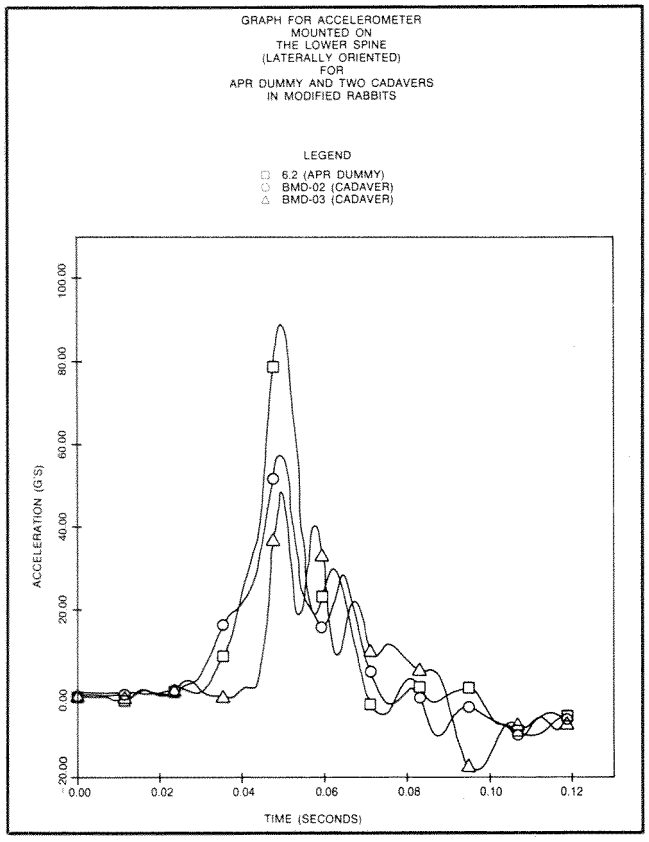


Figure 41.

BMD 02 and BMD 03. As noted in the previous section, the APR dummy had its right lower rib accelerometer oriented in the anterior-posterior direction rather than in the lateral direction. Thus, this set of responses consists of only six figures instead of the complete set of seven listed in Table 4.

A review of this set of figures fails to show close agreement between any of the curves comparable to that of Figures 32 and 35 for the APR dummy in the unmodified Rabbit. The responses of the right upper rib in Figure 39 are perhaps the closest in agreement.

In Figures 37 and 38 for the left upper rib and lower rib the APR dummy exhibits more ringing than the cadavers. Such ringing is not shown in Figures 32 and 33 for the same accelerometers for the APR dummy in an unmodified Rabbit.

The APR dummy's response for the upper spine (Figure 40) is in close agreement with that of the cadaver of Test BMD 02, but the peak of the dummy's response for the lower spine (Figure 41) far exceeds that for the two cadavers.

A significant feature between the dummy and cadaver responses for the pelvis is that the two cadavers attained plateaus for a duration of 10 or 20 milliseconds, whereas the dummy's response peaked and then declined.

CONCLUSIONS

Analysis of barrier-to-car side impact tests conducted with dummies and cadavers allows us to conclude the following:

1) Reduced intrusion at the location of the pelvis seems to decrease pelvic injury severity.

2) Crush reproducibility is very good for the modified Rabbit.

3) The modified Rabbit reduced overall injury severity compared to the unmodified Rabbit.

4) The modified Rabbit in general reduced the maximum responses of the laterally oriented accelerometers.

5) The modified Rabbit had less intrusion at all points measured compared to the unmodified Rabbit.

REFERENCES

1. Melvin, J. W., et al., "Experimental Application of Advanced Thoracic Instrumentation Techniques to Anthropometric Test Devices", Seventh International Technical Conference on Experimental Safety Vehicles, June, 1979.
2. Fayon, A., et al., "Development and Performance of the APR Dummy (APROD)", Eighth International Conference on Experimental Safety Vehicles, October, 1980.
3. Davis, Sol and Ragland, Carl, "Development of a Deformable Side Impact Moving Barrier", Eighth International Technical Conference on Experimental Safety Vehicles, October, 1980.
4. "The Abbreviated Injury Scale—1980 Revision", published by the American Association for Automotive Medicine, Morton Grove, Illinois 60053.
5. Cesari, D., Ramet, M., "Biomechanical Study of Side Impact Accidents", Fifth International Conference on Experimental Safety Vehicles, 1974.
6. Eppinger, R. H., et al., "Development of a Promising Universal Thoracic Trauma Prediction Methodology", Twenty-Second Stapp Car Crash Conference, October, 1978.

Violence of Fatal Car-To-Car Side Collisions and Vulnerability of Population at Risk: A Challenge of Real-World Accidents

F. HARTEMANN, J. Y. FORET-BRUNO, C. HENRY, C. THOMAS and C. TARRIÈRE
Laboratoire de Physiologie et de Biomécanique, Association Peugeot S.A./Renault, Rueil, France

C. GOT and A. PATEL
IRO—IRBA, Hôpital R. Poincaré, Garches, France

Over the past ten years, the emphasis placed on protection in frontal impacts has enabled improvement of safety levels in this accident configuration.

In this respect, safety belts have played a decisive role. The seat belt is recognized as dividing the risks in half. Further progress can still be achieved through improvements in the coupling of car passengers and through architectural features that limit the risks of passenger-compartment intrusion.

For side impacts, the prospects are less open. The following description of fatal side-impact collisions yields insight into the level of the requirements that must be satisfied in order to protect a significant proportion of victims. It enables us to measure the challenge represented by protection against the risk of the occurrence of death in this kind of accident.

FATAL ACCIDENTS—TYPES OF IMPACT

Analysis of accidents that caused the deaths of 1,400 car occupants in April, May and June 1980 on the French highway system overall shows the following distribution of types of collisions for 369 individuals who were killed in side impacts:

—30% of these casualties were involved in a collision with another private car.
—45% hit against a fixed, rigid obstacle (tree, utility pole, etc.).
—17% were victims of collisions against heavy vehicle (trucks, road tractors, etc.).
—5% of the deaths ensued from impacts against unclassifiable objects.

The casualties in side-impact collisions between private cars accounted for only 9% of the total number of deaths occurring to individuals who were passengers in private cars in all types of impacts (Table 1).

The proportion of victims involved in side-impact collisions against rigid objects may possibly be higher in France than in other countries with high automobile traffic levels, because of the many trees along French highways. This point is worth investigating. However, it is a known fact that in the United States, for example, over half the individuals killed in all types of automobile

Table 1. Distribution (%) of the 1,400 fatal casualties in private car accidents for the months of April, May, and June 1980. France.

Principle damage area	Obstacles				
	Car	Truck bus	Rigid object	Other	Total
Front	17.3	12.3	17.8	—	47.4
Side	9.4	7.8	13.2	—	30.4
Rear	0.3	1.0	0.2	—	1.5
Rollover	—	—	—	13.5	13.5
Unclassifiable	1.1	0.4	3.1	2.6	7.2
Total	28.1	21.5	34.3	16.1	100

accidents were the victims of impacts not involving other vehicles.

The first finding is therefore as follows: In a major proportion of cases, the victims of fatal accidents involving side-impact collisions were not the victims of collisions involving other private cars.

Therefore, the countermeasures designed to meet the requirements of a test simulating this type of collision will be but slightly effective in impacts against rigid objects. Actually, these countermeasures will draw a major share of their effect from the side structure resistance to intrusion. In collisions against rigid objects, intrusion is not a severity factor for car occupants, the only thing that matters is the shock-absorbent properties of the inner panel that is struck by the passenger at a speed equal to the speed of his car at the instant of occurrence of impact.

MOTORISTS' AGES AND THE CONFIGURATION OF SIDE-IMPACT COLLISIONS

Another significant aspect of side-impact collisions concerns the relationship between the ages of the motorists involved and the circumstances surrounding the collisions; this is a relationship that has consequences for the statistical distribution of the tolerance of the population at risk exposed to collisions closely similar to the impact that could be simulated by the standard established test. The younger motorists are over-represented in the impacts against rigid objects, whereas the older ones are over-represented in car-to-car collisions (Table 2).

This unequal distribution of obstacles as compared with the victims' ages results from the comparison between motorists' behaviors. Almost exclusively, the youngest drivers sustained the impacts against rigid objects after their cars had veered out of line: these were drivers' errors occurring while speeding. The impacts that occurred under these circumstances were extremely violent in general. One indicator: in 20% of the cases, the cars were sheared in half.

Conversely, the fatal casualties aged over 55 have a high representation among the victims of the car-to-car collisions.

The second finding is as follows: A large proportion of the population that could be concerned by effective protective countermeasures in car-to-car impacts has low tolerances. This observation is backed up by the following distinction: depending on whether the collisions did or did not occur at highway intersections, the age categories are represented in widely differing proportions. Because of lesser adaptation to complex situations, the older motorists were considerably over-represented in crossroads collisions, whereas the majority of the fatalities among the youngest drivers occurred in collisions that took place elsewhere than at crossroads. In general, these collisions resulted from the cars' veering out of line into across-highway positions as the result of loss of control at high speed, and the impacts occurred either against a vehicle coming in the opposite direction or against a car following in the same direction. In these circumstances, the relative velocity of the cars involved not infrequently exceeded 90 km/h (Table 3).

Table 2. Fatal casualties in side-impact collisions. Ages X obstacles.

Obstacles	Age of occupants			
	≤35 Years	36 to 55	>55 Years	Total
Vehicle	61 (35%)	36 (74%)	64 (88%)	161 (54%)
Rigid object	115 (65%)	13 (26%)	9 (12%)	137 (46%)
Total	176 (100%)	49 (100%)	73 (100%)	298 (100%)

Table 3. Fatal casualties in car-to-car collisions. Ages X circumstances.

Place of collision	Ages of individuals killed ≤35 years	35-55 years	>55 years	Total
Crossroads	26	24	56	106
Elsewhere than cross-roads	35	12	8	55
Total	61	36	64	161

AGES OF FATAL CASUALTIES AND VIOLENCE OF IMPACTS

The distribution of fifty casualties who were killed while occupying the impact side in car-to-car collisions, whose ages were plotted in correlation with the relative velocities of their cars during occurrence of impacts with striking cars, therefore largely results from the interactions stated above between ages and the circumstances surrounding the accidents (Figure 1). These fifty casualties constitute a sub-sample of the population presented above (Table 3). Their accidents were selected on the basis of the criterion of the quality of the documentation contained in the relevant police reports (in particular, on the basis of photographs). This sub-sample, *a priori*, is not affected by any biased approach. It can be considered as representative of fatal casualties occurring among individuals seated on the impact side who directly sustained the effects of panel intrusion. The impact conditions are therefore the same as those that would be created by a test procedure involving the staging of an impact against a car body, at the level of the dummy, by another car or by an equivalent mass simulating the shape and rigidity of the front part of a car.

The individuals who were killed under these conditions were aged sixty or over in 40% of the cases. If we consider the casualties who sustained impact velocities equal to or less than 55 km/h from the striking car, 80% of them were aged sixty or over. If we take a speed of 65 km/h as the upper limit, we again include a population of casualties who are well along in years (Table 4.).

EFFECTIVENESS OF COUNTERMEASURES

Rationale

What is the proportion of fatalities that might be prevented by the countermeasures that can be envisaged today? To answer this question, *it is necessary to know the critical admissible tolerances to impact of the population at risk*. For lack of biomechanical data that would be directly usable in this present approach, let us assume that curve A marks non-fatal impact conditions (Figure 2). The hypothesis of a threshold roughly deduced in this way is exposed to two possibilities of error, as follows:

1. The size of the sample does not authorize us to exclude the eventuality of the occurrence of fatal impacts at a lesser degree of violence, hence the risk of underestimating tolerance limits.

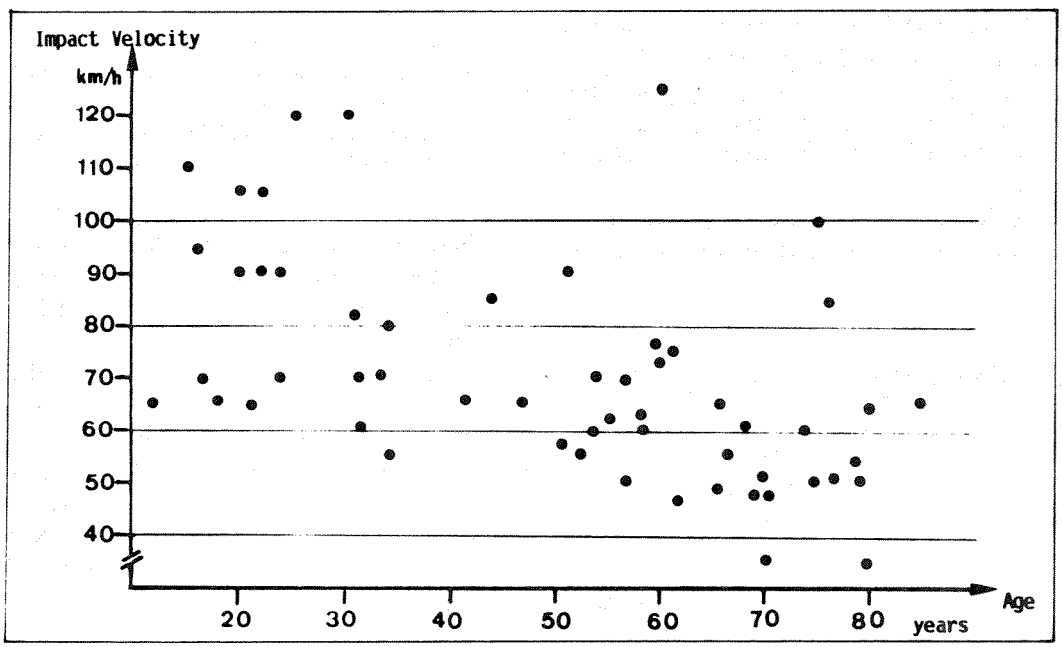


Figure 1. Car-to-car side collisions. Age of 50 nearside killed occupants versus impact velocity.

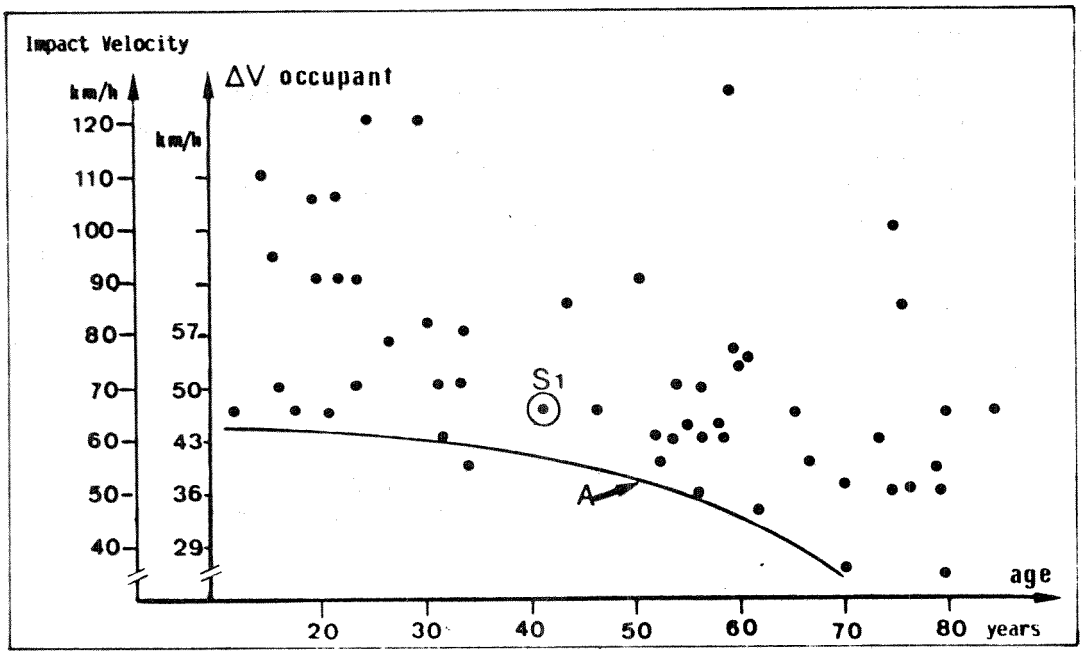


Figure 2. 50 nearside occupants killed in car-to-car collisions.

2. The assumption that death is sure to occur above this limit is equivalent to assuming a zero probability of survival in accidents that are more violent than those for which the curve plots the limits, along relative velocity, at the various ages, hence the risk of underestimation.

The data file on side impacts investigated in the PEUGEOT-RENAULT survey can be used as a means of control. These data include 142 car occupants seated on the impact side and at the level of the panel that was struck in car-to-car collision, for all degrees of injury severity (Figure 3). No fatal injury occurred below the curve; in addition, the probability of survival is far from inconsiderable at any age, in the occurrence of impacts of a violence located above the curve.

In view of our inability to evaluate the performances that might be achieved by a given countermeasure, *it is possible to simplify by considering only the ΔV that would result for the car passenger.* Whence the possibility of stating several hypotheses for the reducing of this passenger ΔV and of deducing the proportions of fatalities that this reduction would make it possible to prevent. This simplification disregards two factors that intervene in the link between passenger ΔV and injury severity, as follows:

1. The local rigidity of the elements that enter into contact with the sensitive body areas, which is a source of variation in risk, at constant ΔV.
2. The "localization" of the ΔV, this meaning that the passenger ΔV is not the same at the pelvic level as at the thorax level. The average ΔV does not take this difference into account.

The ΔV values corresponding to the impact velocity values are the averages of the thorax ΔV and of the pelvic ΔV plotted from the data gathered from cars analyzed in the course of the PEUGEOT-RENAULT investigation (Figure 2).

Curve A therefore plots the limits of the ΔV that are tolerable without involving the death risk, at the various ages. Thus the individual identified as S1 in Figure 2 sustained a collision during which his car was struck by another car whose impact velocity was estimated at 65 km/h. At this impact velocity, the average passenger ΔV is 46 km/h. The countermeasure that would make it possible to prevent the death of this individual should consist of creating impact conditions whose severity would not exceed that of the conditions sustained by a

Table 4. Ages of side-impact collision casualties according to impact velocities of the striking cars (upper limit).

Relative velocity	Ages of individuals killed			Total
	<40 years	40 to 60 years	60 years and over	
≤55 km/h	0	14%	86%	100%
≤65 km/h	13%	33%	54%	100%
≤75 km/h	24%	32%	44%	100%
≤85 km/h	27%	31%	42%	100%

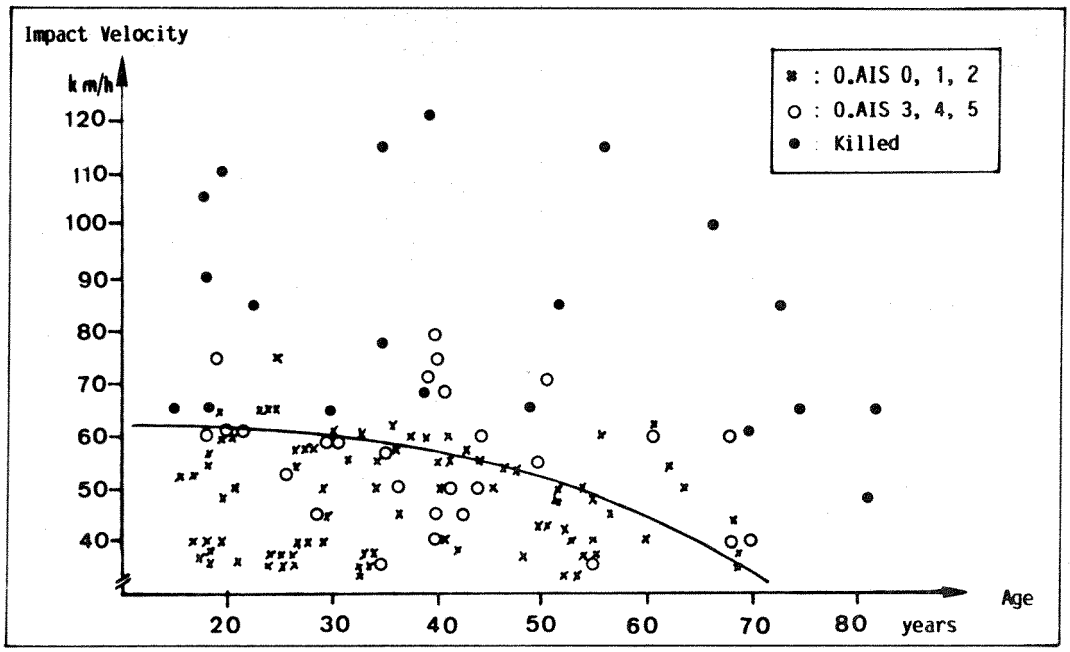


Figure 3. Nearside occupants. Car-to-car side collisions.

passenger undergoing a 40 km/h ΔV in present-day automobiles.

RESULTS

Several hypotheses can be considered for reducing the passenger ΔV. At present writing, the most realistic one is to use as a reference an impact at a 50 km/h velocity by the striking car (car struck while standing still), and to assume that it is possible to implement solutions that would create, for the passenger, what might be called a ΔV equal to 25 km/h, i.e., solutions that reduce the stresses to which the passenger is subjected to a level equivalent to that of the ones he sustains, in present-day cars, for an average ΔV of 25 km/h at the pelvis and thorax. Such a result is not readily accessible. In the cars currently on the road, we note passenger ΔVs of from 30 to 40 km/h for car ΔVs of 25 km/h resulting from impacts occurring at velocities of 50 km/h on the part of the striking car (Figures 4 and 5).

We assumed that at impact velocities of 55 km/h, improvements would still be appreciable, and that the equivalent passenger ΔV would be 35 km/h. Finally, we estimated that at velocities of 60 km/h and over, protection would not be improved.

On the basis of this hypothesis, six out of fifty deaths could probably have been prevented (Figure 6). This would be the case, for example, of the individual identified as S2 in Figure 6, who sustained a 55 km/h impact. We estimated his ΔV as at 40 km/h. If this is reduced to a ΔV of 35 km/h (ΔV scale), it falls just below the critical admissible limit for his age (53 years).

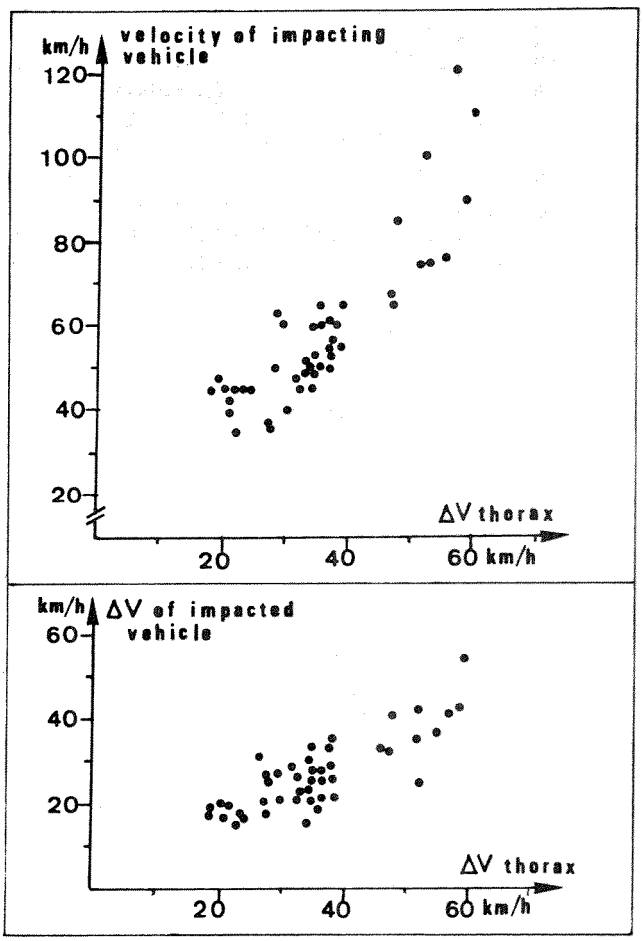


Figure 4. ΔV occupant at thorax level as a function of impact velocity (above) and ΔV vehicle (below). Nearside occupants in car-to-car side collisions.

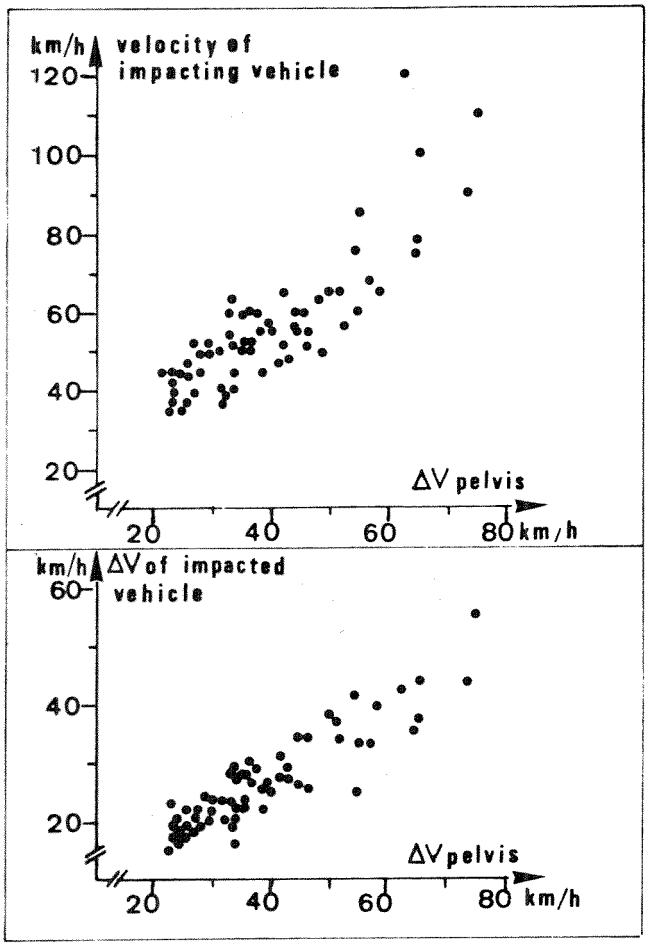


Figure 5. ΔV occupant at pelvis level as a function of impact velocity (above) and ΔV vehicle. Nearside occupants in car-to-car side collisions.

EXTENSION TO ALL TYPES OF SIDE-IMPACT COLLISIONS

What advantages would be yielded by these provisions in side-impact collisions against fixed, rigid objects, against heavy vehicles, against highway tractors, etc.? In view of the levels at which the ΔV (vehicle ΔV) occur in these configurations, we estimate that the number of fatal casualties among individuals seated on the impact side could be reduced by 2 to 4%.

As concerns *the individuals killed who were on the side opposite the impact side*, impact velocities were so high (85 km/h as a median value) that the advantages would be only from 3 to 6%. They would be zero for the casualties seated on the side opposite impact in collisions against rigid objects or against heavy vehicles.

The same evaluations are applicable to the back-seat passengers. The results would be of the same values as for the front-seat passengers.

The total number of fatal casualties that might be prevented by the implementation of the above-described countermeasure amounts to a reduction of 5 to 7% (Table 5.).

COMMENTS

These findings prompt the following comments:

The inclusion in the accidentological data used for fixing test procedure parameters (angle and velocity, in particular) of fatal accidents, most of which circumstances are not those of standard traffic conditions, means assigning to secondary safety a goal that exceeds its field

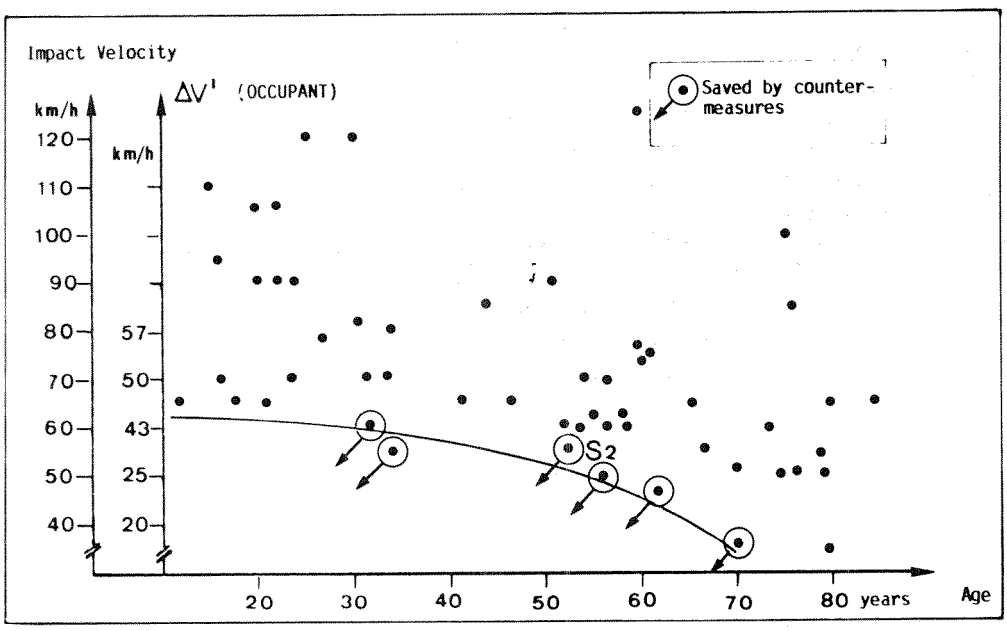


Figure 6. 50 nearside occupants. ΔV lowered by countermeasures.

Table 5. Possibilities for reducing the number of fatal casualties in side-impact collisions.

	Obstacle			Total
	Car	Rigid object	Heavy vehicle	
Number of fatal casualties	109	164	96	369
Effectiveness	12%	2-4%	2-4%	5-7%
Number of fatal casualties avoided	13	3 to 7	2 to 4	18 to 24

of application. The inclusion of fatal casualties (0.AIS 6) in the statistics describing the distribution of the speeds at which grave accidents occur (0.AIS $\geq$ 3 or 0.AIS $\geq$ 4) is hence a "questionable" procedure. Its effect is to increase the average—and the median—of the distribution of impact velocities and ΔV.

As concerns the testing procedure, which should feature a maximum number of conditions similar to those sustained by the victims of accidents inflicting bodily injuries, and in particular from the standpoint of its geometry (angle of impact and localization of interface), this procedure also stands to be distorted by the inclusion of extremely violent accidents that are beyond the range of the countermeasures that can be anticipated for the near future. It is to be hoped that the utilization of the accidentological data gathered from large samples will not disregard this verification.

In the hypothesis that the seat belt was one hundred percent worn by all the passengers in all the seats, the fatal casualties resulting from *frontal impacts* would still account for forty-six percent of the individuals killed in all types of configurations. Analysis of the frontal impact accidents that occurred involving the deaths of 462 individuals—deaths that were not prevented by the seat belt or that probably would not have been prevented had the seat belt been worn—showed us that the survival of twenty percent of these individuals could have been achieved at the cost of countermeasures that consist of improved passenger ride-down via the retention system and of limiting the extent of intrusion. Without further developing this present study, we shall confine ourselves to suggesting the value of research that would be devoted to surveying currently available technologies in the matter of safety countermeasures, to assessing the cost of their industrialization and to strike a cost/advantage balance in all types of impacts. In all likelihood, this method would show that the occurrence of injuries to a large proportion of gravely injured frontal impact victims could be prevented through countermeasures that are less costly than those that would have to be implemented for the protection of the same number of side-impact victims.

Out of one hundred individuals killed in side-impact collisions, seventy are the victims of impacts against rigid objects or against heavy vehicles. For 95 percent of these fatal casualties, no countermeasures can be devised in view of the violence of the impacts. In addition, the bulk of the non-fatal side-impact collisions involve collisions with other private cars.

Such accidentological data justify the assigning of major importance to the matter of reducing the dangerousness of the front parts of cars. The research to be devoted to this matter should also include attention to pedestrian protection.

At a time when the sparing consumption of resources is a prime requirement, it would be paradoxical not to endeavour to optimize countermeasures. They are in interaction with all the accident configurations. Their effectiveness must therefore be judged on the basis of their overall advantages, in all the accident configurations considered as a whole. For this reason, it is not certain that the best way to manage safety consists of devoting separate consideration to protection against frontal impacts, side impacts, rollovers and pedestrian protection.

From this same viewpoint, it is not certain that the crashworthiness rating, which fosters the development of a specific safety involving a type of impact occurring under isolated conditions of the highway environment would produce the most desirable effects in terms of a reduction of the number of victims among highway users.

REFERENCES

1. J. Y. Foret-Bruno, F. Hartemann, C. Thomas, C. Tarriere-B. Loyat, G. Stcherbatcheff, C. Got, A. Patel. "Occupant Velocity Change in Side Impact—Method of Calculation—Application to a Sample of Real-World Crashes—SAE Paper. 80.1308-1980.
2. J. H. Hedlund. "The National Crash Severity Study and its Relationship to ESV Design Criteris". 7th International Technical Conference on E.S.V. Paris 1979.
3. "Program Plan for Coordinated Side Impact Test Procedure Development". N.H.T.S. A and M.V.M.A. of the United States—January 1982.
4. J. Provensal and G. Stcherbatcheff. "Identification of Compatibility Factors in Side Collisions 8th International Technical Conference on E.S.V. Wolfsburg-October 1980.
5. A. Burgett. "Status Program for Improving Side Impact Crash Protection". 8th International Technical Conference on E.S.V. Wolfsburg. October 1980.

Dummy Injury Values Obtained in Side Collision Sled Tests

H. TSUJIMURA, H. ISOBE and K. MAEDA
Nissan Motor Co., Ltd.

ABSTRACT

In order to find an effective measure to improve protection in side collisions, sled tests were conducted to clarify how parameters, such as the collision velocity of the body side with the dummy, the body side intrusion into the compartment, side deformation, collision angle and side padding materials, influence the dummy injury in side collisions. Side impact dummies developed by HSRI were used in this study, we examined its characteristics by dummy drop tests and sled tests.

Of the variables in side collisions, the collision velocity of the dummy is found to have the greatest effect on the dummy injury value. In addition, when the side impact dummy undergoes a lateral impact on the chest, the dummy shows characteristics apparently different from those of the Hybrid-II dummy due to the modification of the chest. However, there are still some problems to be solved in the future including cases where the dummy chest receives an oblique impact.

INTRODUCTION

Research for improved side collision safety is being carried out in many countries, and our company is examining all possible angles, including a car-to-car test procedure, a sled test procedure, subsystem test procedure, and an analytical procedure using a computer.

This paper discusses our basic studies of the dummy characteristics and the effect of individual parameters on the dummy injury values as determined by sled tests.

DEVELOPMENT OF SIDE CRASH SLED TEST METHOD

In the development of a sled test method that simulates collision phenomenon when the body side collides with the occupant in car-to-car side collisions, the following objectives were included:

(1) The main parameters such as the collision velocity of the body side with dummy, intrusion of the body side, deformation of the body side and collision angle, etc. are controllable.
(2) The injury values and G waveforms of specific locations of the dummy's parts are reproducible.
(3) The dummy's behavior in side collisions is reproducible.

Outline of Test Equipment

Figures 1 and 2 show an outline of the test equipment.

Variable Parameters and Their Variable Ranges

Collision velocity of the body side with dummy (dummy collision velocity)—Dummy collision velocity can be varied by changing the collision velocity of the sled (B). In this study the variable range of the dummy collision velocity was from 20 to 30 km/h.

Angle of collision—The angle of collision can be varied by changing the angle at which a cut body (C) faces the sled (B). The range of the angle of collision was between 90° and 45°.

Deformation of the body side—The deformation of the body side can be varied by using the impactor jig (A) with a different surface shape. The deformation of the body side was tested using the impactor shapes shown in Figure 3. (However, all the impactors were provided with padding material.)

Intrusion of the body side into the occupant compartment—The intrusion of the body side into the occupant compartment (ℓ) can be varied by adjusting the length of the impactor jig (A). In this experiment the intrusion was between 100 and 300 mm.

G characteristics of sled—The G characteristics of the sled (B) were made to correspond to the G characteristics of the struck vehicle in a typical car-to-car side crash test.

Comparison of Car-to-Car Side Crash Test with Sled Test

In order to confirm that this sled test method simulates the car-to-car side crash test, the sled test data were compared with the injury values, G waveforms and be-

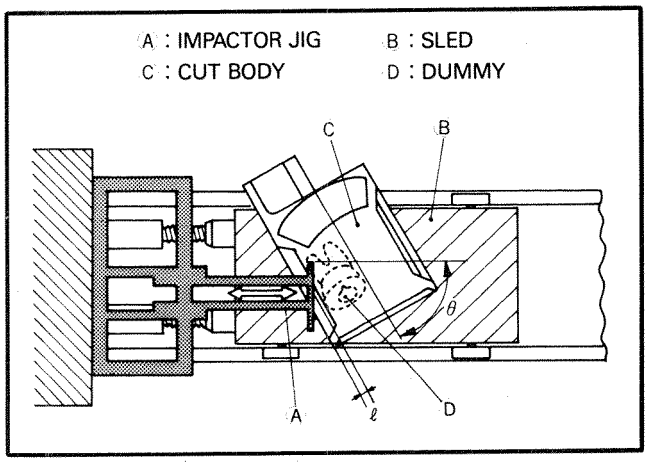
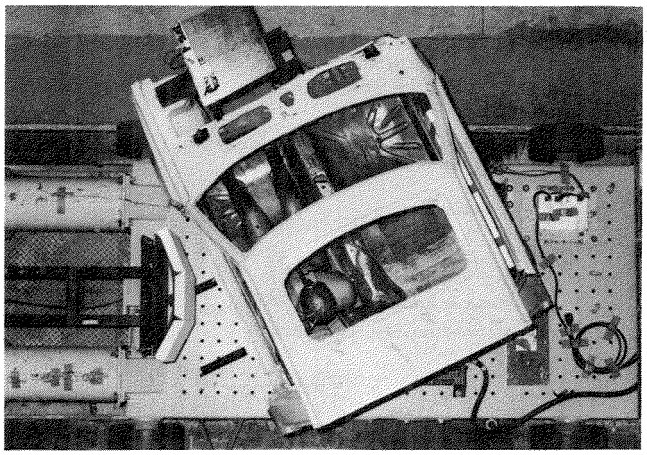


Figure 1. Outline of test equipment.



(COLLISION ANGLE θ=60°)

Figure 2. Photograph of test equipment.

havior of the dummy obtained in the car-to-car side crash tests with collision angles of 90° and 60°.

Figures. 4 and 5 compare the G waveforms at the chest and pelvis.

In the car-to-car side crash tests, the deformation and stiffness of the body side changes continually during collision. On the other hand, because in the sled test the shape and stiffness of the impactor is constant during collision, it is difficult to reproduce the G waveform of each part of the dummy in detail. However, the G wave form characteristics and injury values of the dummy at each collision angle are reproducible by the sled test.

Further, a comparison of the high-speed films reveals that the behavior of the dummy in the car-to-car side crash test corresponds to that of the sled test. However, the dummy behavior after collision differs with the deformation of the body side and the collision angle.

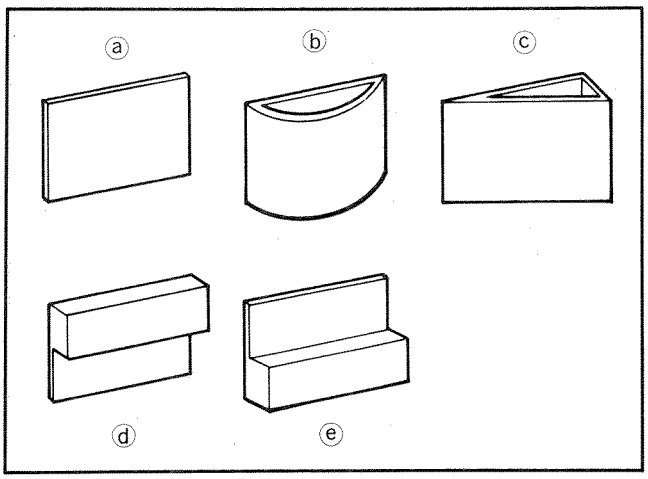


Figure 3. Shapes of impactors.

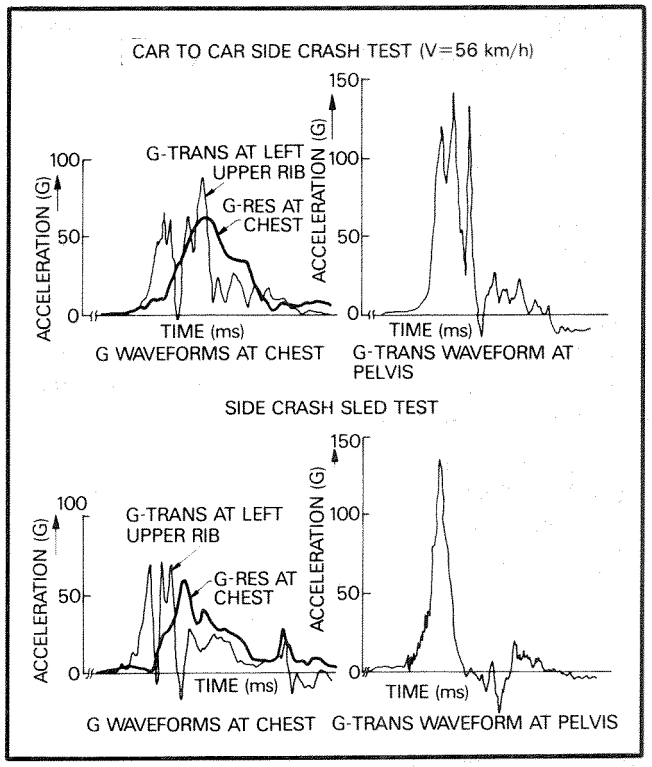


Figure 4. Comparison of dummy G waveforms at 90° collision angle.

From the above results, this sled test method is considered capable of reproducing roughly the dummy injury value and behavior in the car-to-car side crash test. It provides an effective measure in developing and evaluating padding materials, and in examining the relation between the parameters and the dummy injury values in side collisions.

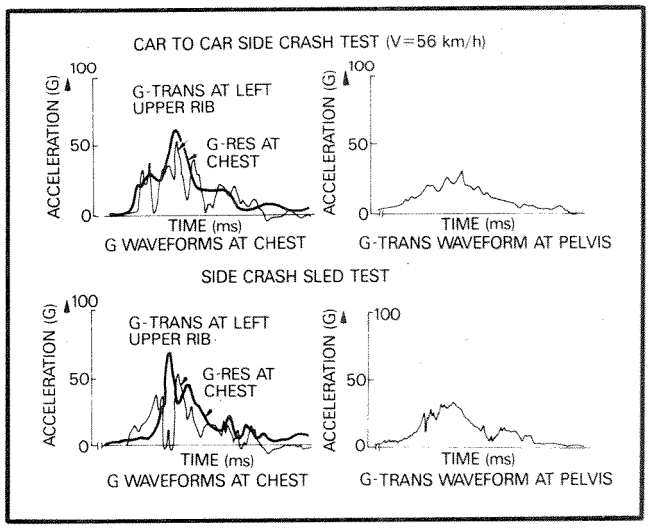


Figure 5. Comparison of dummy G waveforms at 60° collision angle.

RELATION BETWEEN PARAMETERS AND DUMMY INJURY VALUES

In side collisions, the body side intrudes into the compartment and collides with the occupant. This makes side collision a more complex phenomenon than the frontal crash where the occupant is restrained by a three-point belt system. The relation between various parameters and occupant injuries in side collisions had not been sufficiently clarified. Therefore, sled tests using side impact dummies developed by HSRI were conducted to study how the following parameters influence the injury values of each part of the dummy.

(1) The effect of dummy collision velocity
(2) The effect of intrusion of the impactor into the compartment
(3) The effect of collision angle
(4) The effect of the deformation of the body side
(5) The effect of padding materials
(6) The effect of seat belts

Relation between Dummy Collision Velocity and Dummy Injury Values

There is a close relation between the dummy collision velocity and the injury value of each part of the dummy. In a collision velocity range from 20 to 30 km/h, the injury value of each part of the dummy increases in proportion to the dummy collision velocity.

Figure 6 shows the relation between the dummy collision velocity and the dummy injury values at collision angles of 90° and 60°. The dummy injury values at a 90° collision angle differ from those produced at 60°. For example, with the same collision velocity, the resultant G-3ms at the chest is smaller in a collision angle of 90° than at 60°.

Therefore, reducing the dummy impact velocity is effective in decreasing the dummy injury values.

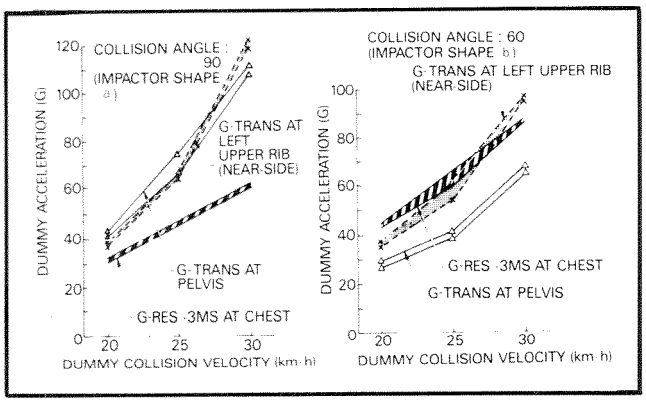


Figure 6. Dummy collision velocity and dummy injury values.

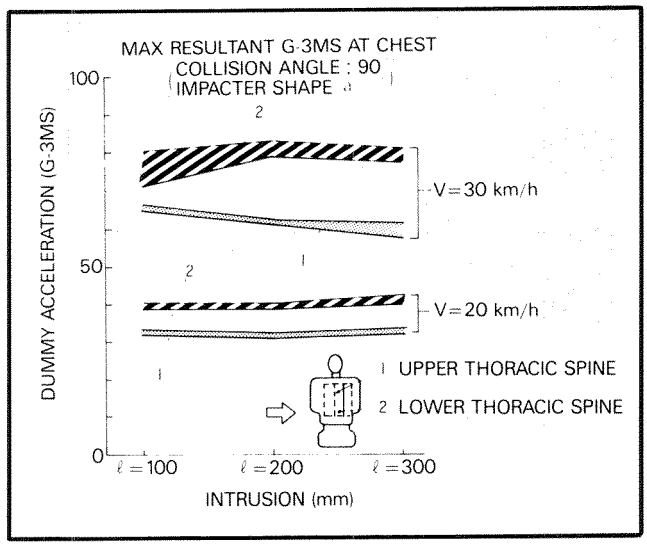


Figure 7. Intrusion and dummy chest injury value.

Relation between Impactor's Intrusion into Compartment and Dummy Injury Values

The relation between the impactor's intrusion and the dummy chest value was examined by changing the impactor's intrusion, i.e., 100, 200, and 300 mm under the same test conditions. The results are shown in Figure 7.

When the dummy collision velocity is the same, the dummy chest injury value does not vary greatly even if the impactor's intrusion changes. In the car-to-car side crash test, there is a certain relation between the intrusion and the dummy chest injury value, as shown in Figure 8. This is due to a change in the dummy collision velocity which was caused by the extent of the intrusion.

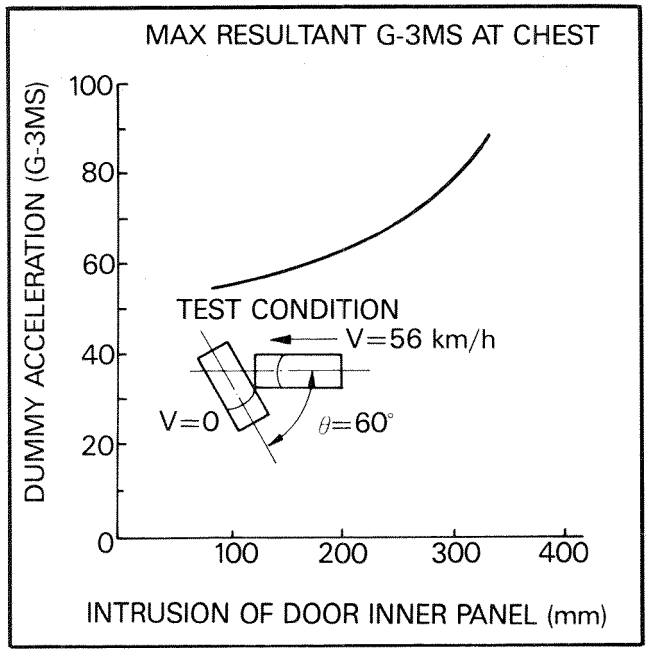


Figure 8. Dummy chest injury value and intrusion in actual vehicle test.

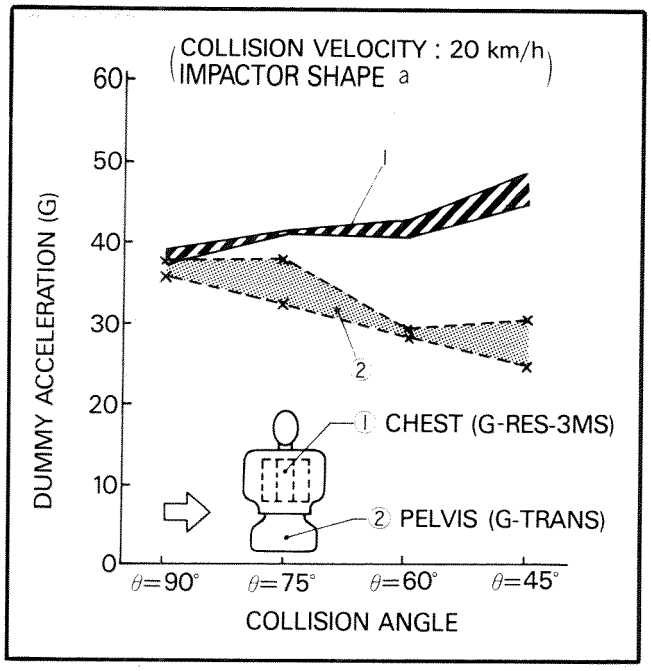


Figure 9. Collision angle and dummy injury values.

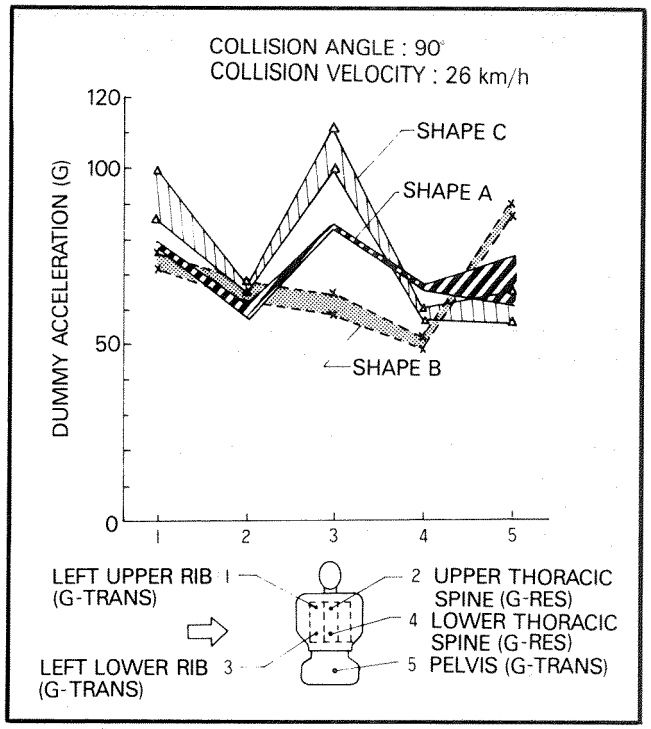


Figure 11. Impactor shape and dummy injury values.

Effect of Collision Angle

In order to understand how the collision angle between vehicles influences the dummy injury value in car-to-car side crash tests, sled tests were conducted at collision angles of 90°, 75°, 60° and 45°. The test results are shown in Figure 9.

The injury value of the dummy chest and pelvis change with the collision angle. If the dummy collision velocity is the same, the dummy chest injury value shows a minimum when the dummy chest is impacted at a 90° angle. This is primarily due to the characteristics of the dummy chest which will be discussed in more detail in later paragraphs.

Effect of the Body Side Deformation

The two experiments mentioned below were conducted to clarify how the deformation of the body side (door, center pillar, etc.) influences the dummy injury values in side collisions.

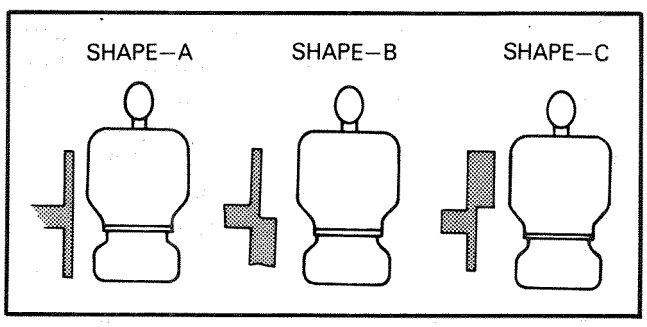


Figure 10. Shapes of impactor (No. 1).

First, in order to examine the effect of the vertical section of the door, sled tests were carried out using the impactors shown in Figure 10 and a 90° collision angle.

As shown in Figure 11, the injury values and G waveforms at the dummy chest and pelvis vary with the shape of the impactor, A, B or C. The characteristics of the impactor of each shape are as follows:

Shape A . . . This shape is characterized by the resultant G at the lower thoracic spine being higher than that at the upper thoracic spine.

Shape B . . . The transverse G at the pelvis increases, and the resultant G of the upper thoracic spine does not decrease.

Shape C . . . The transverse G at the ribs on the struck side increases, and the transverse G at the pelvis decreases.

As described above, the injury value at the point where the impactor first comes into contact with the dummy increases. Accordingly, it is desirable that the body side be designed so that it deforms with a uniform load distribution throughout the whole dummy.

In order to determine how the deformation of the body side at a 60° collision angle influences the dummy injury value, sled tests were carried out using the impactors, D, E and F in Figure 12. The results are shown in Figure 13.

The injury value of each part of the dummy varies greatly with the shape, D, E or F. For example, comparing shape D with shape E, the injury value of the dummy pelvis increases rapidly, because the latter length is 100 mm shorter. Also, shape F causes a higher chest injury

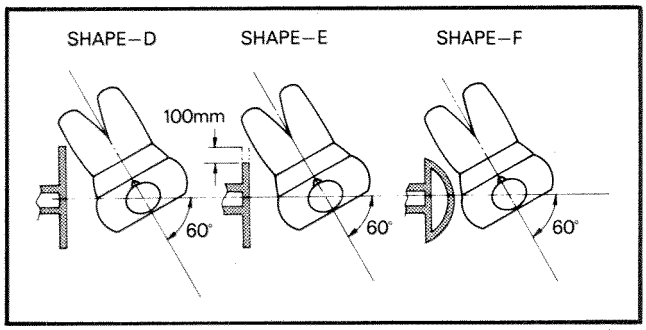


Figure 12. Shapes of impactor (no. 2).

value and a lower pelvis injury value as compared with shape D.

When the impactor collides with the dummy obliquely as at a 60° collision angle, the way in which the impactor comes into contact with the dummy's thigh has a great effect not only on the dummy pelvis injury value, but also on its chest injury value.

Reproducibility of Dummy Injury Values—The dummy injury values are found to be influenced by parameters such as the collision velocity of the body side with the dummy, collision angle of the body side with the dummy, deformation of the body side, etc., but are reproducible to some degree under the same sled test conditions.

Accordingly, in order to obtain satisfactory reproducibility of dummy injury values in a car-to-car side crash test, these parameters representing complex collision phenomena must have good reproducibility. However, in actual car-to-car side crash tests, the reproducibility of these parameters is poor and the injury value of each part of the dummy varies.

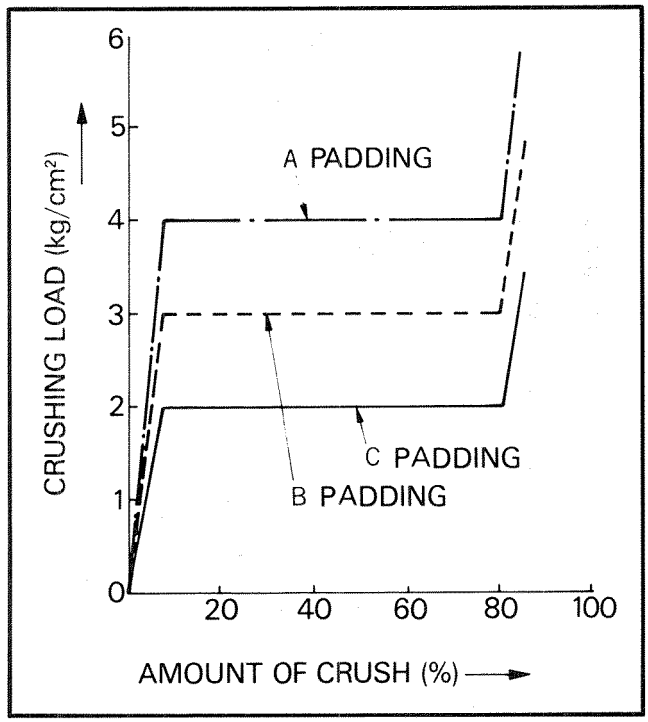


Figure 14. Static crash characteristics.

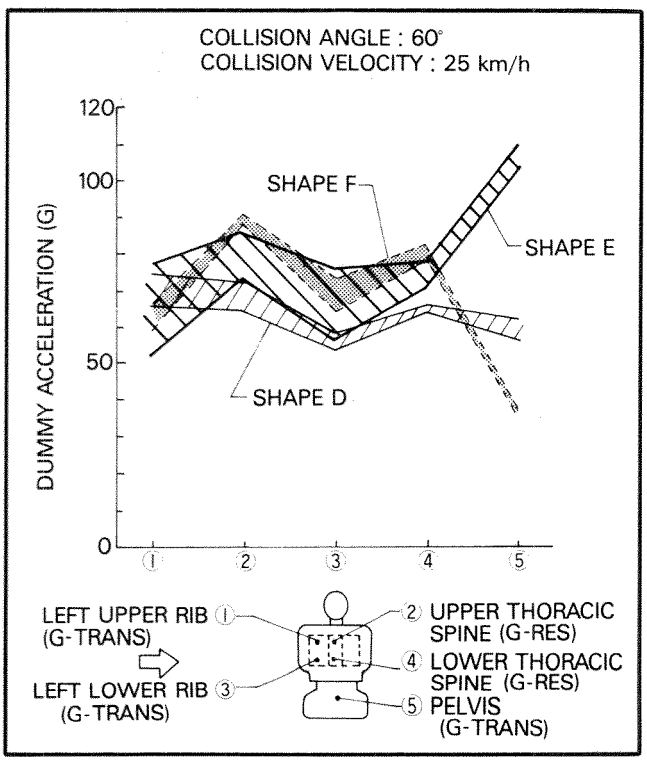


Figure 13. Impactor shape and dummy injury values.

Characteristics of Padding Materials

Padding materials of different characteristics were prepared and their effectiveness was examined by sled tests. The tests were conducted at a 90° collision angle and the impactor shape A was used (see Fig. 3).

Characteristics and Effect of Padding Materials—In order to determine how the dummy injury values change with the thickness and characteristics of the padding material and the dummy collision velocity, padding materials, A, B and C, which are 50 and 30 mm in thickness and have the static crash characteristics shown in Figure 14, were made and evaluated by sled tests. These evaluated results are indicated in Figure 15.

When the pad thickness is 50 mm, the soft padding material C gives good performance at a collision velocity below 25 km/h; however, at a collision velocity of 30 km/h, padding material C is too soft and padding materials B and A show better performance. Further, when the pad thickness is 30 mm, while padding material C bottoms out even at a collision velocity below 25 km/h, padding material B provides good performance at a collision velocity below 25 km/h.

As described above, because the dummy injury values vary with the thickness and characteristics of the padding

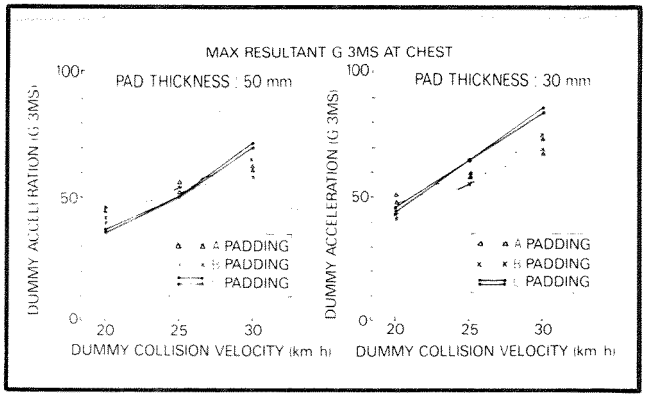


Figure 15. Dummy collision velocity, pad thickness and dummy chest injury values.

material and the dummy collision velocity, it is necessary to take these relations into account when selecting padding material.

Relation between Pad Thickness and Dummy Injury Value—The relation between the pad thickness and dummy injury value was investigated using padding materials 30, 50 and 80 mm thick. The results are shown in Figure 16.

The 80 mm thick padding material is effective even at a dummy collision velocity of 30 km/h. Despite the fairly good characteristics at a dummy collision velocity of 20 km/h, the 50 mm thick padding material bottoms out at 30 km/h. In order for a 30 mm thick padding material to provide a satisfactory padding effect, appropriate material and further improvement in crash characteristics of the padding are required.

Therefore, the padding material must be more than 80 mm thick to obtain a satisfactory padding effect. In order to avoid spoiling the roominess of the vehicle, it is necessary to develop a thinner padding material in providing good padding effect.

Optimum Combination of Padding Materials for Chest and Pelvis Levels—The injury value of each part of the dummy changes greatly depending on the padding materials. A combination of padding materials for the chest and pelvis levels with different characteristics is a factor that reduces the injury value of each part of the dummy.

The transverse G at the ribs on the struck side and transverse G at the pelvis vary depending on stiffness and the crash characteristics of the padding material, compared to the resultant G at the thoracic spine. Based on a comparison between the padding materials for the chest and pelvis levels, the padding material should be softer and thicker for the pelvis level than for the chest level.

Effect of Seat Belts

According to a sled test at a collision angle of 90°, the current 3-point seat belt shows no significant effect.

However, in car-to-car side collision on the road, because a second and third collision may follow the first, making the vehicle behavior very complicated, the seat belt seems to have an effect which cannot be evaluated by this sled test.

CHARACTERISTICS OF HSRI SIDE IMPACT DUMMY

The characteristics of HSRI side impact dummies were examined by drop tests and sled tests, and these test results were compared with the Hybrid-II dummy.

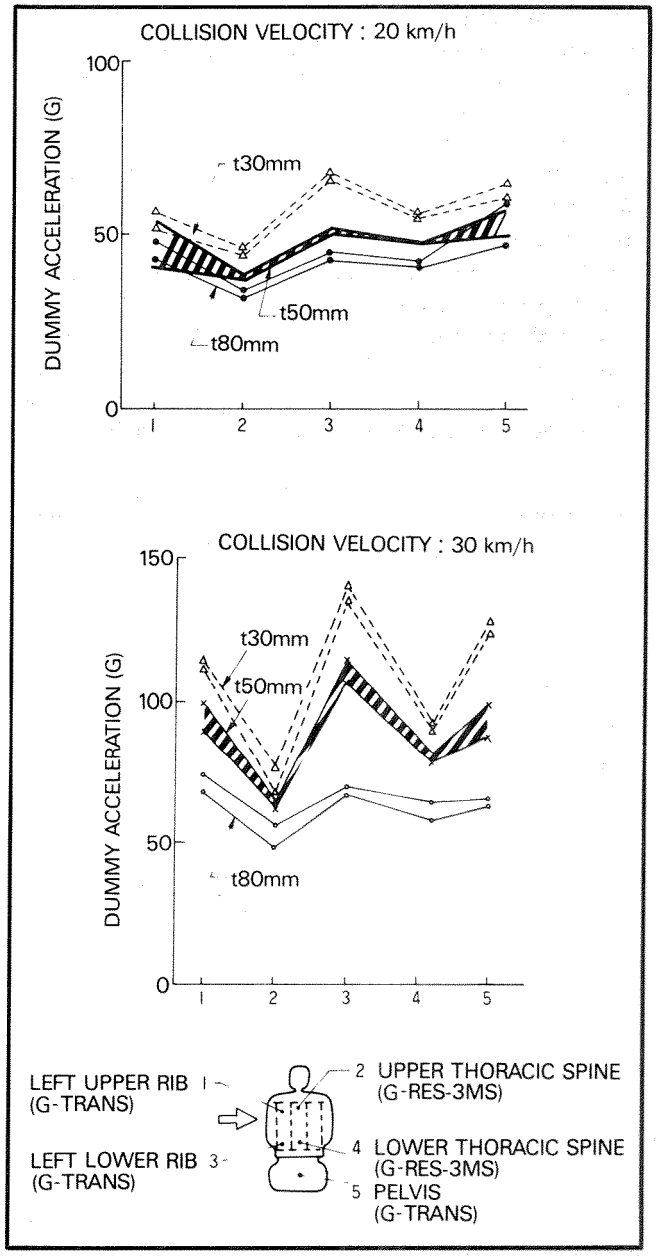


Figure 16. Pad thickness and dummy injury values.

Characteristics Comparison between Hybrid-II Dummy and HSRI Side Impact Dummy

Dummy Head Characteristics—In the HSRI side impact dummies, the deformation of the chest and the lateral rotation of the head is greater than in the Hybrid-II dummy, so that the former shows higher head injury values than the latter (see Fig. 17).

Therefore, the side impact dummy is improved because the lateral rotation of the head is not restricted by the shoulder and clavicle.

Dummy Chest Characteristics—As shown in Figure 18, when the dummy chest receives a lateral impact, the chest injury value is smaller in the side impact dummy than in the Hybrid-II dummy due to a damping effect. However, with an oblique impact, while the side impact dummy shows a higher injury value than at a 90° collision angle, the Hybrid-II dummy has a lower value. Both dummies display almost the same characteristics at a collision angle of 60°.

Therefore, the chest of the side impact dummy shows an improvement due to modification against lateral impact; however, the modification had little effect in an oblique impact.

Dummy Pelvis Characteristics—Judging from the dummy pelvis G, both the HSRI and Hybrid-II dummies provide almost the same characteristics in an oblique collision, such as a 60° collision angle. But in a high-speed crash at a 90° collision angle, the injury value is higher in the side impact dummy than in the Hybrid-II dummy

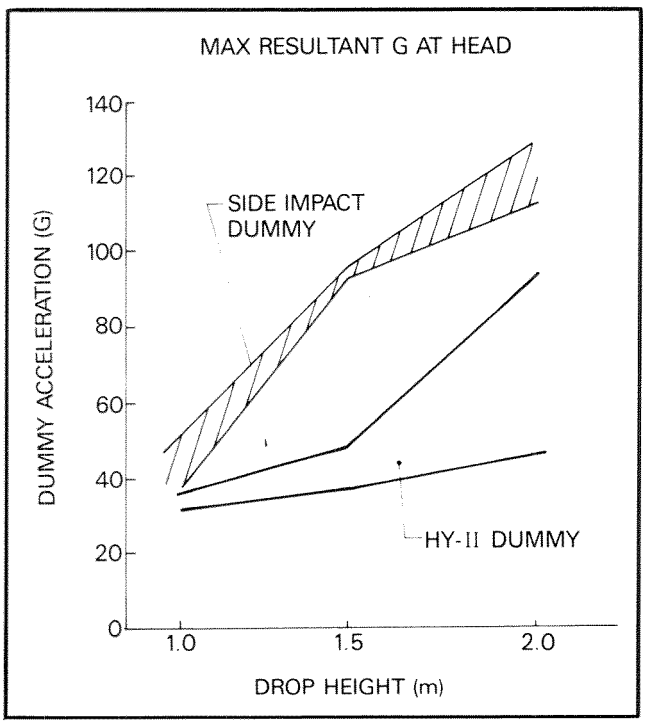


Figure 17. Comparison of dummy head injury values (drop test).

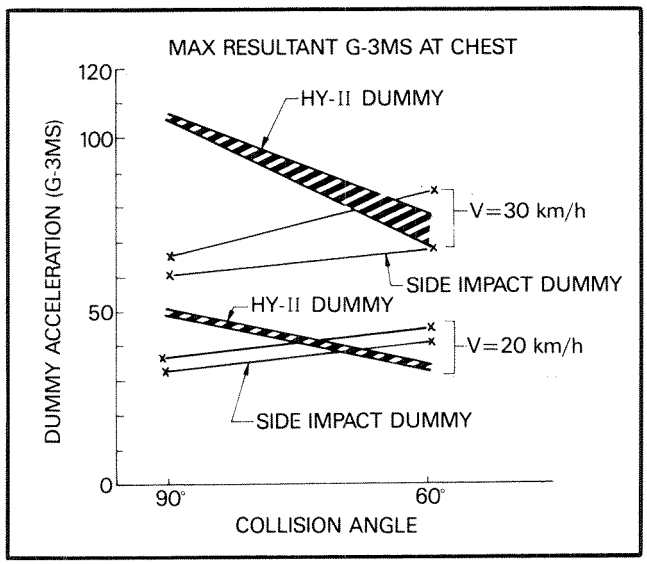


Figure 18. Variation of dummy chest injury value with collision angle (sled test).

(see Fig. 19). This is because a greater load is applied to the pelvis when the chest has a large deformation.

Relation between Collision Angle and Dummy Chest Characteristics

In order to examine the relation between the collision angle and the HSRI dummy chest characteristics in further detail, a sled test was conducted at collision angles,

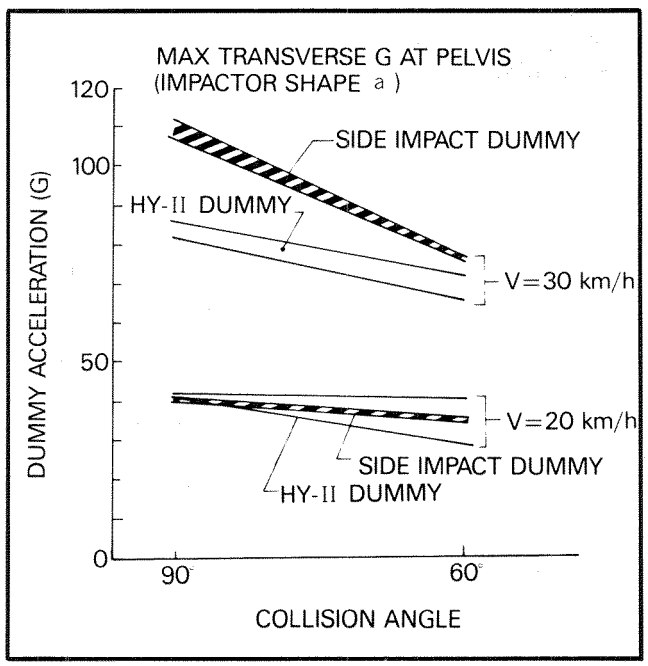


Figure 19. Comparison of transverse G at pelvis (sled test).

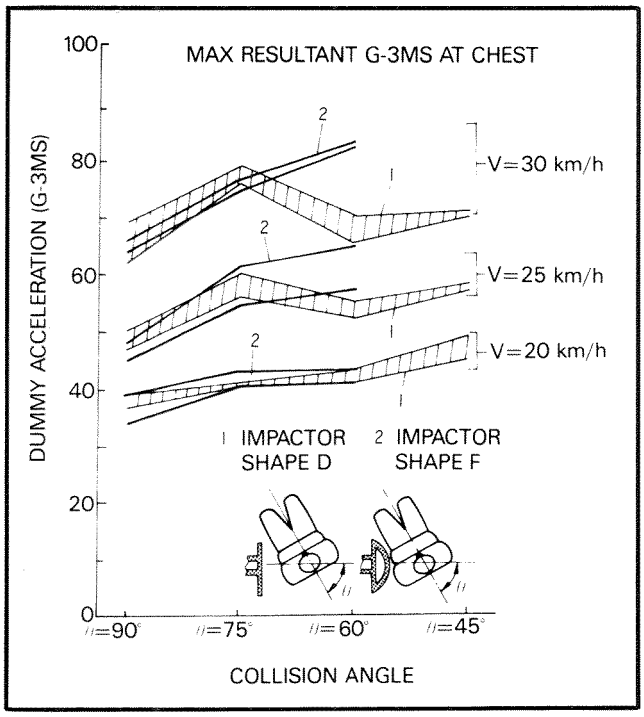


Figure 20. Collision angle and dummy chest injury value.

90°, 75°, 60°, and 45°. Figures 20 and 21 illustrate the test results.

The dummy chest characteristics differ with the collision angle. When the dummy chest is impacted obliquely, the chest injury values are higher and a G waveform having a sharp rise and a high peak G is produced.

Further, close correlation is observed between the dummy injury value and the shape of the impactor. In the sled test using a shape F impactor (in Fig. 20), the chest injury value became higher as impact occurred at more oblique angles. A shape D impactor (in Fig. 20), the chest injury value did not rise considerably even at collision angles of 60° and 45°, when the dummy collision velocity was over 24 km/h.

The reason for this is that when the impactor comes into contact with the dummy thigh, the dummy rolls and the collision angle between the impactor and the dummy chest changes. Thus the side stiffness of the dummy thigh is one of the factors that governs the dummy characteristics.

To summarize, the chest characteristics of the HSRI side impact dummy vary with the direction of impact on the chest, and the features are as follows:

Characteristics Caused by Lateral Impact to Dummy Chest—Because the G at the ribs is damped by the damper and then transferred to the thoracic spine, G at the thoracic spine becomes a G waveform with a lower peak G and has a slower rise compared to the G at the ribs.

Characteristics Caused by Oblique Impact to Dummy Chest—The damper hardly functions, so the G at the thoracic spine is greater than at the ribs. Also, the longitudinal G at the chest increases.

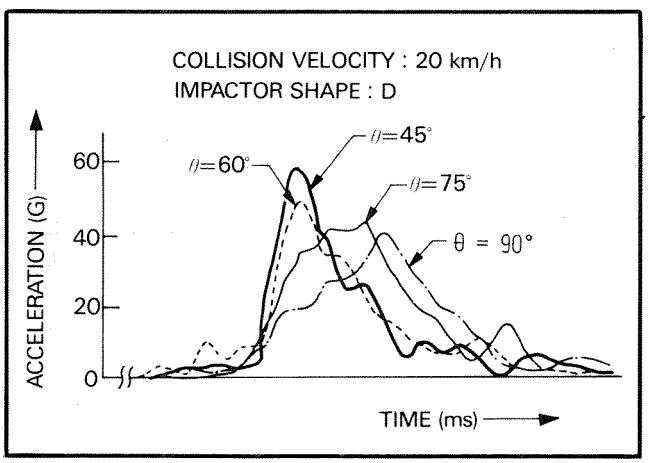


Figure 21. Comparison of resultant G waveforms at dummy chest.

SUMMARY OF SLED TEST

(1) This newly developed sled test method can control parameters such as the collision velocity of the body side with the dummy, intrusion of the body side into the compartment, deformation of the body side, collision angle and padding material. The method can approximately reproduce the injury values and behavior of the dummy in the car-to-car side crash test, providing an effective measure for evaluating padding materials as well as for examining the relation between each parameter and the dummy injury values.

(2) Table 1 shows the correlation between the major parameters that change in side collisions and the dummy injury value.

There exists a very strong relation between the dummy collision velocity and the dummy injury value, and the latter increases in proportion to the former. The dummy collision velocity required to reduce the resultant G of the dummy chest below 40 G 3 ms is less than 25 km/h, though it varies with side deformation, pad characteristics and collision velocity.

Table 1. Correlation between parameters and dummy injury values.

PARAMETER	CORRELATION
① DUMMY COLLISION VELOCITY	GREAT
② COLLISION ANGLE	MODERATE
③ INTRUSION OF IMPACTOR	SMALL
④ IMPACTOR SHAPE	MODERATE
⑤ PADDING MATERIAL CHARACTERISTICS	MODERATE
⑥ USE OF SEAT BELT	SMALL

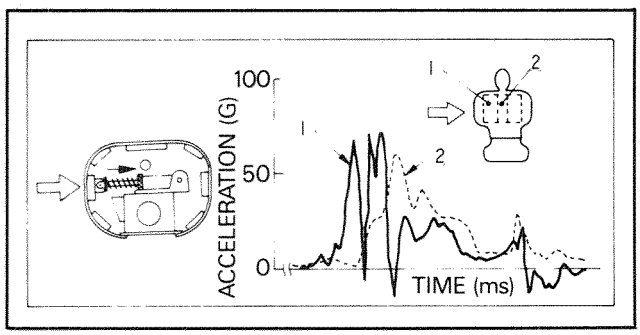


Figure 22. Characteristics caused by lateral impact to dummy chest.

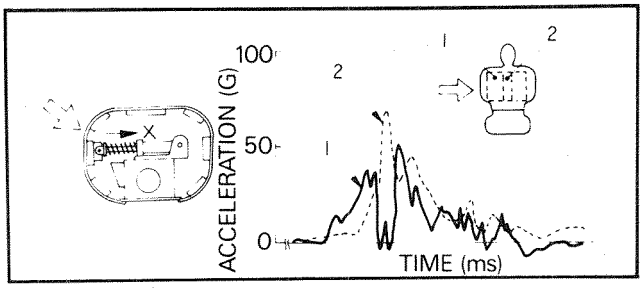


Figure 23. Characteristics caused by oblique impact to dummy chest.

There is some relation between the collision angle and the dummy injury value. When the dummies collide at the same velocity, the injury value of the dummy chest becomes higher in oblique impact or at collision angles of 60° and 45°, than at a 90° collision angle. This is primarily because of the chest characteristics of the side impact dummy.

The shape of the impactor, or the deformation of the body side, has a great effect on the injury value at each part of the dummy. Therefore, there is a need to examine countermeasures that can reduce the injury value at each part of the dummy uniformly, rather than at a certain part of the dummy.

Use of padding materials is an effective means of reducing dummy injury values. In the present stage, however, the thickness of a pad, effective enough for occupant protection, will have to be more than 80 mm. A decrease in the width of the compartment caused by using a pad of this thickness will lead to a decline in roominess comfort. This will eventually necessitate the enlargement of the body width resulting in a considerable increase in body weight.

(3) Characteristics of HSRI side impact dummy

The side impact dummy impacted from the lateral shows head and chest characteristics which are apparently different from those of the Hybrid-II dummy displaying the full effect of the modified chest. However, in the case of an oblique impact, the side impact dummy shows the same characteristics as those of the Hybrid-II dummy and no effect of the modified chest.

Furthermore, it is already confirmed that the side impact dummy chest characteristics agree with those of the human chest in lateral impact. However, the correspondence between the characteristics of the dummy and human chests has not sufficiently been clarified in oblique impacts.

(4) Reproducibility of dummy injury values

In sled tests, the injury value at each part of the dummy is, to some degree, reproducible under the same conditions, but varies according to change in parameters such as the dummy impact velocity, deformation of the body side, impact angle of the dummy to the body side, etc. A side collision is a complicated phenomenon compared to a frontal collision. In crash tests using actual vehicles, the reproducibility of each parameter is not sufficient even under the same conditions and the injury value at each part of the dummy varies.

CONCLUSIONS

(1) The side impact dummy developed by HSRI shows the chest characteristics that vary greatly with the impact angle. In oblique impacts the correspondence of the dummy chest characteristics with the human chest characteristics has not been well established and many problems remain to be solved.

(2) The side collision is a more complicated phenomenon than the frontal collision. In crash tests using actual vehicles, the reproducibility of each parameter is unsatisfactory even under the same conditions, thereby making the reproducibility of the dummy injury values poor.

Therefore, as things stand, even if an effectual dummy is developed, it will present problems to legally regulate the occupant protection performance of vehicles in side collisions by such dummy injury values.

REFERENCES

1. August Burgett, and William Brubaker, "The Role of the Side of the Motor Vehicle in Crash Protection", SAE 820245.
2. Richard M. Morgan, and Hal P. Waters, "Comparison of Two Promising Side Impact Dummies", 8th ESV Conference, Wolfsburg, October 1980.
3. Michael W. Monk, Richard M. Morgan, and Lisa K. Sullivan, "Side Impact Sled and Padding Development", SAE 801307.
4. L. M. "Morrie" Shaw, and Dr. Carl Clark, "Side Impact Restraint Development and Evaluation Techniques", 8th ESV Conference, Wolfsburg, October 1980.

5. A. Burgett and J. R. Hackney, "Status of National Highway Traffic Safety Administration's Research and Rulemaking Activities for Upgrading Side Impact Protection", 7th ESV Conference, Paris, June 1979.
6. J. W. Melvin, D. H. Robbins, and J. B. Benson, "Experimental Application of Advance Thoracic Instrumentation Techniques to Anthropomorphic Test Devices", 7th ESV Conference, Paris, June 1979.
7. E. Franchini, Fiat Technical Presentation, "Side Collision", 7th ESV Conference, Paris, June 1979.

Side Impact Component Test Development

CHARLES J. GRISWOLD
Fisher Body Division-General Motors Corporation

INTRODUCTION

General Motors has been engaged in a concerted effort to develop improved methods of occupant protection in vehicles involved in side impact accidents. At the Eighth Experimental Safety Vehicle Conference we discussed the wide spectrum of conditions and configurations that are represented in side impact accidents. We also discussed concepts of component tests which could be designed to encompass the variety of requirements of a body design in providing improved occupant protection under these varying circumstances. Since then, we have periodically reported on the development of hardware for component tests that can be expected to be reliable and repeatable, as well as flexible enough for the specific evaluation of each significant key element that contributes to overall side impact protection. This paper will cover the current status of the test hardware development and will also discuss some test work that is providing insight into the relative effects of exterior structure and interior energy absorption. The understanding of this relationship is an important factor in the choice and design of exterior and interior tests.

Currently, the output from this research is being merged with the work of others in a joint Industry-Government test development study sponsored by the American Motor Vehicle Manufacturers Association and the National Highway Traffic Safety Administration. This is a seven step program in which the first three steps, which are studies of Accident Data, Test Effectiveness and Biomechanical Criteria, are nearing completion as scheduled. These studies will serve as a basis for steps four and five, in which component and full-scale test methodology will be assembled and demonstrated. All of this will lead to the final steps of Test Evaluation and Estimation of Benefit. General Motors is strongly supporting this effort as a sound and rational means of reaching the goal of improved side impact performance. (Figure 1.)

"MOST EFFECTIVE" SIDE IMPACT COMPONENT PERFORMANCE

The case-by-case accident analysis (2) has been expanded by an in-depth study of the "key elements" of the body design in these accidents. "Key elements" are the individual components such as interior panels, upper interior pillars, door latches, hinges and structural members that function in their own specific way in a side impact. It has been found that no single accident configuration can be chosen as a "typical" side impact accident; it is not even possible to pick a single situation that is "worst case" for all components, since each accident has its own combination of loading and impact conditions. It does appear possible, however, by studying the results of a variety of accidents and/or reconstructing some of the conditions in research-oriented car-to-car tests, to determine "worst case", or perhaps a better term, "most effective" performance for each of the "key elements" in a vehicle design. These "most effective" characteristics can then be used in choosing and developing component tests for each "key element".

ACCIDENT ANALYSIS WITH CAR-TO-CAR ACCIDENT RECONSTRUCTION

As an example of this, the in-depth study raised some question about the effect of intrusion on injury. Many high injury accidents have a high amount of instrusion, however, a review of *low* injury accidents produced instances of relatively substantial intrusion with little accompanying injury. Since exterior structure is used to control intrusion, some car-to-car accident reconstruction tests were run to study the effect of body structure designed specifically to reduce intrusion. These tests, which were described in detail in our October 1981 Report (5), showed that while added structure could substantially reduce intrusion, this reduction, in turn, yielded progressively diminishing returns in impact reduction for the occupant, especially in terms of the additional mass required. The tests also indicated that the interior stiffness of the door inner panel surface was a more effective factor in controlling the impact against the occupant than reduction of intrusion.

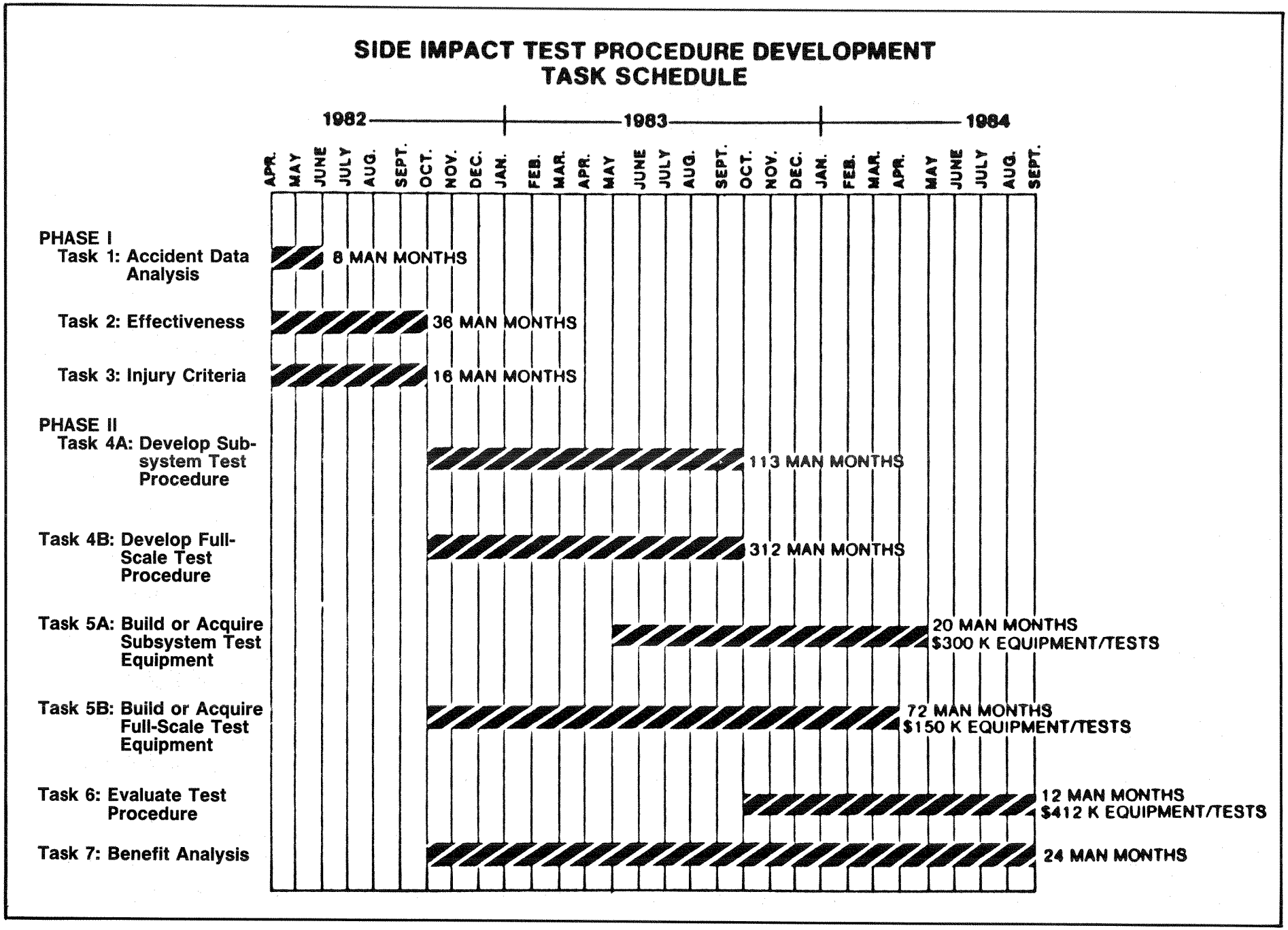


Figure 1. Side impact test procedure development task schedule.

To test this thesis, another car was built and tested under similar conditions. This car had minimum intrusion-reducing exterior body structure. Instead, the primary impact-reducing feature was an energy-absorbing door inner construction. This construction utilized the door thickness between the outer and inner panel as the working acceleration distance to absorb the "second impact" between the door interior panel and the occupant.

The results of this "energy-absorbing inner panel" car test are shown in Figure 2 superimposed on the chart of results from the 1981 "intrusion-resisting structure" car tests. To review, these tests are 33 mph car-to-car side impacts at 90 degrees with both striking and struck cars equally weighted. A Part 572 dummy with no arm was used to provide relative occupant impact measurement without reference to any absolute injury level or criteria. Dummy acceleration measurements were recorded at Chest and Pelvis heights, and are charted against intrusion at the same heights.

In the "intrusion-resisting structure" tests, the light, medium, and heavy structures (12, 20, and 40 pounds, respectively) showed reduction in intrusion at both Chest and Pelvis heights corresponding with the weight of the particular modification.

At the Chest level, the impact accelerations also showed a decrease with each modification, however with a marked diminishing return as the modification weight increased.

At the Pelvis level, the added exterior structure served to stiffen the inner panel, causing the impact accelerations

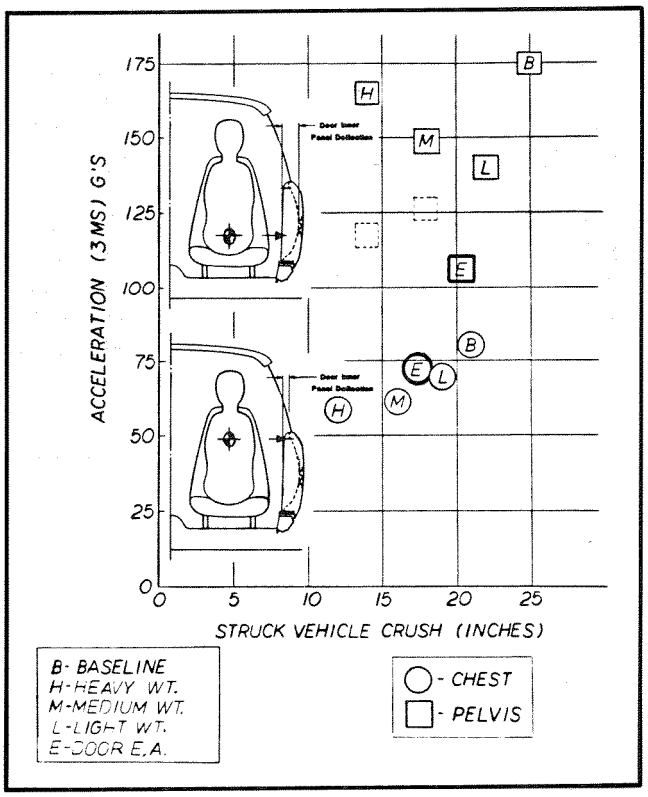


Figure 2. Side crush vs. occupant acceleration.

to increase in the medium and heavy modification tests. If the panel stiffness had remained the same, we would have expected some reduction in impact as shown by the dotted squares, following the pattern seen in the Chest acceleration results.

This description has been repeated from the more detailed 1981 report to serve as a comparison for the "energy-absorbing inner panel" test results.

In this test, the energy-absorbing construction was located in the lower part of the door adjacent to the Pelvis. The door panel next to the Chest was unchanged from the previous tests. The exterior body structure was similar to the light modification with some improvements that reduced the weight penalty to around 6 pounds.

The Pelvis acceleration was reduced to about 60% of the baseline test, which even the estimated "best expected" performance of the heavy 40 pound exterior structure modification was not able to approach.

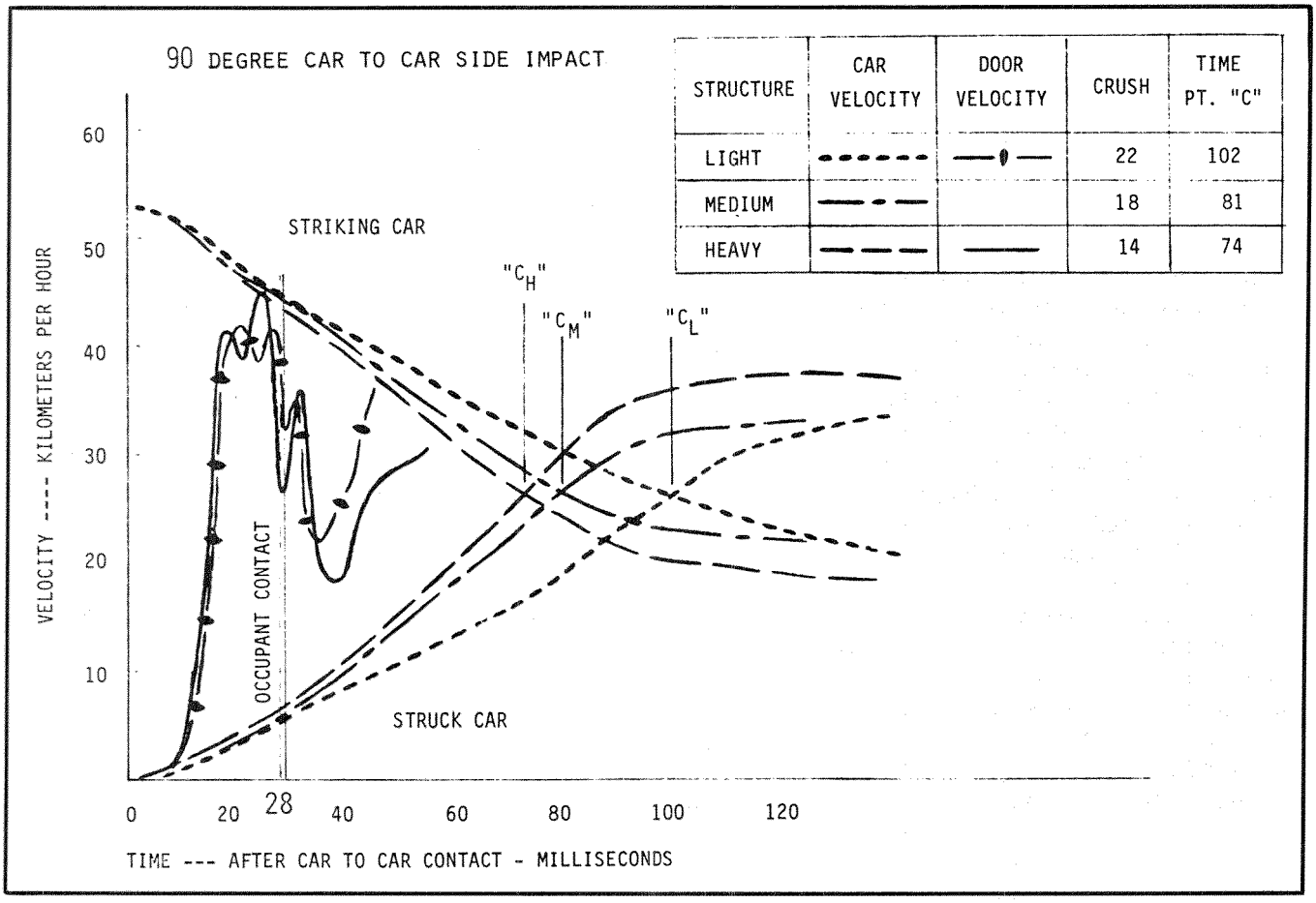
A significant conclusion that can be reached from this is that the inner panel energy absorption capability is shown to be a "most effective" characteristic. Conversely, adding stiffness to the exterior structure was found to be much less effective, especially in terms of the mass increase involved, partly because of the diminishing return in impact reduction with reduced intrusion, and partly because the added structure can actually add to the effect of the interior impact against the occupant.

To further illustrate the "diminishing return" of exterior structure modifications exhibited in these tests, let us look at the floor pan and door inner panel velocities that were measured. (Figure 3).

The principal purpose and effect of exterior structure stiffness is to accelerate the struck car, and by a trade-off in energy, decelerate the striking car. The amount of side intrusion is the result of this interaction. The less intrusion allowed, the quicker the trade-off of energy, and the slower the striking car will be moving at the time of impact with the occupant. On this chart, where both the velocities of the striking and struck cars are plotted, Point "C", where the velocity traces cross and are equal, is the point in time when maximum intrusion has taken place. Beyond this time, the two cars are beginning to separate. An effective structure would seem to be one that traded off velocities quickly enough to cause Point "C" to occur before the occupant is contacted.

The occupant, of course, is actually struck by the door inner panel as the door is "intruded". Figure 4 shows the door velocity curves superimposed on the previous charts. At the beginning of the car-to-car impact the door quickly becomes an extension of the front of the striking car, and at the moment of occupant contact the velocity of the striking car essentially determines the velocity of the door inner panel.

In all of these tests, occupant contact occurred about 28 milliseconds after initial vehicle contact. Point "C", common velocity, occurred at 102, 81, and 74 milliseconds



Figures 3 and 4.

respectively for the "Light", "Medium", and "Heavy" modification vehicles. It can be seen that in these tests most of the energy "trade-off" occurred *after* the occupant had been struck, even though substantial reduction in intrusion had been accomplished. In addition, the "diminishing return" effect of this method of energy management is illustrated in that while the reduction in intrusion was approximately equal between the modifications, the reduction in the time to reach common velocity became progressively less for each modification. The mass required to reduce intrusion is dependent, of course, on specific design factors, however it seems reasonable to assume that a further reduction in intrusion would require further increases in mass in the same proportion.

RELATIONSHIP—EXTERIOR STRUCTURE VERSUS INTERIOR ENERGY ABSORPTION

In summary, then, the use of "exterior structure" or "interior energy absorption" can be viewed as two separate methods of controlling the impact against the occupant. The "exterior structure" method is an indirect method which works by trading energy with an impacting vehicle. This method is dependent on the ratio of the mass of the striking car to the mass of the struck car (Figure 5). If the two cars have equal mass, the velocity at Point "C" will be about half the original striking velocity. If the striking car is heavier than the struck car (big car to small car) the Point "C" velocity will be increased in proportion, reducing the effectiveness of the energy trade-off. In the case of a single car sliding into a pole or object that is fixed and immovable, no energy trade-off can take place, making exterior structure ineffective.

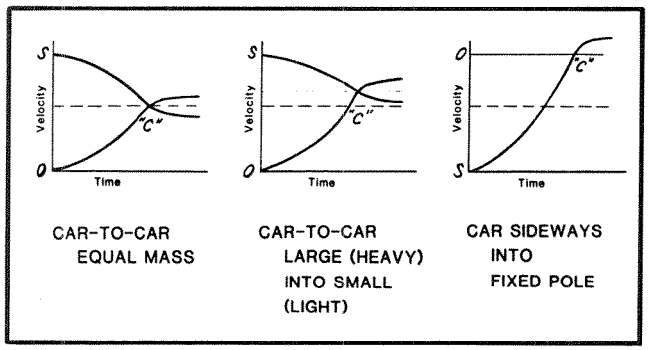


Figure 5. Exterior structure "energy trade-off."

In contrast, the use of "interior energy absorption" is a direct method of reducing the severity of the impact to the occupant. It also provides reduction in impact in collisions with heavier vehicles and with fixed objects. While in theory, it would seem that both methods could be used simultaneously, in practical terms both methods are competing for the same "real estate" in the vehicle, the limited space between the occupant and the outside surface of the car. In the tests described earlier, it was even found that exterior structure, while accomplishing its purpose of reducing intrusion and trading off energy, could actually contribute to, rather than reduce, the impact against the occupant. Conversely, the test using the available "real estate" to absorb the second impact, without attempting to reduce intrusion, yielded more effective results because of the "most effective" characteristic of energy absorption of the interior. These tests demonstrate that the *most efficient* use of the available space and mass in the body side construction is in management of the second impact between the door and the occupant, rather than management of the initial impact between the two cars.

DEVELOPMENT OF THE DOOR LOWER INTERIOR IMPACT TEST

These observations, then, clear the way for the development of a simple and direct test for the "most effective" characteristic of body side structure, interior energy absorption. The basic concept of this test has been discussed earlier (3)(5). The test equipment with which we now are experimenting has the following principal features:

1. Compliance Representing the Human Thorax

The impactor is designed with internal compliance to produce the dynamic characteristics of an impact between the occupant and the door inner surface. This is accomplished by the use of a two element device consisting of a relatively light impact face which is loaded compliantly during impact by the inertia of a larger mass acting through a spring and shock absorber system. The compliance is modeled after known human Thorax response (6).

2. Impact Measurement Capability

The impact intensity can be measured in three different ways, each of which could be used separately or in combination:

(a) Deflection of the larger mass with respect to the impact face.
(b) Acceleration of the impacting face.
(c) Acceleration of the larger mass.

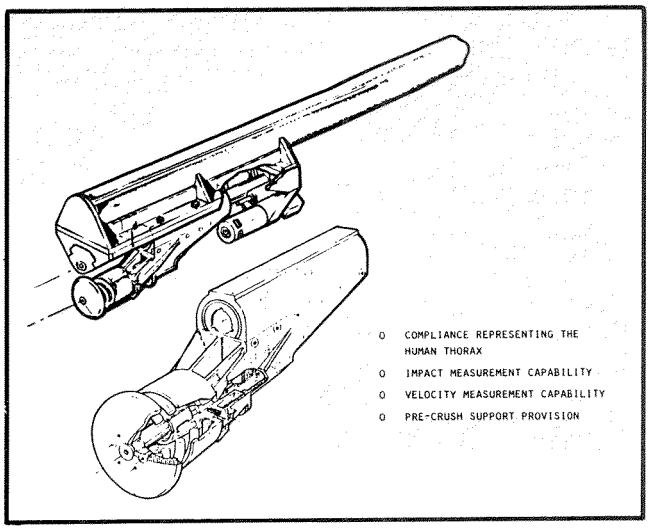


Figure 6. Torso area impactor.

3. Velocity Measurement Capability

The impactor velocity is measured just before impact and just after rebound.

4. Pre-Crush Support Provision

We are currently experimenting with methods of "pre-crushing" the door to see if this is necessary to assure that the energy-absorbing construction will function after being crushed from outside the car. Support provisions for the door exterior are being incorporated in the impact fixture.

LOWER INTERIOR IMPACTOR MECHANISM

As can be seen from the photographs (Figures 7 and 8) the operating portion of the Lower Interior Impactor is relatively compact. The moving unit is supported by

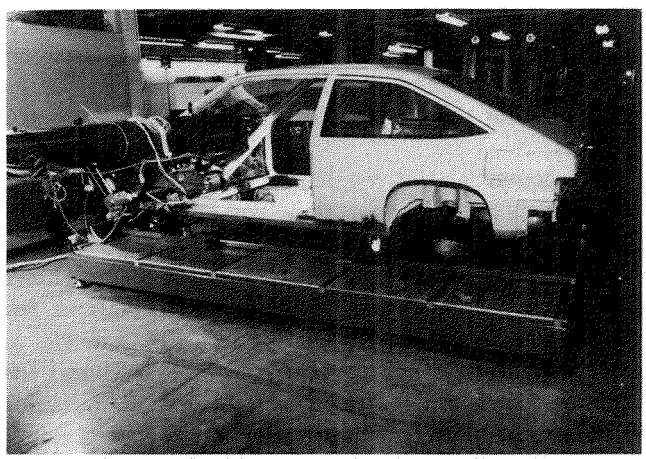


Figure 7.

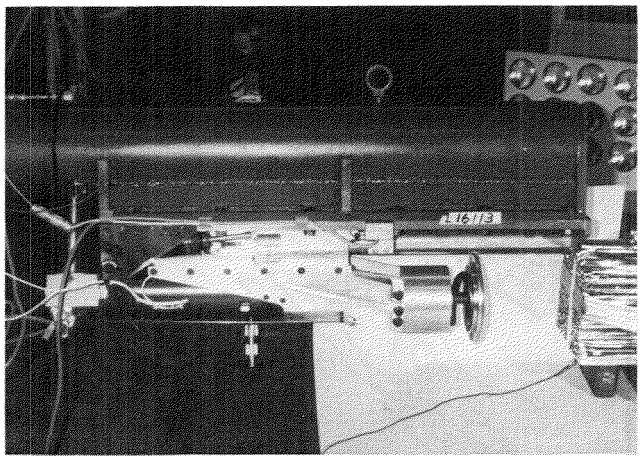


Figure 8.

two linear ball bearing units running on the 2 inch diameter shaft mounted below the tubular mounting beam. The unit is designed to be operated inside a full vehicle body. The mounting beam can be inserted into the body through an open window or door. Mounting beams of various shapes, or an articulating beam, can be used to accommodate various body configurations.

The moving unit itself weighs 50 pounds and is 28.5 inches long. The velocity range is variable up to 30 mph. The details of the stored gas propulsion system and controls are similar to the Head Area Impactor described in our 1981 report ((5) and Appendix Figures 1-4) since the basic propulsion concept is the same. The working travel is 17.3 inches, of which 7.5 inches is used for acceleration and 9.8 inches is available for impact measurement.

The device is now being evaluated and supplementary mechanisms are being assembled. The next step is to compare impact responses with other known Thorax test devices.

EVALUATION TEST PLAN

While this test device has been designed using human cadaver impact response data, it was noted in the 1981 report that this data spread was considerable, which is understandable given the wide range of human architecture. It seems useful, then, to establish comparison information for this device with other existing Thorax test devices.

To accomplish this, we plan to run a series of sled test evaluations using the general method followed in the SAE "Round Robin" Anthropomorphic Test Device series. The Impactor will be mounted on a sled fixture as shown in Figure 8 and allowed to freely impact various test surfaces at several speeds. The Impactor outputs can be compared with similar test results with other Thorax test devices. The ultimate objective, of course, is to develop a repeatable and reliable test tool that will also be simple enough for efficient development of body interior design.

PRE-CRUSH DEVELOPMENT

It seems reasonable to expect that an effective lower interior body structure be able to maintain its interior energy-absorbing capacity after it has been subjected to the type of distortion which could result from the exterior collision. A simple way to evaluate this would be to pre-crush, from the outside, the portion of the door to be tested by the interior Impactor. We are currently experimenting with this as shown in the photograph (Figure 9). The exterior crush face being used is a solid bumper face similar to the section used for the Part 581 Bumper Test. This type of pre-crush conditioning should promote the type of energy-absorbing design that will perform in a variety of side impact accidents.

HEAD AREA IMPACTOR

The head area Impactor (Figure 10) has been described thoroughly in the 1981 report ((5) and Appendix 1) and a detailed engineering description along with part draw-

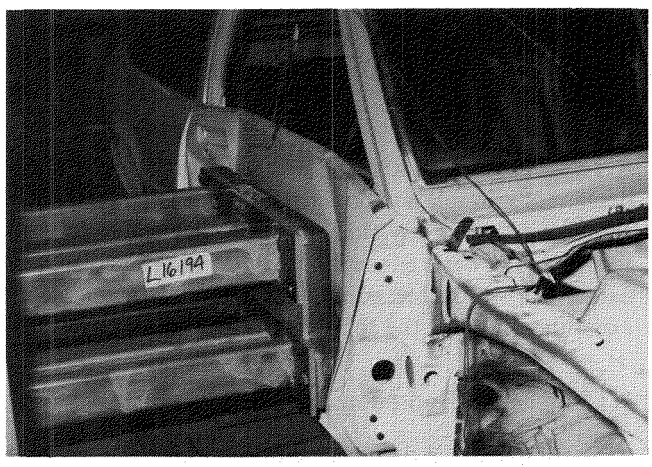


Figure 9.

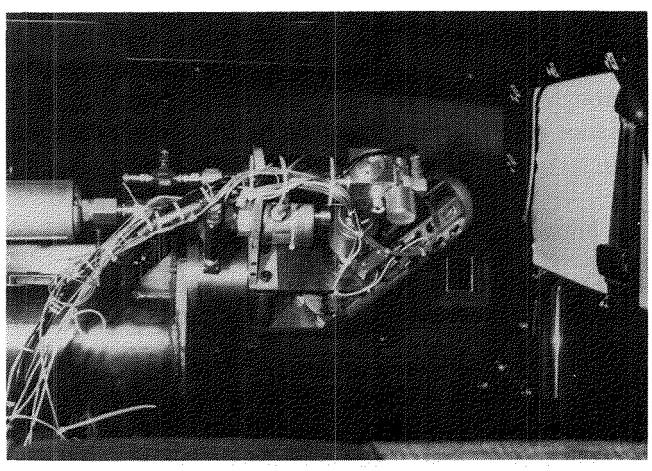


Figure 10.

ings of the prototype have been made available for public use. This Impactor is proving to be a reliable, repeatable and versatile test device.

Tests have been run to evaluate the effect of using a soft covering similar to the dummy head skin. It has been found that the difference in test results using the soft covering as compared to the original hard face is negligible. Because of this, we are intending to use only the original hard face in future testing, especially since the hard face has the potential for being more sensitive to hard spots.

"MOST EFFECTIVE" SIDE IMPACT TESTS

It can be seen from this discussion that the most effective vehicle body characteristics are those that relate to "interior energy absorption." The interior component tests described are a direct, repeatable and reliable means of evaluating this characteristic. The areas (Figure 11) that can be evaluated can reasonably cover any contactable area, much as current FMVSS Instrument Panel tests do now. It would be reasonable to expect the lower interior immediately adjacent to the occupant to have a somewhat higher energy absorption capacity than the forward, less contactable areas. The upper interior test can cover areas that are seen as contact points in accident analysis, but are seldom contacted in full-scale testing.

RELATED SIDE IMPACT COMPONENT TESTS

Since many injuries in side impact accidents occur as a result of the impact between the door interior and the occupant, the interior tests just described can be considered to be the "performance" tests needed to evaluate a vehicle design. Other tests, however, are important to assure that body integrity is maintained under side impact accident conditions. The low incidence of door hinge and lock separations as shown in the accident analysis (2) is an indication that present door lock and door hinge test procedures are successful in promoting designs that function well in real accidents. We have seen in extreme cases that the body attachment may have an effect on lock or hinge performance. We are experimenting now with tests

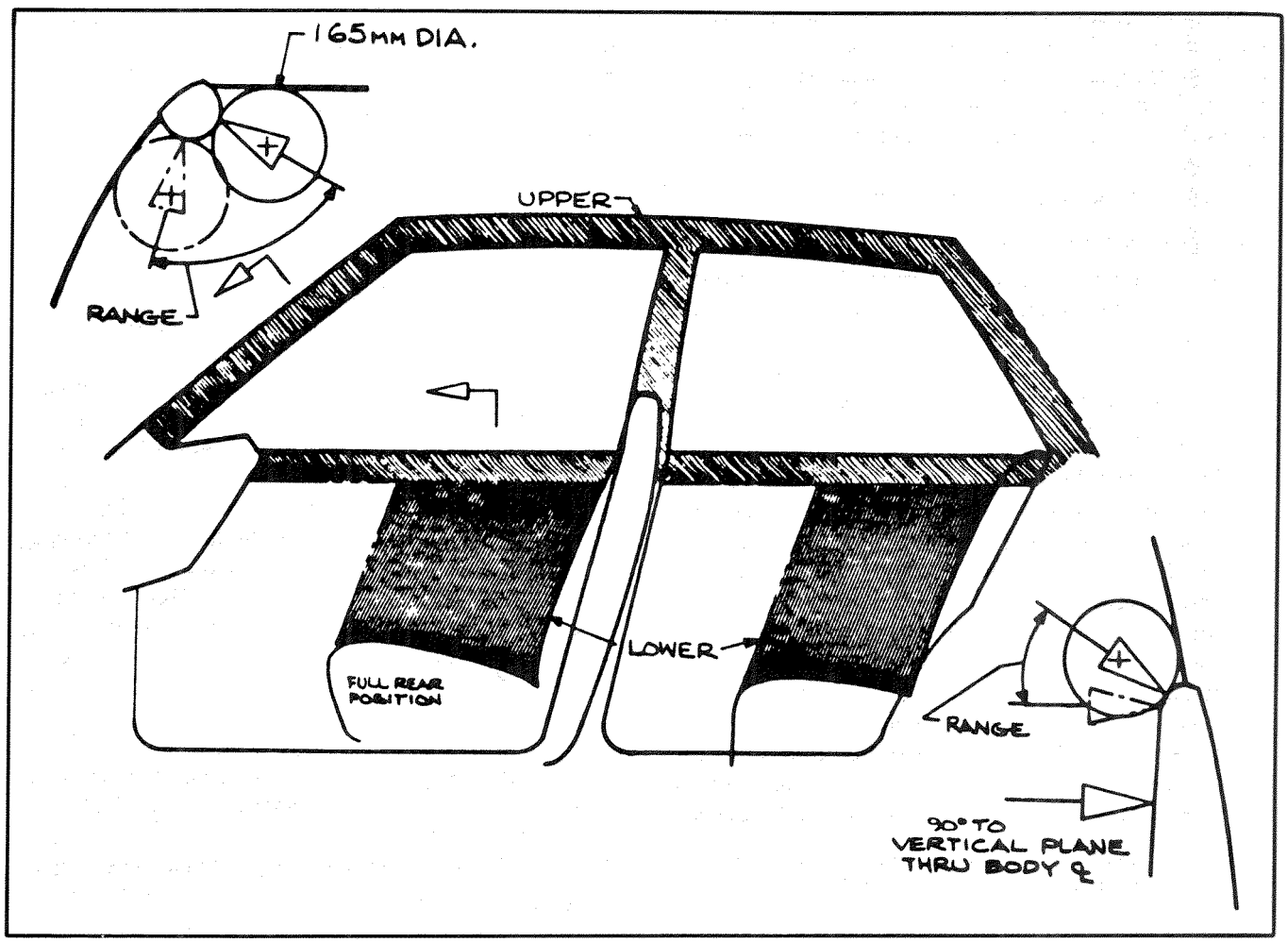


Figure 11. Impact zone.

that will also evaluate the mounting provisions to the door and body structure.

CURRENT FMVSS 214 DOOR BEAM TEST

The most important function of exterior structure is to maintain body integrity. Analytical techniques, such as are described in the companion side impact paper by Chi Mou Ni (6) are being developed to predict structural performance in side impacts.

The current FMVSS 214 test procedure includes a local stiffness requirement for the first six inches of crush that produces a relatively thick and heavy door beam. It has been shown that this space requirement "competes" for room that would be more efficiently used for management of the interior impact. We are experimenting with an exterior test which would promote the ability of door outer structure to deflect exterior collisions without countering the effect of the energy-absorbing characteristics needed from the interior of the door.

BENEFIT ANALYSIS

The ultimate purpose of improved test capability is that designs that will be evaluated by these tests will result in improved occupant protection in field accidents. It would seem desirable to find a means of showing the actual field benefit that will accrue from the application of these test procedures.

Several different methods have been suggested:

- *Direct Incremental Improvement*

  A simple and direct procedure would be to use the test methods described here to sample existing current production vehicles to establish a mean level of performance. An improved (and practicable) level of performance could be established and used as a basis for projection of field benefit.

- *Validation with Demonstration Full-Scale Tests*

  Typical examples of "baseline" and "improved" vehicles, evaluated with component test methodology, could be compared on a "one-time" basis in a demonstration in which a wide enough variety of test conditions could be included to encompass the spectrum of side impact accidents. This procedure would make use of the availability of a test dummy which would be able to evaluate injury level in the full-scale tests. After the validation procedure has been completed, the component tests could be used as direct and repeatable evaluators for future designs.

- *Direct Application of Bio-Mechanical Data To Calibrate the Impactors for Injury Level*

  The interior Impactors have been designed to produce the dynamic characteristics of an impact between the occupant and the interior surface. It appears reasonable that the bio-mechanical relationships being used to calibrate other anthropomorphic test devices could be used to calibrate the outputs of the interior Impactors.

CONCLUSION

In summary, it has been shown that there is a need for both full-scale and component test methodology in the development of improved side impact protection. The full-scale test is an invaluable tool for simulating accident configurations for intensive research into the mechanisms involved in specific situations. A full-scale test, however, must be instrumented and observed thoroughly and the results analyzed carefully. It is very useful in the determination of "what may be happening" in a particular accident configuration. It is much more difficult, because of the complexity of the test, to determine actual vehicle performance.

A vehicle's performance in an accident is the combined performance of all its components. Once the "most effective" performance characteristics have been determined, individual requirements can be established for each component and these can be evaluated reliably and repeatedly by properly designed component tests. This direct, simple approach will enable the manufacturers to concentrate on the important process, the design of efficient body components to improve occupant protection in real accidents.

REFERENCES

1. NHTSA Docket 79-04; Notice 1—Comments of General Motors Corporation Regarding Side Impact Protection (FMVSS 214) USG—1903.
2. General Motors Corporation—Side Impact Insights From General Motors Field Accident Data Base—R. Mehta, J. C. Pearson, R. A. Wilson—8th ESV Conference—October 21, 1980.
3. General Motors Corporation—Side Impact Subsystem Test Development—C. J. Griswold, R. A. Wilson, R. Mehta—8th ESV Conference—October 21, 1980.
4. Twenty-Third Stapp Conference—Modification of Part 572 Dummy for Lateral Impact According to Biomechanical Data—R. Stalnaker, C. Tarrière, A. Fayon, G. Walfisch, M. Balthazard, J. Masset, C. Got, A. Patel.
5. NHTSA Docket 79-04; Notice I—048 General Motors Corporation—Side Impact Subsystem Test Development—Progress Report—October 1, 1981—USG 2092 Part II.
6. General Motors Corporation—Vehicle Side Impact Structural Analysis—Chi Mou Ni—Ninth International Technical Conference On Experimental Safety Vehicles—November 1, 1982.

APPENDIX

Automotive Interior Head Impact Test System-Operation Procedure

ABSTRACT

An automotive interior head impact test system has been developed to assess head injury potential due to impact with a vehicle interior. This report documents design features, operating sequence, and test procedure for this laboratory tool.

OBJECTIVE

The objective of this project was to design and fabricate a laboratory tool for assessing head injury potential due to impacts with a vehicle interior. The test system design criteria included the following capabilities:

1. Assess head injury potential due to impact with a passenger car interior, especially as a result of a vehicle collision to the sides or quarters (i.e., occupant head contact with the top of the vehicle door trim pad, roof rails, "A" and "B" pillars, side glass, and windshield header).
2. Measure energy absorption characteristics of a vehicle interior in a manner related to impact with an occupant's head.

The design (Figure A-1) permits use with a complete automotive vehicle requiring a minimum of preparation. An alternative approach where only a removed portion of a vehicle is supported by a test fixture permits use of the impact test device for vehicle interior component testing. The test system can also be used to impact areas of head contact identified from analysis of field accident data for side collisions, and can duplicate the direction of motion at impact expected under actual accident conditions.

SUMMARY

An interior head impact test system which meets the above criteria has been developed. Currently, a working model of the impact device and beam assembly is operational (Figure A-2). Parameter and prooftesting of the impact device (up to 30 km/h) has been completed.

DISCUSSION

The following discussion consists of design features, a general operating sequence, and a standard test procedure for the interior head impact test system.

Features:

1. Moving mass approximates that of a human head (approximately 5 kg).
2. Curvature of impacting surface approximates that of a human head (165 mm spherical zone surface).
3. Motion of moving mass is linearly constrained to one degree of freedom by a low friction, high rigidity bearing system to minimize sensitivity to side loading from angled impacts and off-axis impact pressure distributions (Figures A-3 and A-5). Maximum crush of the impacted surface of at least 118 mm can be accommodated.
4. There are no significant extraneous forces acting on the moving mass in the direction of motion while it is in contact with the impact target. This results from a low friction linear bearing system (Figures A-3 and A-5), rearward-vented gas discharge (Figure A-4), free piston design (Figure A-4), and ventilated push-rod (Figure A-4).
5. Head impacts at speeds up to at least 50 km/h can be simulated. However, the safety systems have only been prooftested to 30 km/h.
6. Head form acceleration is measured by an integral accelerometer (Figure A-4). The signal may be processed to obtain injury assessment parameters such as maximum acceleration, Gadd Severity Index, or other measurement functions.
7. Measurement of head form velocity prior to and after the impact event is made by an interrupted light beam transducer (Figures A-3 and A-5). Energy absorbed by the impacted structure may be calculated as:

$$\text{Energy Absorbed} = \frac{\text{Moving Mass}}{2} (\text{Velocity Out}^2 - \text{Velocity In}^2)$$

8. Velocity measurement correction for any motion of the stationary portion of the light beam velocity transducer can be obtained from the integrated signal of an integral velocity ground reference accelerometer.

   Velocity correction is calculated as:

Determine average value of the computed ground reference velocity over the time period from when the velocity trap flag enters the light beam to when it exits. The end of the time period is indicated by the velocity trap contact signal.

$$V_{(actual)} = V_{(light\ beam\ transducer)} + V_{(ground\ ref.\ correction)}$$

9. The head impact areas within the test vehicle can be impacted in the appropriate directions through mutual functioning of the following design features.
   A. The impact device has a relatively short length and small diameter, and requires a small pretest spacing from the surface to be impacted. The short length is rendered possible by a unique means for structural support, linear bearing configuration, angular adjustment, and common axis gas entry path (Figures A-3, A-4 and A-5), and is particularly critical for downward impacts to the top of the door trim pad (Figure A-6).
   B. A two-axis 180 degree solid angle angular adjustment mechanism is used to orient, support, and rigidly clamp the impact device (Figure A-6).
   C. A structural beam supports the above angular adjustment mechanism in a vertically offset manner with sufficient length to extend through the width of a vehicle (Figures A-1 and A-6).
10. A moving mass rebound energy control system protects the impact test device and prevents multiple impacts (Figure A-7).
11. A moving mass over-travel energy control system protects the impact test device from significant mechanical damage by restraining the moving mass in the event of over-travel (Figure A-7).
12. A pneumatic system accelerates the moving mass (Figure A-4).
    A. A pressurized gas reservoir provides an energy storage medium.
    B. A rapidly acting high flow area valve releases the pressurized gas charge into the impact device.
    C. A valve and muffler/diffuser rapidly and safely aborts the gas charge through a check valve to prevent moisture laden air from entering the pneumatic system.
    D. A gas flow swivel and mounting configuration, in conjunction with the two-axis angular adjustment mechanism, allow the pneumatic system to clear the test vehicle interior.
    E. Machine control is provided by a remote gas charge and pneumatic valve control console.
    F. A small orifice between the charge hose and the reservoir minimizes the effect of stored gas energy in the compliant hose connected to the reservoir. This maintains a repeatable reservoir volume.
13. An electromechanical locking mechanism in the rear of the impact device provides additional protection against accidental operation.
14. Electrical switches inhibit operation of the impact device unless the following conditions are satisfied.
    A. Moving mass must be fully retracted.
    B. Rebound energy control shock absorber must be fully extended.
    C. Locking mechanism must be fully engaged to permit charging of the gas reservoir.
    D. Locking mechanism must be fully disengaged to permit release of gas charge to actuate the impact device.
15. A magnetic device restrains the moving mass prior to being accelerated for downward angled impacts.
16. A pneumatic waste gate system with selectable orifice sizes permits low speed impact tests (Figures A-4 and A-8).

The Effects of Lateral Collision Speeds, Vehicle Side Stiffness and Occupant Spacing to the Vehicle Door Upon Initial Impact Speed of the Occupant

S. BACKAITIS
National Highway Traffic Safety Administration

D. H. ROBBINS
Highway Safety Research Institute
University of Michigan

ABSTRACT

The effects of vehicle impact speeds, door stiffness and occupant spacing with respect to the impacted door surface on occupant collision speeds were investigated in simulated lateral impacts using the MVMA-2D model. The study matrix included 10, 20 and 30 mph ΔV collisions; 2, 4 and 6 inch occupant to door spacings; and two side structures of different stiffness characteristics. The data showed that the control of whole door stiffness is more effective in achieving reduced occupant impact velocities than occupant spacing or the attempts to limit the intrusions at either the upper or lower portions of the door. The study also showed that the height of the predominant intrusion controls the direction of occupant rotation and that increased lateral vehicle stiffness results in lower residual occupant velocities.

BACKGROUND

Most of the lateral collision studies conducted to date compare the injury outcome to the occupant on the basis of forces, g-levels, severity indices, etc. These were arrived at using either mathematical modeling, experimental laboratory tests, or actual vehicle tests. While all of these attempts to predict injury have certain merit, each of them suffers from certain shortcomings with respect either to the ability to measure the desired phenomenon or to the rigorous definitions of the dynamic characteristics within the model which determine the impact response of the human simulation.

The aim of this study is to circumvent some of the problems and uncertainties encountered in previous studies by comparing only the initial impact speed between the occupant and the interior surfaces of the vehicle door during lateral impacts. This paper is based on the assumption that the initial impact speed of the occupant by the interior surfaces of the vehicle is one of the important factors in injury causation. It also recognizes the fact that vehicle interior shape and energy absorption characteristics as well as occupant age and size factors are critical corresponding elements. Furthermore, secondary and third impacts could also enter into the injury causation picture, but these are believed to be of lesser importance in the side impact mode.

This study aims to produce some insight of how vehicle stiffness and occupant spacing parameters can be effectively coordinated to minimize the initial occupant impact speed in side collisions. All other aspects of occupant protection are beyond the scope of this study.

APPROACH

This study employs the MVMA 2-D model (1) to predict occupant initial impact speeds into interior surfaces of the vehicle (doors) as a function of side impact speed, side stiffness of the vehicle, and occupant spacing to the inner door panels. In this study, the MVMA 2-D model was converted to the side impact configuration. The occupant model is seated on a simulated vehicle seat with its feet resting on the simulated floor (Fig. 1). The door panels are arranged in a vertical orientation adjacent to the side of the human simulation. At impact, the door is permitted to collapse laterally towards the occupant with

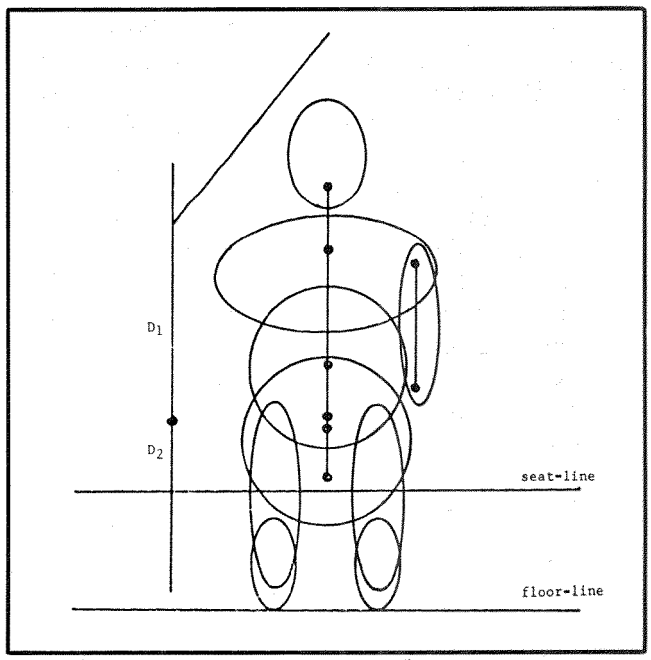


Figure 1. MVMA-2D simulation in the lateral impact environment.

an overshoot of either 1.5 or 2.0 times the common vehicle speed which in turn causes the vehicle compartment to move underneath the occupant.

The computer model exercises were performed under contract at the Highway Safety Research Institute (HSRI). The MVMA 2-D model was adapted for this purpose by lumping the right arm and its links with the torso. For the purpose of this study the masses of both legs were lumped together. The specifications of vehicle contact regions by the dummy are listed in Appendix A.

This model exercises aims to explore the importance of occupant spacing, vehicle side stiffness (doors), and vehicle differential velocities (ΔV) in the control of initial occupant impact speeds, thorax penetration and residual occupant velocities, and to quantify the changes when these parameters are varied. To some extent this study extends the scope of the investigation performed by Padgaonkar (2) as reported in the 23rd Stapp Car Crash Conference. None of this work, however, was correlated to real world experiments, thus the validity of the conclusions are subject to later verification.

DESCRIPTION OF THE EXPERIMENT

The selected impact speeds for this study were 10, 20 and 30 mph with occupant spacing 2, 4 and 6 inches from the door inner panel surface for each of the impact speeds. The door crush was established by assuming that the door is experiencing relative to the delta V of the impacted vehicle a short duration velocity overshoot of either 1.5 or 2.0 ΔV which then gradually drops off to the common vehicle speed. Figures 2a and 2b portray graphically the acceleration and velocity pulse profiles used in this study. Their general characteristics correspond reasonably well with those cited in References 2, 6, 7, 8. Three types of vehicle deformations were considered for this study: 1) the complete door collapsing at a uniform rate and depth, 2) the upper part of the door collapsing approximately 30% more (at the outer door panel) than the lower portion of the door, and 3) the upper portion of the door collapsing approximately 30% less (at the outer door panel) than the lower half. In all cases this also causes some intrusion of the door inner panel into the occupant compartment.

To accomplish the above, the door was selectively allowed at impact a short time overshoot of the impact speed at $2 \times \Delta V$ resulting in a larger door panel deflection and $1.5 \times \Delta V$ for the smaller door panel deflection. Table 1 summarizes the test matrix of the model exercise which consists of a total of 36 runs.

The MVMA occupant model used in this exercise has the 50% size characteristics and represents essentially the Part 572 mass distribution. It is unrestrained to motion except for the effects of seat and foot friction and the existence of the door line which is adjacent to the occupant's side if and when they come into contact with each other. Because of some problems with the head-liner geometry representation, this study compares only the kinematics of the upper and the lower halves of the occupant torso (represented by the interaction of the respective model ellipsoids with the door surfaces). The effects of head kinematics on the impact speeds of the two torso surfaces appear to be negligible due to the fact that in most instances it takes place only after the initial impact by the torso has already occurred.

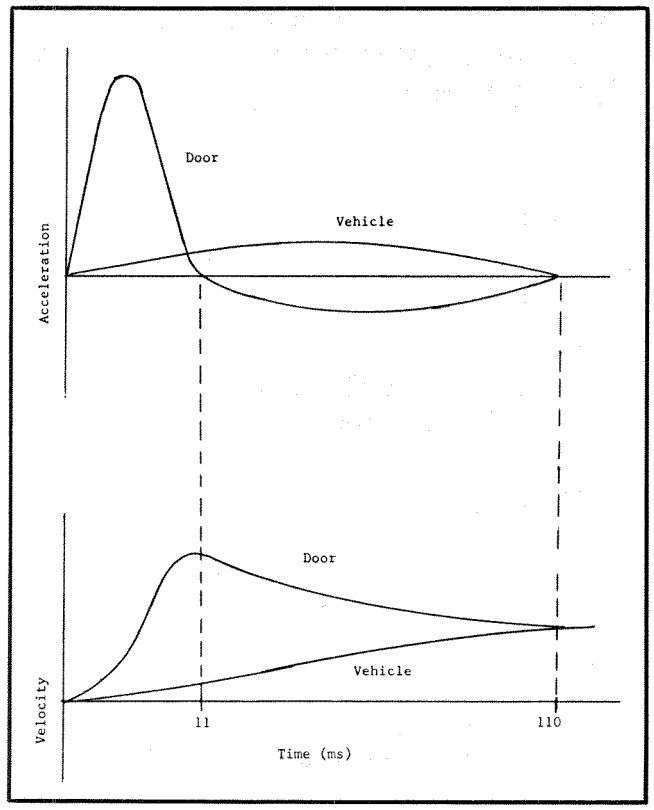


Figure 2. Acceleration and velocity profiles of the vehicle and its doors in lateral impacts.

The maximum occupant impact speed values are established by adding the calculated thorax deflection rates to the corresponding deflection rates of the door line (Table 2). In all instances, the maximum values occur within 0 to 4 ms of first contact. The tabulated data are presented in digitized tabular form with calculated values listed in one millisecond intervals for a total duration of 110 ms. This time duration appears to be adequate to provide a good visibility over the entire first contact crash event and to assure the analyst that no other impact speeds exceed the value listed for that particular body region.

Although the computer runs also generated a substantial amount of other occupant response data, only maximum thorax deflections and the rebound velocities of the torso at the end of 110 ms were additionally extracted to gain some further insight into the consequences of the first impact speed. Analysis of other calculated responses

Table 1. MVMA-2D model lateral impact matrix (50th percentile occupant).

G = 2, 4 & 6 in.

ΔV IMPACT SPEEDS (MPH)		10		20		30		
IMPACT DURATION (MS)		110		110		110		
MAXIMUM VEHICLE ACCELERATION (g)		7.2		14.4		21.6		TOTAL NO. OF RUNS
	COMBINATION	1	2	1	2	1	2	18
FOR 2ΔV OVERSHOOT AND 1.5ΔV OVERSHOOT $D_1 \gtrless D_2$	D_1 *(Acceleration - g)	143/-6.5	107.3/-3.2	(286/-13)	214.6/-6.5	429/-195	322/-9	
	Time - T_1/T_2 (MS)	10/110	10/110	10/110	10/100	10/100	10/100	
	D_2 *(Acceleration - g)	107.3/3.2	143/-25	(214.6/-65)	286/-13	322/-9.6	429/-19	
	Time - T_1/T_2) (MS)	10/110	10/110	10/110	10/110	10/110	10/110	
	INTRUSION at D_1* (in.)	7.9	3.5	15.8	7.1	23.7	10.4	
	D_2* (in.)	3.5	7.9	7.1	15.8	10.4	23.7	
	COMBINATION	1	2	1	2	1	2	18
		2ΔV	1.5ΔV	2ΔV	1.5ΔV	2ΔV	1.5ΔV	
FOR 2ΔV OVERSHOOT AND 1.5ΔV OVERSHOOT $D_1 = D_2$	D_1*(Acceleration - g)	143/-6.5	107.3/-6.5	286/-13	214.6/-6.5	429/-19.5	322/-9	
	Time - T_1/T_2 (MS)	10/110	10/110	10/110	10/110	10/110	10/110	
	D_2*(Acceleration - g)	143/-6.5	107.3/-6.5	286/-13	214.6/-6.5	429/-19.5	322/-9	
	Time - T_1/T_2 (MS)	10/110	10/110	10/110	10/110	10/110	10/110	
	INTRUSION at D_1* (in.)	7.9	3.5	15.8	7.1	23.7	10.4	
	D_2* (in.)	7.9	3.5	15.8	7.1	23.7	10.4	
	TOTAL NO. OF RUNS	6	6	6	6	6	6	36

G - Occupant to door line clearance
D_1 - Upper portion of the door line
D_2 - Lower portion of the door line
* - Intrusion and acceleration values at the door level based on initially calculated values. Final values are listed in Appendix A.

were avoided in order to maintain focus on the subject of this investigation and to preclude the generation of potentially erroneous conclusions which may be created by shortcomings in the characterization of the model.

LIMITATIONS

This study, focalizing on impact velocities, is far from ideal. It must be recognized that modeling is still as much art as it is science, especially when it involves the replication of the human being. The characteristics used in the model at best only approximate the physical properties of the human. In many instances these properties are not known in the dynamic response sense and in some instances they are not well understood. It must also be realized that the two-dimensional model is a crude representation of a three-dimensional event even if the event occurs along a uniplanar axis. The appropriateness of lumping of masses to achieve kinematic realism in side impacts still needs to be verified.

Unlike in the frontal collision mode, the side collision simulation requires kinematic inputs of vehicle structures which even to date are only crudely understood. The kinematics used in this study is based on idealized structural responses which may not necessarily be occurring with that precision and sequence in real world accidents. Furthermore, the three-dimensional event has been compressed into a single lateral plane in which the initial load surface(s) is a straight vertical line. In addition, the floor and seat (occupant compartment) responses are indexed to occur by a certain delayed phasing relative to the door impact which may not necessarily reflect the realism of the accident event. The impact event is based on a uniform 110 ms structural response duration for all impact speeds. A single time duration such as this probably does not reflect the average reality. However, for the purposes of this study, in which the first impact of the occupant is the focus, a great precision for the pulse profile beyond the first contact is not needed.

The results of this study are also highly dependent on the definition used for the occupant impact speed. It is defined as the summation of the deflection rates of either the thorax or the pelvic bone ellipsoids and their respective door surfaces until the maximum is found at some particular time. In most instances, but not in all, the combined values are nearly identical to the inertial velocity values calculated for the overall thorax at that particular time. When viewing the results, it should be kept in mind that the impact speed calculations are based on idealized interactions of surfaces, such as undistorted perfectly vertically oriented door-lines, armless human simulations, etc., which certainly do not occur in this form in real world accidents. Nevertheless, the authors believe, that the model exercise provides on the basis of inertial responses reasonably accurate data to allow the prediction of trends within the bounds of the parameter variance.

Table 2. Typical digital output format of the results.

DEC 5, 198102:18:39 DOT S-33 PAGE 31-04- 1
3D-2D: RIGHT ARM-ARM LINKS/LEFT ARM-LUMPED WITH TORSO/RIGHT AND LEFT LEGS-LUMPED TOGETHER OCCUPANT IS STRUCK FROM LEFT SIDE

CONTACT INTERACTION BETWEEN

ELLIPSE UPPER TORSO MADE OF THORAX MATERIAL

AND

LINE DOORLINE WHICH IS AN ELEMENT OF REGION D1 MADE OF DOOR MATERIAL

INITIAL LINE LENGTH = 22.00(IN) EDGE CONSTANT = 0.0

		DEFLECTION		DEFL. RATE		FORCE		CONTACT LOCATION ON LINE		CONTACT LOCATION IN SPACE		CONTACT LOCATION ON BODY SEG.	
TIME		LINE	ELLIPSE	LINE	ELLIPSE	NORMAL	TANGNTL.	POSITION	RATE	X	Z	X	Z
(MSEC)		(IN)	(IN)	(IN/SEC)	(IN/SEC)	(LB)	(LB)	(NONDIM.)	(IN/SEC)	(IN)	(IN)	(IN)	(IN)
0.0		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
1.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
2.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
3.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
4.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
5.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
6.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
7.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
8.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
9.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
10.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
11.00	X	0.03	0.13	177.	884.	25.7	0.7	0.500	-1.	-9.05	-29.00	0.00	9.05
12.00		0.10	0.49	155.	777.	98.4	2.8	0.500	-1.	-9.05	-29.00	0.00	9.05
13.00		0.13	0.90	54.	751.	128.5	4.0	0.500	-2.	-9.05	-29.00	0.01	9.05
14.00		0.16	1.30	46.	630.	157.4	5.7	0.500	-2.	-9.05	-29.01	0.01	9.05
15.00		0.19	1.71	38.	509.	186.2	8.6	0.500	-2.	-9.05	-29.01	0.01	9.05
16.00		0.32	2.00	134.	296.	321.8	20.6	0.500	-3.	-9.05	-29.01	0.01	9.05
17.00		0.55	2.20	231.	195.	553.9	49.5	0.500	-4.	-9.04	-29.01	0.01	9.05
18.00		0.78	2.39	228.	193.	783.6	95.3	0.500	-6.	-9.03	-29.01	0.01	9.05
19.00		1.01	2.59	224.	190.	1009.8	158.2	0.500	-8.	-9.01	-29.01	0.02	9.05
20.00		1.23	2.77	220.	186.	1231.9	243.3	0.500	-10.	-8.98	-29.01	0.02	9.05
21.00		1.45	2.96	214.	181.	1448.9	289.8	0.500	-13.	-8.95	-29.01	0.03	9.05
22.00		1.68	3.12	225.	159.	1677.1	335.4	0.500	-15.	-8.90	-29.01	0.03	9.05
23.00		1.90	3.27	221.	148.	1902.9	380.6	0.500	-18.	-8.84	-29.01	0.04	9.05
24.00		2.02	3.51	118.	233.	2262.0	452.4	0.500	-19.	-8.77	-29.01	0.04	9.05
25.00		2.06	3.81	39.	290.	2711.6	542.3	0.501	-20.	-8.67	-29.01	0.05	9.05
26.00		2.10	4.09	36.	266.	3128.9	625.8	0.501	-20.	-8.55	-29.02	0.07	9.05
27.00		2.14	4.34	33.	239.	3508.3	701.7	0.502	-19.	-8.40	-29.04	0.08	9.05
28.00		2.17	4.56	29.	209.	3844.9	769.0	0.503	-18.	-8.22	-29.06	0.10	9.05
29.00		2.19	4.76	24.	176.	4134.4	826.9	0.504	-14.	-8.01	-29.10	0.12	9.05
30.00		2.22	4.92	19.	141.	4372.7	738.8	0.507	-8.	-7.75	-29.15	0.14	9.05
31.00		2.25	5.02	31.	87.	4775.3	423.9	0.510	-4.	-7.46	-29.21	0.17	9.04
32.00		2.31	5.06	40.	29.	5378.4	240.5	0.513	-2.	-7.11	-29.29	0.21	9.04
33.00		2.33	5.07	9.	7.	5653.3	192.1	0.518	-2.	-6.72	-29.39	0.25	9.04
34.00		2.33	5.07	-22.	-16.	5581.3	270.6	0.523	-2.	-6.27	-29.51	0.30	9.03
35.00		2.29	5.04	-53.	-38.	5164.6	429.6	0.529	-4.	-5.77	-29.64	0.35	9.03
36.00		2.23	4.99	-74.	-64.	4484.7	687.6	0.536	-8.	-5.22	-29.79	0.42	9.02
37.00		2.21	4.85	-22.	-160.	4273.6	854.7	0.543	-13.	-4.63	-29.95	0.49	9.00
38.00		2.18	4.67	-27.	-197.	4006.2	801.2	0.551	-21.	-3.99	-30.11	0.57	8.99
39.00		2.15	4.46	-32.	-232.	3684.3	736.9	0.558	-30.	-3.31	-30.29	0.65	8.97
40.00		2.12	4.21	-36.	-267.	3309.7	661.9	0.566	-41.	-2.59	-30.46	0.75	8.94
41.00		2.08	3.92	-41.	-299.	2884.8	577.0	0.574	-54.	-1.83	-30.63	0.85	8.91
42.00		2.04	3.61	-45.	-328.	2414.0	482.8	0.582	-67.	-1.04	-30.81	0.96	8.87
43.00		1.96	3.30	-84.	-316.	1956.1	391.2	0.590	-80.	-0.22	-30.97	1.08	8.82
44.00		1.71	3.14	-254.	-169.	1709.1	341.8	0.597	-91.	0.63	-31.12	1.21	8.76
45.00		1.45	2.96	-260.	-181.	1454.6	290.9	0.603	-102.	1.50	-31.26	1.35	8.69
46.00		1.21	2.76	-246.	-208.	1211.8	242.4	0.608	-111.	2.38	-31.38	1.49	8.61
47.00		0.96	2.55	-251.	-212.	963.0	192.6	0.612	-118.	3.28	-31.47	1.64	8.51
48.00		0.71	2.33	-253.	-214.	710.5	142.1	0.615	-124.	4.18	-31.53	1.79	8.41
49.00		0.46	2.12	-254.	-215.	456.8	91.4	0.617	-129.	5.08	-31.57	1.94	8.29
50.00		0.20	1.90	-251.	-213.	204.0	40.8	0.617	-133.	5.99	-31.58	2.10	8.15
51.00		0.17	1.48	-34.	-424.	169.8	34.0	0.617	-136.	6.88	-31.56	2.25	8.01
52.00		0.14	1.05	-30.	-421.	139.5	27.9	0.614	-139.	7.77	-31.52	2.41	7.84
53.00		0.11	0.64	-30.	-413.	109.7	21.9	0.611	-141.	8.65	-31.44	2.57	7.67
54.00	X	0.05	0.26	-58.	-375.	51.2	10.2	0.606	-141.	9.53	-31.33	2.73	7.47
55.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
56.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
57.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
58.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
59.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
60.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
61.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
62.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
63.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
64.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
65.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
66.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
67.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
68.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
69.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
70.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
71.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
72.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
73.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
74.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
75.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
76.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
77.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
78.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
79.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0
80.00		0.0	0.0	0.	0.	0.0	0.0	0.0	0.	0.0	0.0	0.0	0.0

TEST RESULTS AND DISCUSSION

The calculated impact speeds of the thorax and the hip are summarized in Table 3 for the 10, 20 and 30 mph impact speeds at 2, 4 and 6 inch occupant spacings from the door. The maximum penetrations of the upper torso ellipse due to door impact (region D1) are shown in Table 4.

Table 5 lists the rebound velocities of the thorax and the hips and the general angular orientation of the torso relative to the vehicle at the end of the 110 ms crash period to indicate the remaining energy within the body and to permit the reader to estimate where secondary impacts could be expected to occur. Positive velocity value indicates a velocity vector away and minus towards the impacted vehicle surface. The vectorial representation of body orientation is with respect to the vertical and viewing from the rear of the vehicle.

Data of Table 3 were dissected to determine the relative increase or decrease of occupant impact speeds as a function of occupant spacing to the door line and of vehicle impact velocities. The results are summarized in Tables 6, 7 and 8.

The data in Table 6 show that for those crashes where the upper half of the door intrusion predominates ($D_1 > D_2$) 52% reductions of the impact speed of the thorax are achieved with 4 and 6 inches of occupant spacing at 10 mph vehicle ΔV, and 32% with 6 inches at 20 mph ΔV over the comparable 2 inch clearance. There are no benefits obtained at 30 mph ΔV with any of the occupant spacings investigated. The pelvic bone does not experience any impact velocity reductions with occupant spacing above 2 inches at 10 mph ΔV. At 20 mph ΔV the 4 and 6 inch spacings produce reductions of 59%. At 30 mph only the 6 inch spacing results in the reduction of pelvic impact speeds of 59%, whereas the 4 inch clearance reduces these benefits to 11%.

The data in Table 7 show that for impacts where intrusion predominates at the lower portion of the door ($D_2 > D_1$) additional spacing above 2 inches between the occupant and the door has no effects at 10 mph ΔV. At 20 mph the effects of 4 and 6 inch spacing become quite substantial for both the thorax and the pelvis. At 30 mph only the 6 inch spacing is of any value in reducing occupant impact speeds.

Table 8 compares the percent change of occupant impact velocities against vehicle ΔV when the overall door deflection ($D_1 = D_2$) is reduced by approximately 30% (vehicle side is made dynamically stiffer). The data show a general decrease of approximately 25% of occupant

Table 3. Thorax and hip impact velocities (MPH) for 2, 4, and 6 inch occupant—door spacings and 10, 20, and 30 MPH vehicle lateral impacts.

Door Intrusion	Body Area	Impact Velocity (MPH) 2* 10**	20	30	4 10	20	30	6 10	20	30
$D_1 > D_2$	Thorax	17.6	39.7	59.8	8.4	39.8	60.2	8.3	16.8	60.3
$D_1 \propto 2\Delta V$ $D_2 \propto 1.5\Delta V$	Pelvis	6.1	30.1	44.2	6.0	12.3	39.4	6.1	12.3	18.1
$D_2 > D_1$	Thorax	6.1	30.1	44.7	6.1	12.3	44.9	6.0	12.3	18.3
$D_2 \propto 2\Delta V$ $D_1 \propto 1.5\Delta V$	Pelvis	8.3	39.5	56.7	8.2	25.6	60.2	8.3	16.7	45.7
$D_1 = D_2$	Thorax	17.6	39.7	59.8	8.4	39.8	60.2	8.3	16.8	60.3
$D_1 = 2\Delta V$	Pelvis	8.3	39.5	56.7	8.2	25.6	60.2	8.3	16.7	45.7
$D_1 = D_2$	Thorax	6.1	30.1	44.7	6.1	12.3	44.9	6.1	12.3	18.4
$D_2 = 1.5\Delta V$	Pelvis	6.1	30.1	44.2	6.0	12.3	39.4	6.1	12.3	18.1

* Occupant to door panel clearance (in.)

** ΔV of impacted vehicle (mph)

D1 - Upper portion of the door
D2 - Lower portion of the door

Table 4. Thorax penetration (inches) for 2, 4, and 6 inch occupant/door spacings and 10, 20, and 30 MPH vehicle impact speeds.

Door Intrusion	Thorax Penetration (Inches)								
	2*			4			6		
	10**	20	30	10	20	30	10	20	30
$D_1 > D_2$ $D_1 \propto 2\Delta V$ $D_2 \propto 1.5\Delta V$	2.6	3.8	5.1	2.6	3.8	5.1	2.6	3.8	5.1
$D_2 > D_1$ $D_2 \propto 2\Delta V$ $D_1 \propto 1.5\Delta V$	2.2	2.8	3.2	2.1	2.7	3.2	2.1	2.6	3.0
$D_1 = D_2$ $D_1 = 2\Delta V$	2.6	3.6	4.9	2.6	3.6	4.9	2.6	3.6	4.9
$D_1 = D_2$ $D_2 = 1.5\Delta V$	2.3	3.1	3.9	2.3	3.1	3.9	2.3	3.0	3.9

* Occupant to door panel clearance (in.)

** ΔV of impacted vehicle (mph)

D_1 - Upper portion of the door

D_2 - Lower portion of the door

Table 5. Torso orientation and residual velocities (MPH) of thorax and hip (MPH).

Door Intrusion	Body Area	Residual Velocity (MPH) and Torso Orientation								
		2*			4			6		
		10**	20	30	10	20	30	10	20	30
$D_1 > D_2$ $D_1 \propto 2\Delta V$ $D_2 \propto 1.5\Delta V$	Thorax	3.0	6.5	10.4	3.7	4.7	8.6	3.5	5.3	7.4
	Pelvis	↗ -.8	↗ -1.5	↗ 0.7	↗ 2.9	↗ -0.9	↗ -1.3	↗ -1.9	↗ -0.9	↗ -1.1
$D_2 > D_1$ $D_2 \propto 2\Delta V$ $D_1 \propto 1.5\Delta V$	Thorax	-0.7	4.7	20.0	7.4	4.2	8.1	-1.9	5.6	5.6
	Pelvis	↖ 3.4	↖ 6.4	↖ 1.6	↖ 3.4	↖ 4.4	↖ -5.3	↖ 3.5	↖ 3.2	↖ -2.1
$D_1 = D_2$ $D_1 = 2\Delta V$	Thorax	2.5	4.9	NA	4.1	2.6	13.9	5.4	3.6	10.0
	Pelvis	↖ 3.8	↖ 12.2	NA	↖ 3.6	↖ 12.0	↖ 19.0	↖ 3.8	↖ 11.4	↖ 18.3
$D_1 = D_2$ $D_2 = 1.5\Delta V$	Thorax	0.1	-1.9	-0.9	1.3	-1.7	-5.4	.10	0	-5.0
	Pelvis	↖ 0.1	↖ 1.2	↖ 4.7	↖ 0.4	↖ 1.2	↖ 5.1	↖ .6	↖ 0.9	↖ 4.7

* Occupant to door panel clearance (in.)

** ΔV of impacted vehicle (mph)

D_1 - Upper portion of the door

D_2 - Lower portion of the door

Table 6. % Change in occupant impact speeds vs. occupant door spacing for $D_1 > D_2$*.

Space Between Occupant and Door Line (in.)	% Change in Occupant Impact Speeds** 10 mph Thorax	10 mph Pelvis	20 mph Thorax	20 mph Pelvis	30 mph Thorax	30 mph Pelvis
2	0	0	0	0	0	0
4	-52	0	0	-59	-1	-11
6	-53	0	-32	-59	-1	-59

* D_1 is subjected to 2ΔV overshoot and D_2 to 1.5ΔV.
**Based on 2 inch Occupant to Door Line Spacing.

Table 7. % Change in occupant impact speeds vs. occupant door spacing for $D_2 > D_1$*.

Space Between Occupant and Door Line (in.)	% Change in Occupant Impact Speeds** 10 mph Thorax	10 mph Pelvis	20 mph Thorax	20 mph Pelvis	30 mph Thorax	30 mph Pelvis
2	0	0	0	0	0	0
4	0	0	-59	-35	0	+6
6	0	0	-59	-58	-59	-19

* D_1 is subjected to 2ΔV overshoot and D_1 to 1.5ΔV.
**Based on 2 inch Occupant to Door Line Spacing.

Table 8. % Change in occupant impact speeds vs occupant to door spacing for 30% reduction of door intrusion.

Space Between Occupant and Door Line (in.)	% Change in Occupant Impact Speeds* 10 mph Thorax	10 mph Pelvis	20 mph Thorax	20 mph Pelvis	30 mph Thorax	30 mph Pelvis
2	-65	-26	-24	-24	-25	-22
4	-26	-26	-69	-33	-25	-35
6	-26	-26	-27	-27	-69	-60

* Based on 2 inch Occupant to Door Line Spacing.

impact speeds for the three collision speeds and at all occupant spacings. These benefits are much more substantial for the thorax which sees 69% reductions at 10 mph with as little as 2 inches occupant to door spacing and at 20 mph with 4 inches clearance. Six inches of occupant spacing produce over 50% reductions of occupant impact speeds at 30 mph ΔV.

Data of Table 3 were transposed to a bar graph in Figure 3 showing that the thorax impact speeds increase by at least the same ratio as the increments in vehicle collision speeds. These ratios become exponential if the door intercepts a nearly stationary occupant in the early part of the intrusion and while it has a substantial velocity content as demonstrated by the lower stiffness baseline vehicle.

Table 4 shows the predicted thorax penetrations for various vehicle impact speeds and occupant spacings. As may be expected, the predominance of intrusion at the

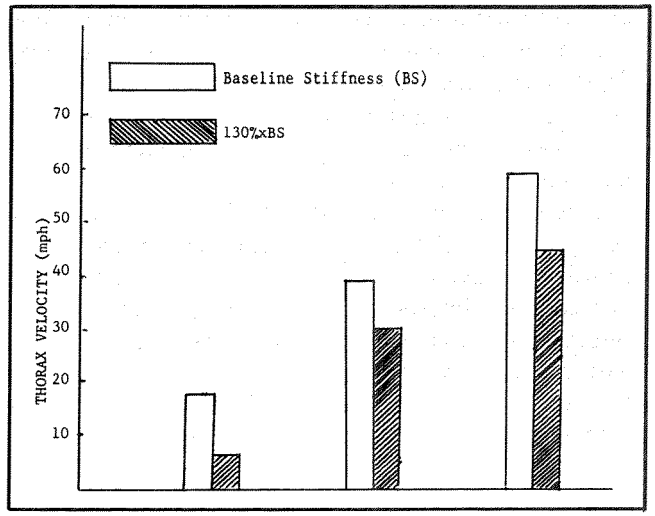


Figure 3. Thorax impact velocity vs. vehicle ΔV in lateral impact.

upper portion of the door yields generally the highest penetration values. Stiffening the side of the vehicle to reduce the door intrusion by approximately 30% decreases the thorax deflections approximately 11% at the 10 mph vehicle ΔV, 15% at 20 mph, and 20% at 30 mph (Figure 4).

Table 5 shows, except for one instance at the 30 mph vehicle ΔV and 2 inches occupant spacing, an increase of residual occupant velocities with the increase of vehicle crash speeds at the 110 ms milestone for both the high and the low door loading conditions. Stiffening the whole door produces lower overall residual impact velocities. There is some indication that larger occupant spacings tend to reduce the residual velocities of the thorax.

Table 5 also contains vectorial information about the general angular direction of the torso orientation at the end of the 110 ms period. The indicated direction is with respect to the vertical and does not contain any data on the magnitude of the rotation. All of the impacts associated with higher magnitudes of intrusion at the upper

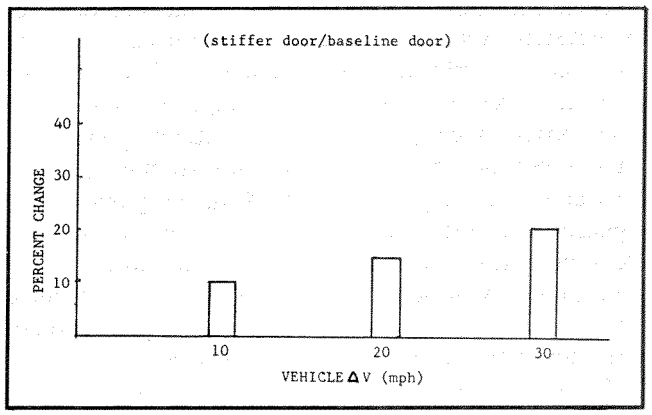


Figure 4. % Reduction in thorax penetration vs. vehicle ΔV in lateral impacts.

door level result in a clockwise occupant rotation. Other impact modes produce counterclockwise motion, except for the one case at 10 mph ΔV, 6 inches occupant spacing and stiffer side structure which allows the occupant to remain essentially vertical due to very low impact speeds transmitted to the occupant.

This study, using the MVMA-2D simulation for investigating the effects of occupant spacing and vehicle collision speeds on the first impact speeds of the occupant, yielded some interesting but not necessarily surprising results. The gross occupant kinematics agree fairly well with occupant motion analysis described by Padgaonkar (2), except that occupant contact durations are somewhat shorter in this study. For initial occupant impact velocity studies this apparent difference is not an important consideration.

The occupant impact data show that maximum impact speeds occur either at or within 4 ms from the first contact with the door-line. The data indicate that highly amplified occupant impact speeds are associated more with vehicle (door) surface impacts into a relatively stationary occupant rather than the occupant impacting relatively stationary vehicle surfaces. Occupant to door spacing is an important consideration in the control of occupant impact speeds for a given vehicle door stiffness. These results contradict somewhat the findings in (2) which indicated practically no benefits due to additional occupant clearance. This discrepancy may not be as significant as it was first thought to be in as much as this study also shows that relatively large occupant spacings do not necessarily produce benefits at low crash speeds, just as at high vehicle crash speeds even large occupant to door spacings, such as 6 inches, are of virtually no benefit.

The study agrees with the findings in (3), (4) and (5) that the best way to reduce occupant to door impact speeds is to reduce the door intrusion through the increase of dynamic door stiffness. This technique lowers the occupant impact speeds at all vehicle crash severities and at all occupant spacings. Of course these benefits are also reflected in considerable reductions of the occupant thorax penetrations.

Door stiffening indicates likewise reductions of occupant residual velocities indicating a lesser chance of injury in second or third collisions. As might have been expected a higher level of intrusion at the upper portion of the door produces clockwise occupant rotations indicating that the occupant's head is moving away from the collision surface towards a potential second impact point on the opposite side of the vehicle. On the other hand a uniform door stiffness or the one that favors intrusions at the hip level produces clockwise rotations of the occupant which are also coupled with simultaneous overall translation of the body, away from the impacted surface.

Review of the timing of impact of the head with its corresponding contact surfaces does not appear to have much effect relative to the time of occurrence of the first impact by the thorax and/or pelvis ellipses. The data show (not listed) that thorax and pelvic bones sustained maximum speeds before the initiation of head impacts. This may not be true for residual torso velocities and rotations especially in those cases where impact by the head occurs. The effects of head impact for these circumstances, however, were not investigated.

SUMMARY AND CONCLUSIONS

The MVMA-2D model was employed to explore the effects of door stiffness, occupant spacing relative to the door and the intensity of the crash speed upon the initial impact velocities of the occupant in simulated vehicle-to-vehicle side collisions. Because of the nature of this two-dimensional analytical study and the assumptions used to characterize the door and the vehicle crash pulses, the results should be viewed only as an indication of trends rather than the statement of absolute values.

The results of the model exercise indicate that occupant spacing, structural intrusion locations and levels, and vehicle crash speeds are important elements in the reduction of first impact speeds that the vehicle occupant will experience during side collisions. Occupant spacing has been found to be less important at lower impact speeds, but of great importance at higher impact speeds, although conceivably, if side structures do not provide adequate stiffness, additional occupant spacing may provide only minimal benefits. With all other parameters held constant the study showed that the occupant's impact speeds are proportional to vehicle crash speeds. Occupant impact speeds go up in direct proportion with vehicle crash speeds when the occupant impacts a nearly stationary door panel. Occupant impact speeds assume an exponential function when the door panel impinges on the relatively stationary occupant with a substantial impact velocity. Increases in the vehicle side stiffness reduce the effects of changes in vehicle impact speeds and the sensitivity associated with occupant to door spacing. Changes in impact speeds, occupant spacings, and door stiffness produce similar results in thorax deflections. While the influence of intrusion by the high and low portions of the door are less clear, the general stiffening of the whole door indicates the reduction of residual velocities for all occupant spacings and impact speeds.

This limited study leads to the conclusion that occupant to door spacing and vehicle door stiffness must be carefully tailored to maximize occupant benefits for the desired range of impact speeds. It also suggests that the mathematical modeling is a good analytical technique to tell the designer how to achieve it.

ACKNOWLEDGEMENT

The authors would like to express their appreciation to Dr. A. Burgett of NHTSA for assistance and advice in setting up the test matrix for this study, to the NHTSA-RM management for providing funds to conduct this study, and to the HSRI staff for their excellent cooperation in performing the computer work.

This paper reflects the personal opinions of the authors and is not necessarily the position of the National Highway Traffic Safety Administration.

REFERENCES

1. B. M. Bowman et al. *MVMA Two-Dimensional Crash Victim Simulator, Version 4, Vol. 3.* Final report to the Vehicle Manufacturers Association, Inc., June 29, 1979. HSRI, University of Michigan, Ann Arbor, Michigan.
2. A. J. Padgaonkar and P. Prasad. *Simulation of Side Impact Using Cal 3-D Occupant Simulation Model,* SAE #791007, 23rd Stapp Car Crash Conference, 1979, Society of Automotive Engineers, Warrendale, Pennsylvania.
3. B. Loyat. *Improvement in the Protection Against Side Impact.* Proceedings, Seventh International Conference on Experimental Safety Vehicles, Paris, France 1979; U.S. Department of Transportation, Washington, D.C.
4. J. Provensal. *Occupant Protection in Lateral Collisions: Special Features of Renault E.P.U.R.E.* Proceedings, Seventh International Conference on Experimental Safety Vehicles, Paris, France, 1979; U.S. Department of Transportation, Washington, D.C.
5. J. Provensal, J. Stcherbatcheff. *Identification of Compatability Factors in Side Collisions.* Proceedings, Eighth International Conference on Experimental Safety Vehicles, Wolfsburg, Germany, 1980; U.S. Department of Transportation, Washington, D.C.
6. L. M. Shaw, C. Clark. *Side Impact Restraint Development and Evaluation Technique.* Proceedings, Eighth International Conference on Experimental Safety Vehicles, Wolfsburg, Germany, 1980; U.S. Department of Transportation, Washington, D.C.
7. J. Hoffmann, H. Appel. *Mathematical Simulation of Side Impact—A Contribution to the Problem of Rigid/Deformable Barriers.* Proceedings, Eighth International Conference on Experimental Safety Vehicles, Wolfsburg, Germany, 1980; U.S. Department of Transportation, Washington, D.C.
8. L. Epron, M. Zaccariotto. *Passenger Protection in Lateral Collision—Non-Destructive Mean Test Development for Lateral Collision Safety Device Study.* Proceedings, Eighth International Conference on Experimental Safety Vehicles, Wolfsburg, Germany, 1980; U.S. Department of Transportation, Washington, D.C.

DEC 5, 198103:50:49 DOT S-44 PAGE 12-00- 1
3D-2D: RIGHT ARM-ARM LINKS/LEFT ARM-LUMPED WITH TORSO/RIGHT AND LEFT LEGS-LUMPED TOGETHER OCCUPANT IS STRUCK FROM LEFT SIDE

DESCRIPTION OF REAL LINE CONTACT REGIONS

SPECIFICATIONS OF REGION FLOOR

MATERIAL OF REGION: FLOOR MATERIAL

NUMBER OF SURFACES IN THE REGION: 1

REGION (X,Z) INPUT IS RELATIVE TO VEHICLE

OUTPUT FOR REGION IS PRINTED IN VEHICLE COORDINATES

MULTIPLE FORCES ACTING ON ONE LINE SEGMENT ARE INDEPENDENT

STANDARD MODEL OF PERMANENT DEFORMATION IS USED

WHEN ONE ELLIPSE CONTACTS SEVERAL SEGMENTS, RESULTING FORCES ARE COMPUTED INDEPENDENTLY

CAVITY ANALYSIS IS NOT USED

STRUCTURAL DEFORMATION IS NOT ALLOWED

DEFINITION OF THE LINES IN THE REGION FLOOR

PARAMETERS OF THE LINE FLOORLINE

PENETRATION LIMIT: 4.0(IN) EDGE CONSTANT: 0.0 DIRECTION FACTOR: 1.0 LINE SEGMENT POSITION WITHIN THE REGION:1

MASS COMPLIANCE AT FIRST ENDPOINT 0.0 (IN/LB SEC**2) BENDING CONSTANT AT FIRST ENDPOINT 0.0 (1/IN**2)

MASS COMPLIENCE AT SECOND ENDPOINT 0.0 (IN/LB SEC**2) BENDING CONSTANT AT SECOND ENDPOINT 0.0 (1/IN**2)

SPECIFIED SEGMENT LOCATIONS AT GIVEN TIMES

TIME (MSEC)	X-COOR. OF FIRST ENDPOINT (IN)	Z-COOR.OF FIRST ENDPOINT (IN)	X-COOR. OF SECOND ENDPOINT (IN)	Z-COOR.OF SECOND ENDPOINT (IN)
0.0	-22.00	0.00	22.00	0.00

DEC 5, 198103:50:49 DOT S-44 PAGE 13-00- 1
3D-2D: RIGHT ARM-ARM LINKS/LEFT ARM-LUMPED WITH TORSO/RIGHT AND LEFT LEGS-LUMPED TOGETHER OCCUPANT IS STRUCK FROM LEFT SIDE

DESCRIPTION OF REAL LINE CONTACT REGIONS

SPECIFICATIONS OF REGION SEAT CUSHION

MATERIAL OF REGION: SEAT MATERIAL

NUMBER OF SURFACES IN THE REGION: 1

REGION (X,Z) INPUT IS RELATIVE TO VEHICLE

OUTPUT FOR REGION IS PRINTED IN VEHICLE COORDINATES

MULTIPLE FORCES ACTING ON ONE LINE SEGMENT ARE INDEPENDENT

STANDARD MODEL OF PERMANENT DEFORMATION IS USED

WHEN ONE ELLIPSE CONTACTS SEVERAL SEGMENTS, RESULTING FORCES ARE COMPUTED INDEPENDENTLY

CAVITY ANALYSIS IS NOT USED

STRUCTURAL DEFORMATION IS NOT ALLOWED

DEFINITION OF THE LINES IN THE REGION SEAT CUSHION

PARAMETERS OF THE LINE SEAT CUSHION LN.

PENETRATION LIMIT: 7.5(IN) EDGE CONSTANT: 0.0 DIRECTION FACTOR:-1.0 LINE SEGMENT POSITION WITHIN THE REGION:1

MASS COMPLIANCE AT FIRST ENDPOINT 0.0 (IN/LB SEC**2) BENDING CONSTANT AT FIRST ENDPOINT 0.0 (1/IN**2)

MASS COMPLIENCE AT SECOND ENDPOINT 0.0 (IN/LB SEC**2) BENDING CONSTANT AT SECOND ENDPOINT 0.0 (1/IN**2)

SPECIFIED SEGMENT LOCATIONS AT GIVEN TIMES

TIME (MSEC)	X-COOR. OF FIRST ENDPOINT (IN)	Z-COOR.OF FIRST ENDPOINT (IN)	X-COOR. OF SECOND ENDPOINT (IN)	Z-COOR.OF SECOND ENDPOINT (IN)
0.0	-22.00	-10.35	22.00	-10.35

Appendix A (continued)

DEC 5, 198103:50:49 DOT S-44 PAGE 14-00- 1
3D-2D: RIGHT ARM-ARM LINKS/LEFT ARM-LUMPED WITH TORSO/RIGHT AND LEFT LEGS-LUMPED TOGETHER OCCUPANT IS STRUCK FROM LEFT SIDE

DESCRIPTION OF REAL LINE CONTACT REGIONS

SPECIFICATIONS OF REGION D2

MATERIAL OF REGION: PANEL MATERIAL

NUMBER OF SURFACES IN THE REGION:

REGION (X,Z) INPUT IS INERTIAL

OUTPUT FOR REGION IS PRINTED IN VEHICLE COORDINATES

MULTIPLE FORCES ACTING ON ONE LINE SEGMENT ARE INDEPENDENT

STANDARD MODEL OF PERMANENT DEFORMATION IS USED

WHEN ONE ELLIPSE CONTACTS SEVERAL SEGMENTS, RESULTING FORCES ARE COMPUTED INDEPENDENTLY

CAVITY ANALYSIS IS NOT USED

STRUCTURAL DEFORMATION IS NOT ALLOWED

DEFINITION OF THE LINES IN THE REGION D2

PARAMETERS OF THE LINE HIP PANEL LINE

PENETRATION LIMIT: 7.5(IN) EDGE CONSTANT: 0.0 DIRECTION FACTOR: 1.0 LINE SEGMENT POSITION WITHIN THE REGION: 1

MASS COMPLIANCE AT FIRST ENDPOINT 0.0 (IN/LB SEC**2) BENDING CONSTANT AT FIRST ENDPOINT 0.0 (1/IN**2)

MASS COMPLIENCE AT SECOND ENDPOINT 0.0 (IN/LB SEC**2) BENDING CONSTANT AT SECOND ENDPOINT 0.0 (1/IN**2)

SPECIFIED SEGMENT LOCATIONS AT GIVEN TIMES

TIME (MSEC)	X-COOR. OF FIRST ENDPOINT (IN)	Z-COOR.OF FIRST ENDPOINT (IN)	X-COOR. OF SECOND ENDPOINT (IN)	Z-COOR.OF SECOND ENDPOINT (IN)
0.0	-13.83	0.0	-13.83	-18.00
9.00	-11.72	0.0	-11.72	-18.00
11.00	-10.66	0.0	-10.66	-18.00
109.00	10.52	0.0	10.52	-18.00

Appendix A (continued)

DEC 5, 198103:50:49 DOT S-44 PAGE 15-00- 1
3D-2D: RIGHT ARM-ARM LINKS/LEFT ARM-LUMPED WITH TORSO/RIGHT AND LEFT LEGS-LUMPED TOGETHER OCCUPANT IS STRUCK FROM LEFT SIDE

DESCRIPTION OF REAL LINE CONTACT REGIONS

SPECIFICATIONS OF REGION H1

MATERIAL OF REGION: PILLAR MATERIAL

NUMBER OF SURFACES IN THE REGION: 1

REGION (X,Z) INPUT IS INERTIAL

OUTPUT FOR REGION IS PRINTED IN VEHICLE COORDINATES

MULTIPLE FORCES ACTING ON ONE LINE SEGMENT ARE INDEPENDENT

STANDARD MODEL OF PERMANENT DEFORMATION IS USED

WHEN ONE ELLIPSE CONTACTS SEVERAL SEGMENTS, RESULTING FORCES ARE COMPUTED INDEPENDENTLY

CAVITY ANALYSIS IS NOT USED

STRUCTURAL DEFORMATION IS NOT ALLOWED

DEFINITION OF THE LINES IN THE REGION H1

PARAMETERS OF THE LINE HEADERLINE

PENETRATION LIMIT: 4.5(IN) EDGE CONSTANT: 0.281 DIRECTION FACTOR: 1.0 LINE SEGMENT POSITION WITHIN THE REGION:1

MASS COMPLIANCE AT FIRST ENDPOINT 0.0 (IN/LB SEC**2) BENDING CONSTANT AT FIRST ENDPOINT 0.0 (1/IN**2)

MASS COMPLIENCE AT SECOND ENDPOINT 0.0 (IN/LB SEC**2) BENDING CONSTANT AT SECOND ENDPOINT 0.0 (1/IN**2)

SPECIFIED SEGMENT LOCATIONS AT GIVEN TIMES

TIME (MSEC)	X-COOR. OF FIRST ENDPOINT (IN)	Z-COOR.OF FIRST ENDPOINT (IN)	X-COOR. OF SECOND ENDPOINT (IN)	Z-COOR.OF SECOND ENDPOINT (IN)
0.0	-13.83	-33.73	0.0	-50.15
9.00	-11.72	-33.73	2.11	-50.15
11.00	-10.66	-33.73	3.17	-50.15
109.00	10.52	-33.73	24.35	-50.15

Appendix A (continued)

```
   DEC  5, 198103:50:49                                    DOT S-44                                              PAGE  16-00- 1
3D-2D:  RIGHT ARM-ARM LINKS/LEFT ARM-LUMPED WITH TORSO/RIGHT AND LEFT LEGS-LUMPED TOGETHER     OCCUPANT IS STRUCK FROM LEFT SIDE

                                        DESCRIPTION OF REAL LINE CONTACT REGIONS


                                      SPECIFICATIONS OF REGION D1

            MATERIAL OF REGION: DOOR MATERIAL
            NUMBER OF SURFACES IN THE REGION:    1
            REGION (X,Z) INPUT IS INERTIAL
            OUTPUT FOR REGION IS PRINTED IN VEHICLE COORDINATES
            MULTIPLE FORCES ACTING ON ONE LINE SEGMENT ARE INDEPENDENT
            STANDARD MODEL OF PERMANENT DEFORMATION IS USED
            WHEN ONE ELLIPSE CONTACTS SEVERAL SEGMENTS, RESULTING FORCES ARE COMPUTED INDEPENDENTLY
            CAVITY ANALYSIS IS NOT USED
            STRUCTURAL DEFORMATION IS NOT ALLOWED
                                    DEFINITION OF THE LINES IN THE REGION D1

                                         PARAMETERS OF THE LINE DOORLINE

PENETRATION LIMIT: 6.8(IN)      EDGE CONSTANT:  0.0       DIRECTION FACTOR: 1.0      LINE SEGMENT POSITION WITHIN THE REGION: 1
MASS COMPLIANCE AT FIRST ENDPOINT      0.0   (IN/LB SEC**2)      BENDING CONSTANT AT FIRST ENDPOINT       0.0 (1/IN**2)
MASS COMPLIENCE AT SECOND ENDPOINT     0.0   (IN/LB SEC**2)      BENDING CONSTANT AT SECOND ENDPOINT      0.0 (1/IN**2)
                                      SPECIFIED SEGMENT LOCATIONS AT GIVEN TIMES

 TIME      X-COOR. OF FIRST ENDPOINT    Z-COOR.OF FIRST ENDPOINT    X-COOR. OF SECOND ENDPOINT    Z-COOR.OF SECOND ENDPOINT
(MSEC)              (IN)                         (IN)                        (IN)                          (IN)

  0.0              -13.83                       -18.00                      -13.83                        -40.00
  9.00             -11.72                       -18.00                      -11.72                        -40.00
 11.00             -10.66                       -18.00                      -10.66                        -40.00
109.00              10.52                       -18.00                       10.52                        -40.00
```

Simulation of an Automobile Front End With a Movable Deformable Barrier

J. PROVENSAL, M. BALTHAZARD and M. PETIOT
Renault State Owned Works
Research and Development Department

INTRODUCTION

Contrary to frontal impacts, for which type-tests have been developed and used from the very outset of secondary safety studies (0° impact and principally 30° impact against fixed and rigid barrier), the lateral impact test has remained much more difficult to specify.

With the exception of the test described in FMVSS 214, known since 1973, and of the procedures suggested by WP 29 or contained in Standard 208, the specification of a dynamic test procedure has come up against many difficulties; this has resulted in the submission of an extremely diversified range of proposals from the different parties involved.

Even today—although it seems that a consensus may be arrived at concerning the type of collision to be used, i.e., the front-to-side collision between two passenger cars—the submitted test procedures remain very diverse. These range from a test using car components (1) to a car-to-car test of the same type and to a moving deformable, dynamometric barrier-to-car (frontal and lateral crash, followed by simulations on mathematical models (2).

It is only recently that a consensus has emerged as to the desirability of a procedure in which the colliding vehicle would be represented by a moving deformable barrier. Research works along these lines have been initiated both in the United States (3), and in France (4) and Europe (5).

As regards Renault, we had started studies as early as 1979 in this field, having for main purpose to investigate a car-to-car crash simulation by means of a simplified moving deformable barrier-to-car test.

This research had been initiated in spite of the major drawback implied by such a procedure, i.e., the impossibility of improving front-to-side vehicle compatibility by acting on one of its three components: the stiffness-and-geometry component of the impacting vehicle front surface.

This objective required that answers be provided to the following basic questions:

1. Is it possible to reasonably simulate the front section of a vehicle by using a device of the type moving deformable barrier, once the type of the car-to-car collision has been determined? It was agreed that the quality of such a simulation had to be evaluated in terms of both:
   - —shell-dummy kinematics of the impacted vehicles;
   - —behavioral characteristic of the deformations produced on the impacted vehicle and therefore of the energy dissipation distribution between impacting and impacted vehicles.
2. Should a satisfactory answer be found to this first question, a second point had to be thoroughly investigated: the repeatability of the test thus determined. Experience with frontal impact suggested that some difficulties could be encountered in this respect. Indeed, while on a first examination the scatter of the results observed for the frontal impact were attributable to the vehicle/restraint/dummy chain, the procedure considered for the lateral impact was more complex *a priori* since it involved, schematically, the chain: *impacting object*/impacted vehicle/restraint/dummy.

The following paper recapitulates the studies made by Renault in view of identifying tentative answers to these two questions.

It should be appreciated that these activities are in fact part of a larger picture including in particular:

- —an active participation in the "Moving Deformable Barrier" programs as established by the CCMC for Europe, and by the UTAC—under commission of the Institut de Recherche des Transports (Transport Research Institute)—for France;
- —a follow-up of the studies made by the Physiology and Biomechanics Laboratory jointly operated by the French automobile manufacturers in order to specify an appropriate dummy for lateral impacts.

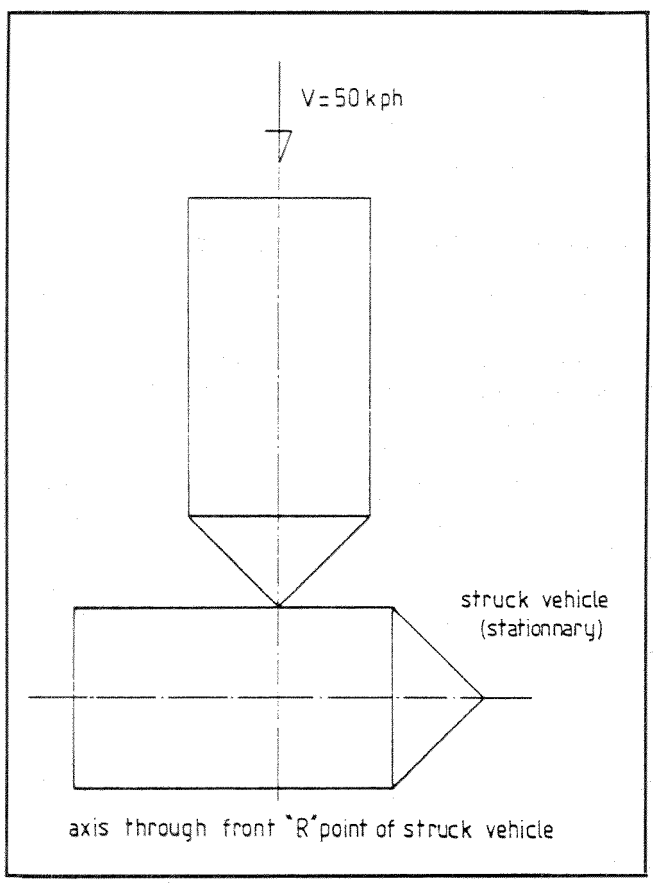


Figure 1. Scheme of experimental collision.

SIMULATION OF A FRONT-TO-SIDE COLLISION BETWEEN TWO VEHICLES

Experimental Collision to Simulate

On the basis of the programs previously mentioned (6), the collision selected for this study is shown in Figure 1.

The two vehicles (type R20) are identical. The impacted vehicle is stationary, in its normal attitude. The impacting vehicle, also in its normal attitude with a dummy placed at the driver's position, travels at a speed of 50 km/h. The impacting vehicle line of travel passes through the projection of the front point R on the outer left panel of the impacted vehicle. The angle formed by the vehicle centerlines is of 90°.

Simulation of Impacting Vehicle Front Section

1. The study of the experimental collisions performed preliminarily to this investigation had pointed to the need for the following:
   - —the deformable face must be capable of allowing a deformation depth of approximately 250 mm;
   - —at the same time, it must have an energy dissipation capability of 30 kJ.

With these assumptions, a determination was to be made of the behavioral characteristic of the load-deflec-

tion law to simulate, in order to obtain the most faithful possible representation of the impacting vehicle front section.

The only available method was to evaluate the deformation law by impacting an R20 against the dynamometric buffer shown in Figure 2, this leading to a later modeling by using appropriately selected energy absorbers.

However, such an approach entails many problems whose answers remain difficult to determine:

a) It is essential that no fundamental discrepancies exist between the behavior of the actual impacting front section and its model. Now, the development of said model is performed by the process described in the chart below, which does not favor the achievement of the agreement sought.

b) The deformation rate of the individual structural components, in a car-to-wall or car-to-car collision, is also a possible source of discrepancy (see Fig. 3).

As regards the panel (sheet metal) components traditionally used in car-making, a recent study (7) has shown that the dynamic gain for localized buckling of a box section component (such as a side member) was related to the deformation rate across the component by the following formula:

$$-\frac{Pmd}{Pms} = 1 + 8.10^{-2}\ Vm^{0,55}$$

where Pmd is the average dynamic load at deformation rate Vm, and Pms is the quasi-static deformation load.

A twofold difference in the deformation rates of the impacting vehicle components (car-to-wall impact as

Impacting object	Obstacle	Impacting structure	Law F = f(e) at interference	Comments
Impacting vehicle	car	A	Fa = f(ea)	Collision to simulate
Impacting vehicle	wall	B	Fb = f(eb)	Determination of law F = f(e)
Deformable face	wall	B′	Fb′ = f(eb′)	Reproduction of law F = f(e)
Deformable face	car	A′	Fa′ = f(ea′)	Collision simulate

It should be noted however that the risk was greater as regards the Renault study (where it is attempted to simulate a specific vehicle) than the risk associated with the programs carried out by the CCMC or by the UTAC where it was attempted, conversely, to reproduce a deformation performance typical of the average vehicle of a given population.

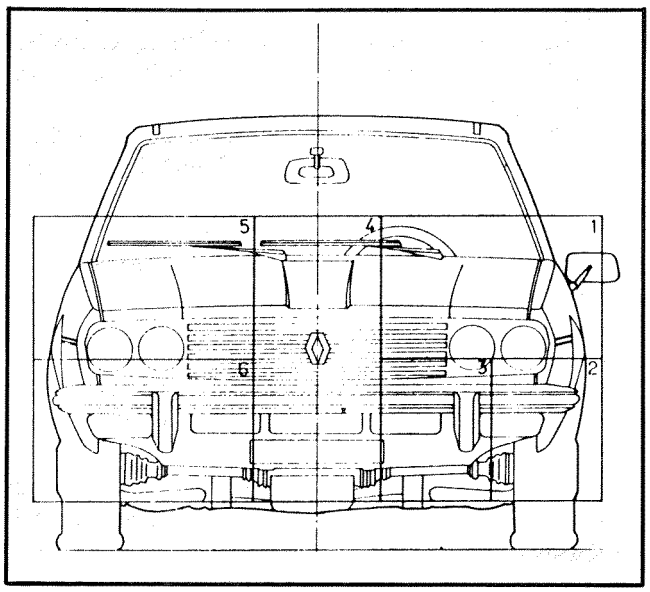


Figure 2. Scheme of R20 against dynamometrical buffer.

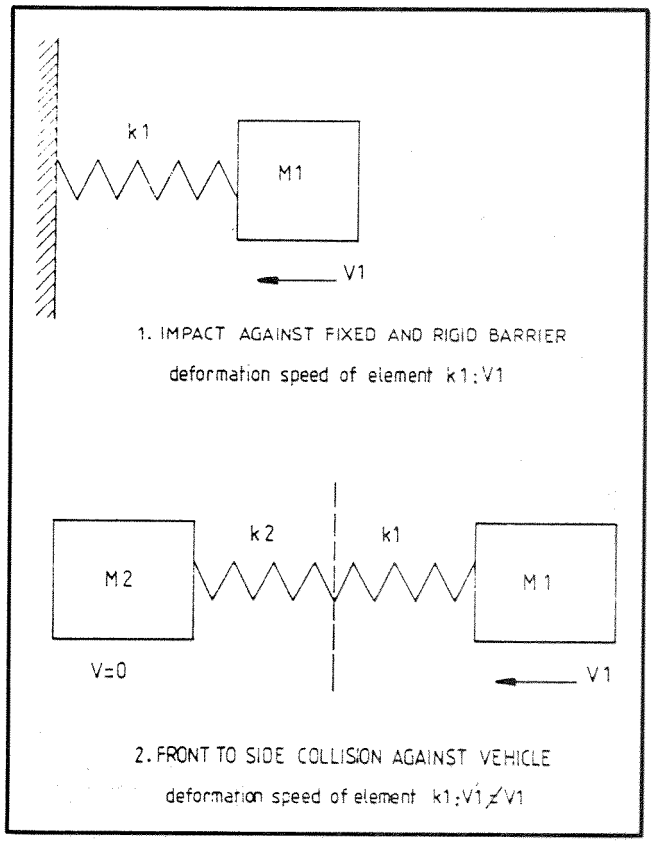


Figure 3. Deformation speeds of structural parts.

compared to car-to-car impact) may then result in a change of approximately 10% in the load, such a change being acceptable only as a first approximation.

c) However, the main difficulty arises out of the heterogeneousness of the impacting vehicle front section which consists of a *combination* of deformable structural components and rigid masses, of which the main one is the power unit. Due to this, there are two types of efforts in the performance observed at the dynamometric buffer: the deformation load which may be appropriately represented by the arrest of the rigid masses which, of course, may not be represented.

A simple mathematical model, already described in reference (8), may be used to bring the problem to light:

—A first vehicle A, schematically shown in Figure 4

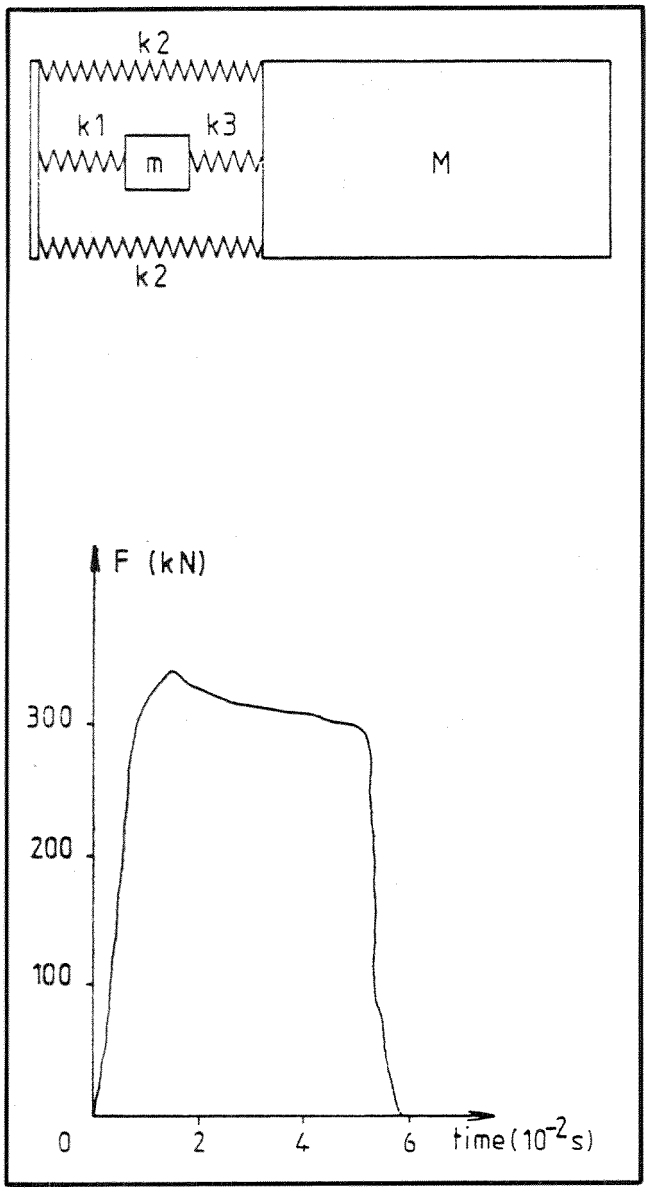


Figure 4. Vehicle "A" simulation.

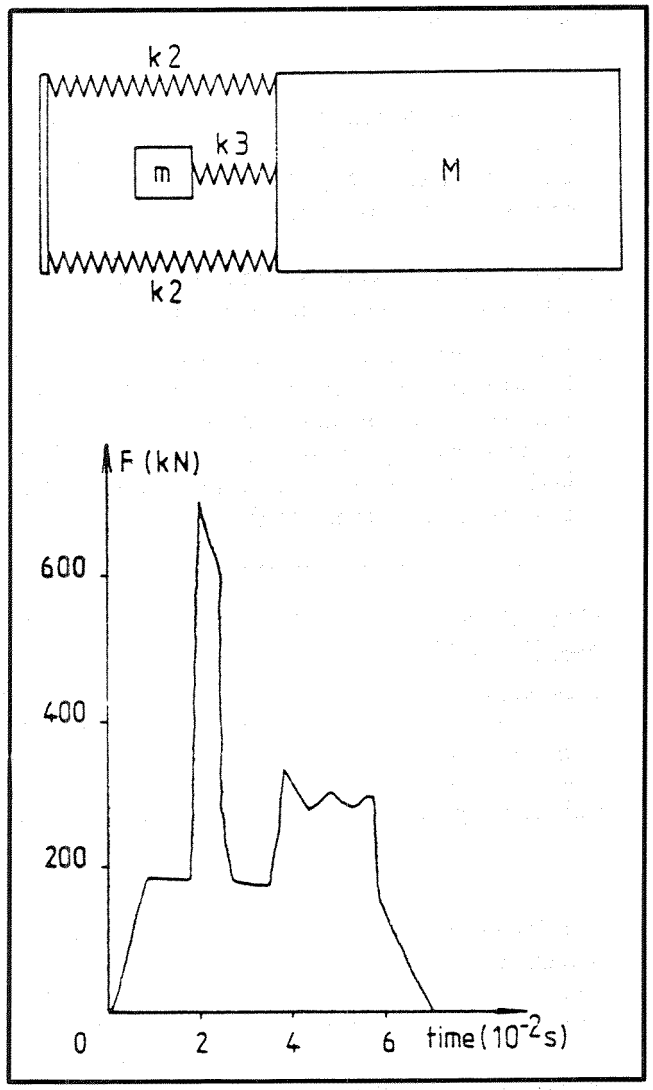


Figure 5. Vehicle "B" simulation.

has the load, deceleration and collapsing characteristics mentioned in said figure for a collision against a perpendicular fixed barrier at 50 km/h.

—The same characteristics are given in Figure 5 for a vehicle B. The front-to-front collision between these two vehicles results in respective decelerations and collapses represented in Table 6.

Replacing vehicle B by a *pure absorber B'* which would behave in accordance with the overall load-deflection law of said vehicle B, would result, upon a collision B'⟶A, in a totally different performance from the first one (see tables). It was therefore essential to avoid this type of error in the design of a deformable face.

2. However, the observation of some car-to-car crash tests previously performed had brought out the following findings:

a) Collapse of the impacting vehicle is kept to a low level in case of lateral collision: Figure 7 compares

Relative impact speed (kph)	Vehicle	Obstacle	Vehicle stroke (m)	Obstacle stroke (m)
50	A	barrier	0,399	/
50	B	barrier	0,456	/
100	A	B	0,393	0,465
100	A	B′	0,605	0,230

B′: Mock up of B, with a force deflexion pulse simulated by a pure energy absorbing device.

Figure 6. Compared results of simulated frontal collisions.

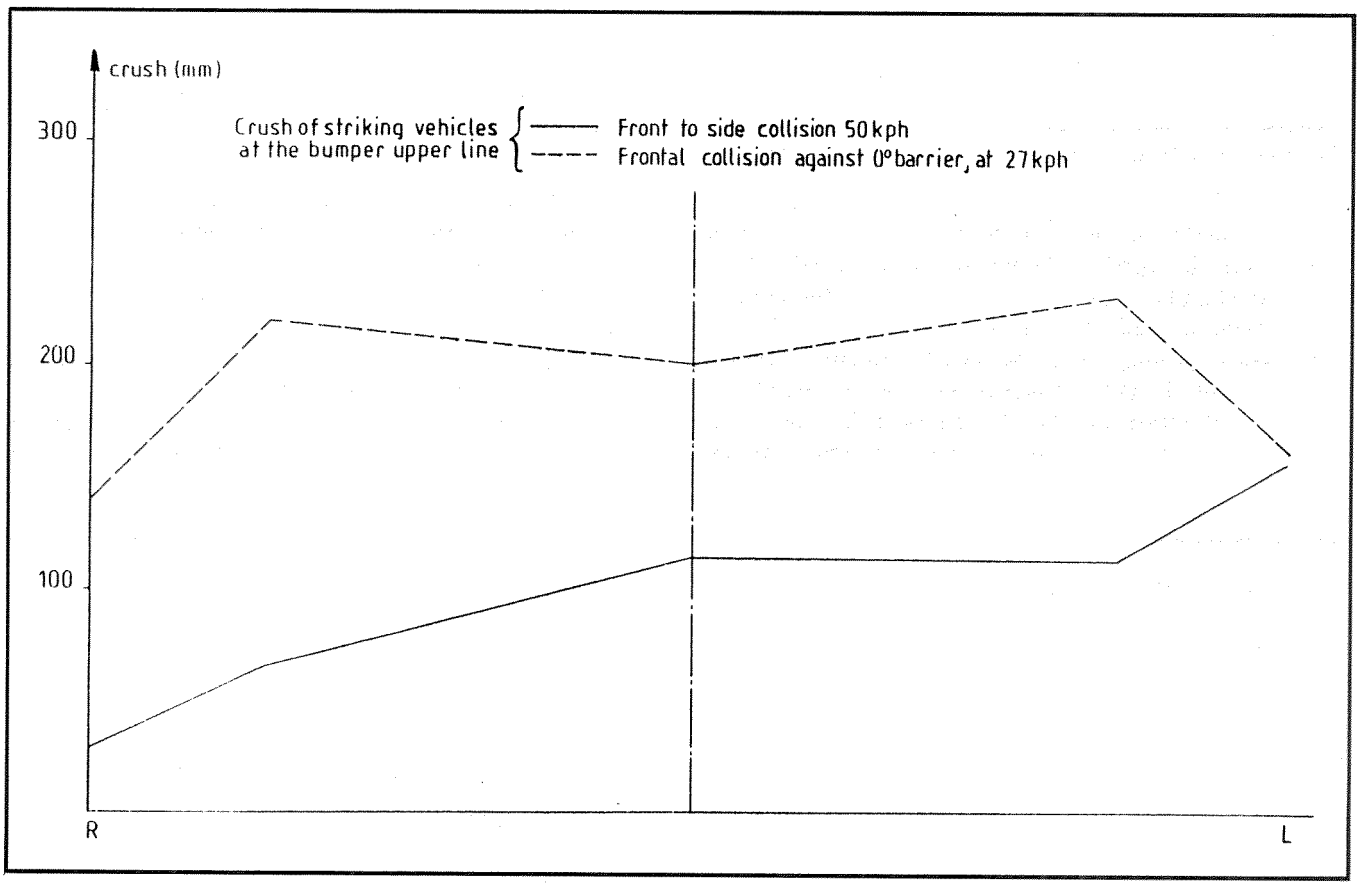


Figure 7. Compared strokes of vehicle front end.

the crushing of the above-bumper part of the front section of a vehicle which was made to crash against a wall, with the crushing of a similar car which was used as the impacting vehicle in a front-to-side crash. This tends to limit the effect of the rigid mass formed by the power unit.

b) The main phenomenon of a lateral collision, for the occupant seated on the percussion side of the impacted vehicle, i.e., the exchange of momentum between the car shell and the occupant himself, occurs at a very early stage in the time sequence of the impact. Figures 8 and 9 show evidence of this fact, for both thorax and pelvis portions. The deceleration pulses for impacting vehicle passenger

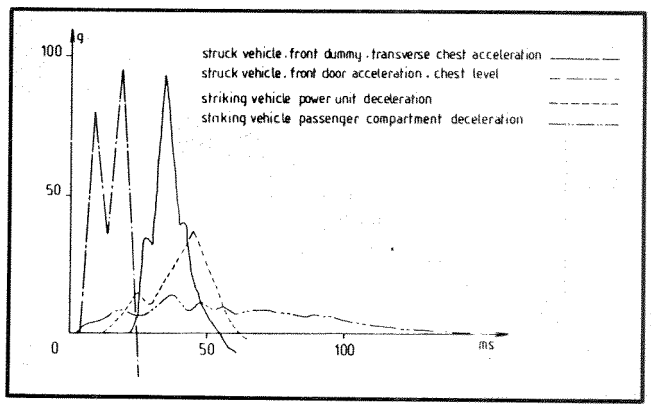


Figure 8. Acceleration pulses chronology—chest level.

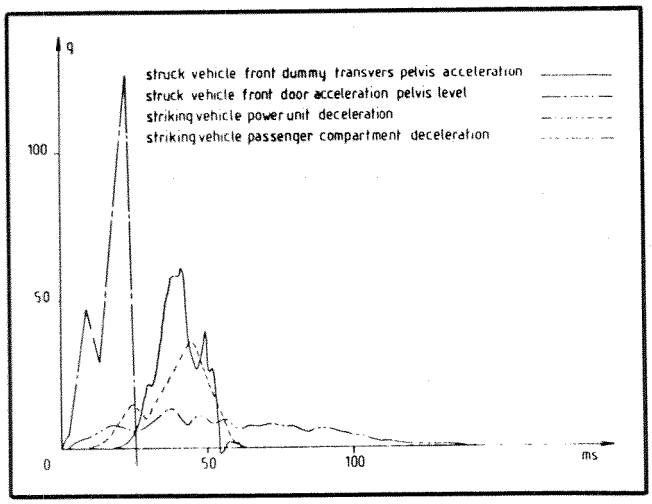


Figure 9. Acceleration pulses chronology—pelvis level.

compartment and power unit have been plotted over the curves relating to the impacted vehicle shell and occupant. It can be seen that the velocity rising of said occupant occurs while the effect of the impacting vehicle power unit remains marginal.

This therefore makes it possible to simulate, as a first approximation, the effects of the power unit by means of an energy absorber located at an appropriate distance from the foremost plane of the deformable face and set to a stress value close to the value recorded for a collision against a perpendicular barrier, at low speed.

Nevertheless, it should be appreciated that this conclusion is liable to be challenged as the sides of the vehicle bodies progress towards increased reinforcement, inasmuch, of course, as an economically feasible reinforcement may achieve on the body side a degree of stiffness close to that of the impacting vehicles front ends.

Determination of the Force Deflection Pulse to Reproduce

Based on the data above discussed, we have plotted together the overall load collapse diagrams for R20 vehicles which were made to crash against a fixed and rigid barrier at speeds of 27 and 50 km/h. From these diagrams, shown in Figure 10, it appears that:

a) These force rising slopes are relatively comparable up to a collapse of 260 mm;
b) The forces obtained after 260 mm are considerably apart, which may be explained essentially by the

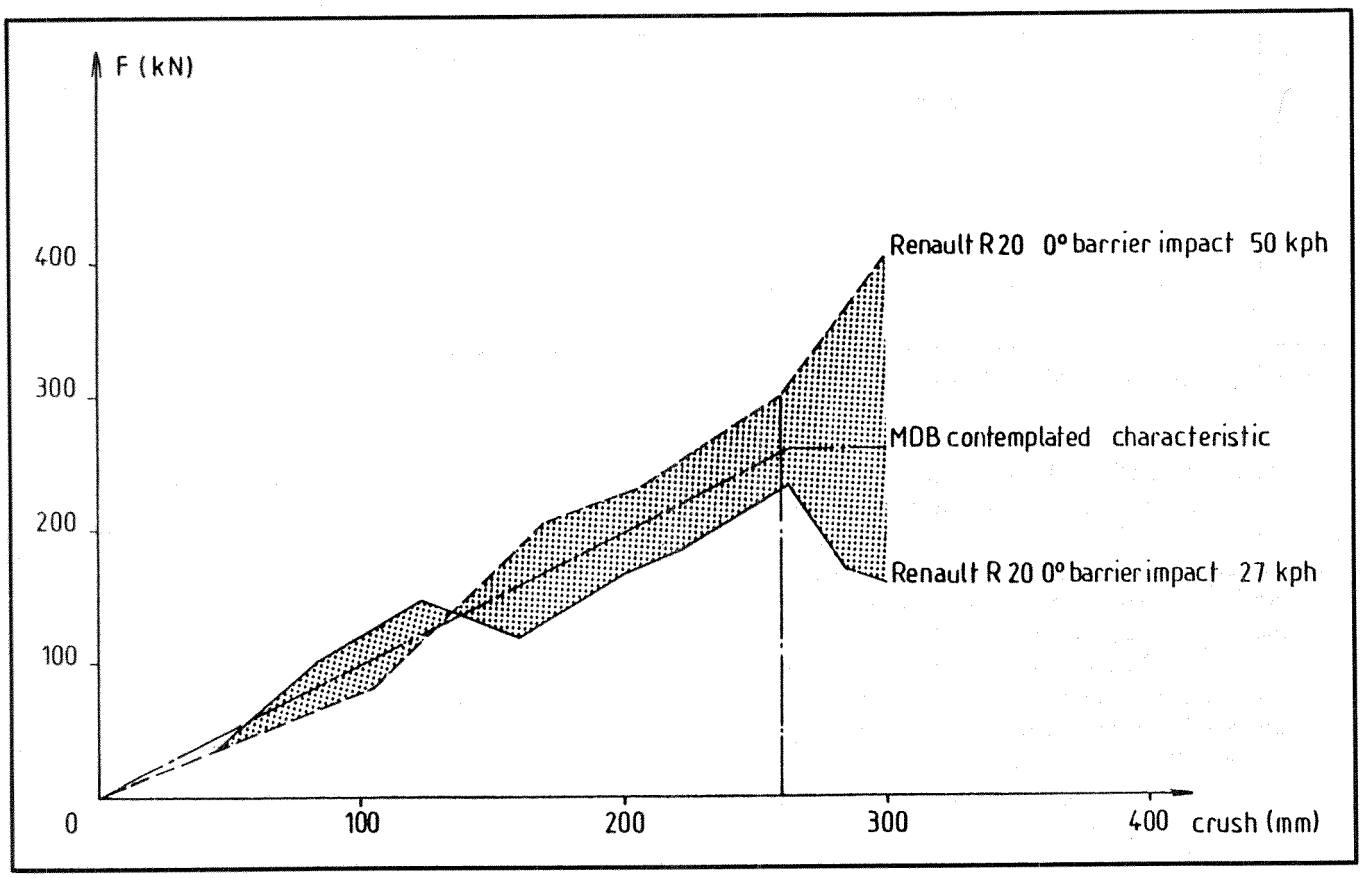


Figure 10. Deformable barrier—target F/D characteristic.

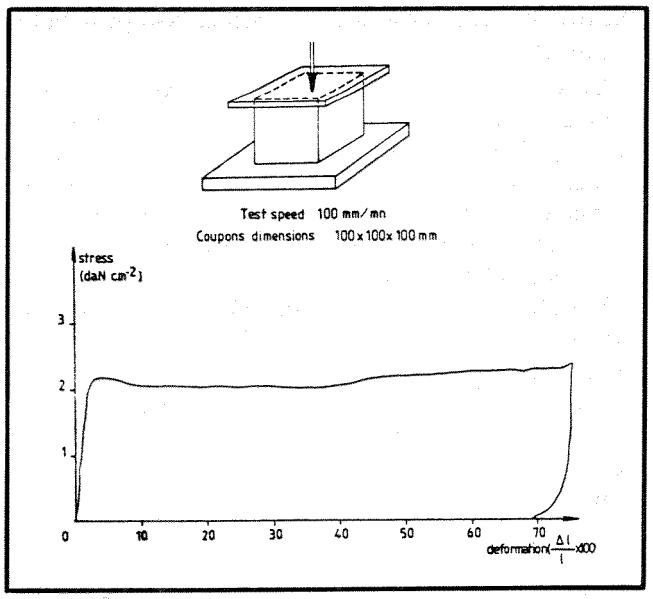


Figure 11. Compression test—phenolic foam sample.

difference in behavior of the power unit at this stage of the deformation phenomenon.

The objective to be established then for the deformable face was an average pulse contained within the region limited by these two curves up to 260 mm, with a plateauing of the force from this degree of collapse on (Fig. 10).

DESCRIPTION OF THE DEFORMABLE BARRIER CONSTRUCTED

Method Used

After an evaluation of the various materials which could be used to absorb the energy of a compressive impact with a good reproducibility, we selected a combination of phenolic foam (PHENEXPAN), of density 30g/litre, whose absorption law is shown in Figure 11, and of aluminum honeycomb with two different stiffnesses; 170 $N.cm^{-2}$ and 90 $N.cm^{-2}$.

The forces variations during collapse are obtained by the deformable face geometry and also by weakening holes for fine tuning, after some verification tests against the dynamometric buffer.

Description

A layout of the deformable face is shown in Figure 12. The figure also shows the characteristics of the honeycomb blocks simulating the vehicle side members and power unit. The deformable face is entirely covered with a flexible laminated coating of the type FLOGOGLASS 5377 Polyester. The deformable face is then mounted on a conventional fixed barrier, the mass of the assembly being adjusted to the mass of the vehicle to simulate, i.e., 1306 kg.

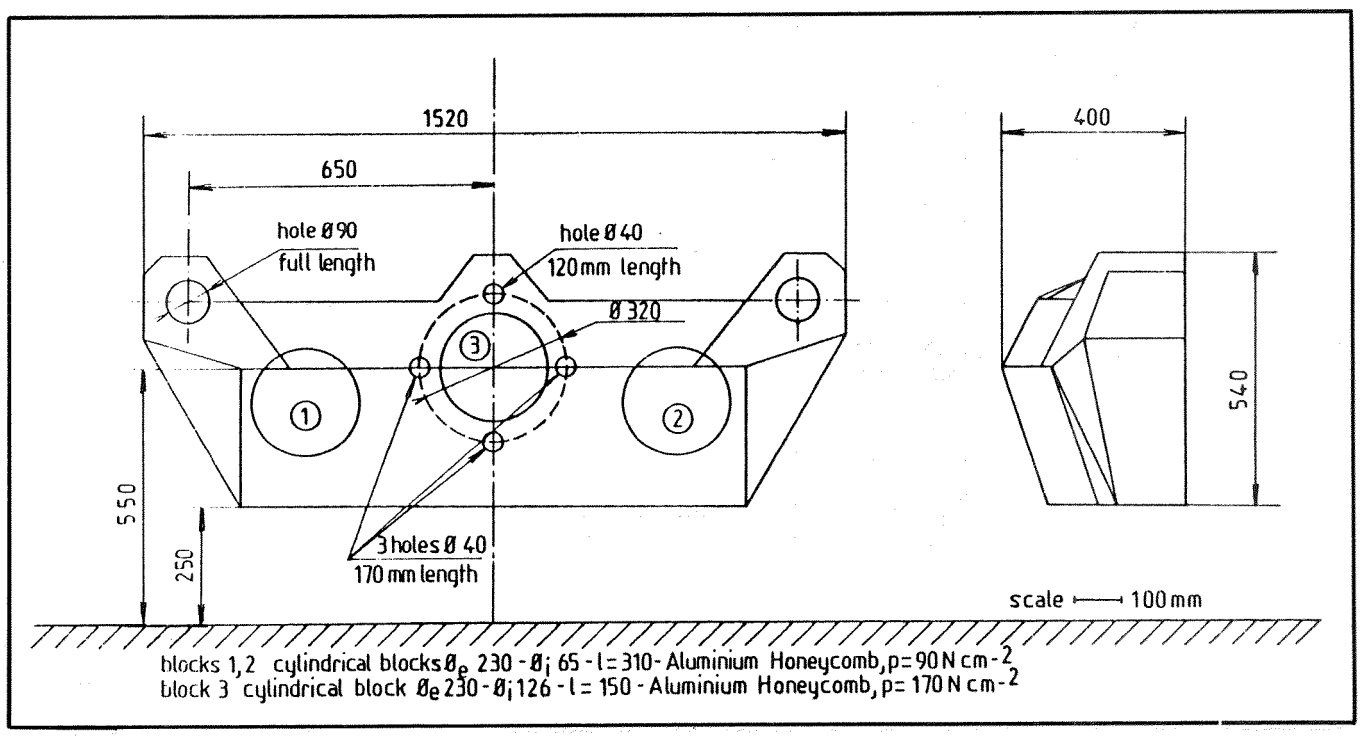


Figure 12. Renault movable deformable barrier.

Comparison of the Force-Collapse Performance Recorded with That of the Actual Vehicle

The superposition of the deformable face on the various slabs of the dynamometric buffer is given in Figure 13.

The moving deformable barrier (MDB) test performed at a speed of 26,98 km/h results in a collapse of 285 mm, with a crushing of 200 mm and 50 mm on the lateral and central honeycomb blocks, respectively.

The compared force-collapse performances (R20-MDB) for each slab of the dynamometric buffer, are given in Figures 14 to 16. The overall performance is represented in Figure 17.

Compared with the objective established in the previous paragraph, the results have been judged acceptable both for the overall performance and for the distribution over the individual cells of the dynamometric buffer.

Comparison of the Characteristics for the Various MDB's

It is of interest to compare some basic characteristics of the various moving deformable barriers which have been recently described (3, 4, 5, 9). A table regrouping these data is shown in Figure 18, and a comparison of the overall stress-collapse performances will be found in Figure 19.

Up to a 200 mm collapse, the agreement is excellent among the crushing performances proposed in Europe (3, 4, 5, 9). From this level of collapse on, the divergence between the CCMC-specified performance and the other European curves is attributable essentially to the taking into account of the power unit impact in a crash against a perpendicular rigid barrier.

With the deformable face designed in the United States, the performance obtained is fairly different, mainly in the region from 100 mm to 300 of collapse. The latter comparison is not however fully significant because the stress-collapse curve of this deformable barrier was essentially developed for a collision at an angle of 30° (3).

In any case, we may conclude that there is a remarkable likemindedness of the various organizations involved in this type of research, as regards the energy absorption characteristics of a deformable face suitable for the simulation of a car-to-car front-to-side collision.

REPRODUCIBILITY OF THE DEFORMABLE FACE FORCE-COLLAPSE PERFORMANCE—COLLISIONS AGAINST A DYNAMOMETRIC BUFFER

Before attempting to study the reproducibility of the tool developed for collisions against a vehicle—which is

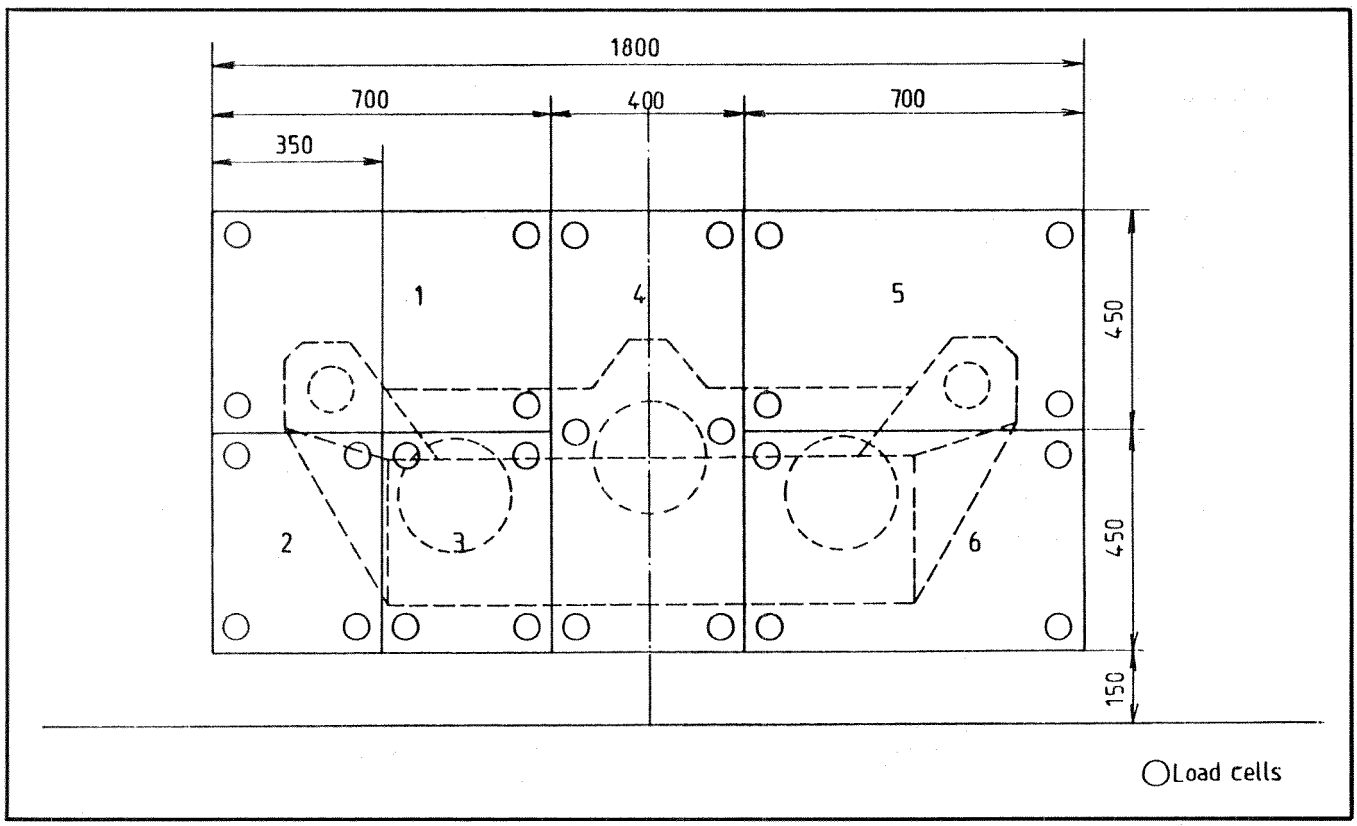


Figure 13. Superposition of MDB front face on dynamometrical buffer.

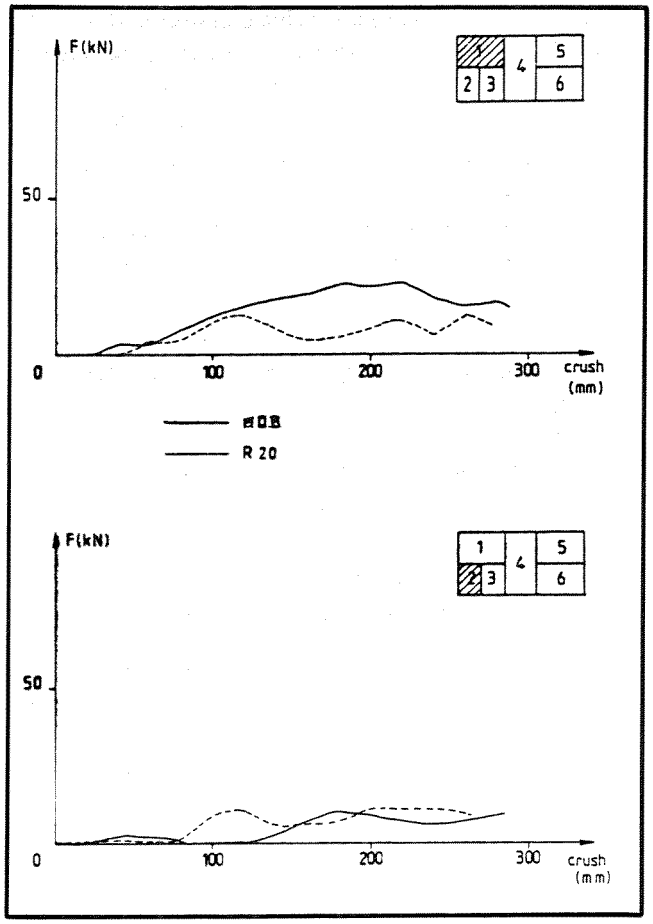


Figure 14. Comparison of F/D pulses—cells 1 and 2.

clearly the final objective of the program undertaken—it was important to check, in a preliminary phase, that the above specified deformable face performed with an adequate fidelity during similar tests against a dynamometric buffer.

A run of 5 collisions, as described in the table shown in Figure 20, was therefore performed under these conditions.

The deformable face condition, before and after the crash, is illustrated in the picture of Figure 21.

The average force-deflection pulse derived from the five collisions is plotted on the diagram of Figure 22. The performances within one standard deviation about this average curve, as well as the ± 25 kN tolerance zone as proposed in reference (9) for the overall performance, are also plotted.

A study of the various results obtained leads to the following conclusions, relating to *a single batch* of deformable faces:

a) With the method used, the variability (ratio of standard deviation to average) of the total force obtained is on the order of 6% at a collapse of 200 mm, which may be considered as relatively low.

b) The method used permits to comply with the tolerance zone specified in ref. (9), *about the average value obtained for a batch of deformable faces manufactured in the same time.* Indeed, none of the five curves recorded is outside this zone.

The investigation of this average performance repeatability is still under scrutiny and may represent a substantial problem.

c) The variability, for each slab of the dynamometric buffer, is on the same order of magnitude as for the overall performance. However, the fact that the overall performance *and* the individual performances must together comply with the tolerance zone, may also generate difficult to solve problems, since many parameters with accumulating dispersions are involved in this measurement.

d) Other aspects which may affect the reproducibility of the deformable face developed (ageing of the materials used, influence of temperature, etc. . . .) remain also to be verified. Such problems are already well known as regards the test dummies. But there is a fundamental difference between the dummy and the deformable face: the latter can be evaluated only by a destructive test. Therefore, the number of validation tests required for a given batch

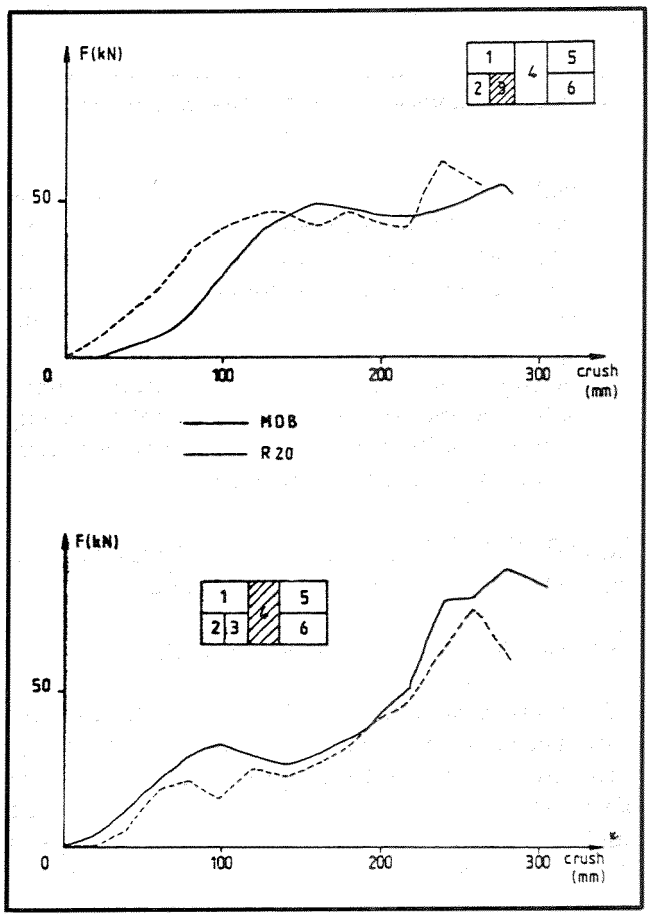


Figure 15. Comparison of F/D pulses—cells 3 and 4.

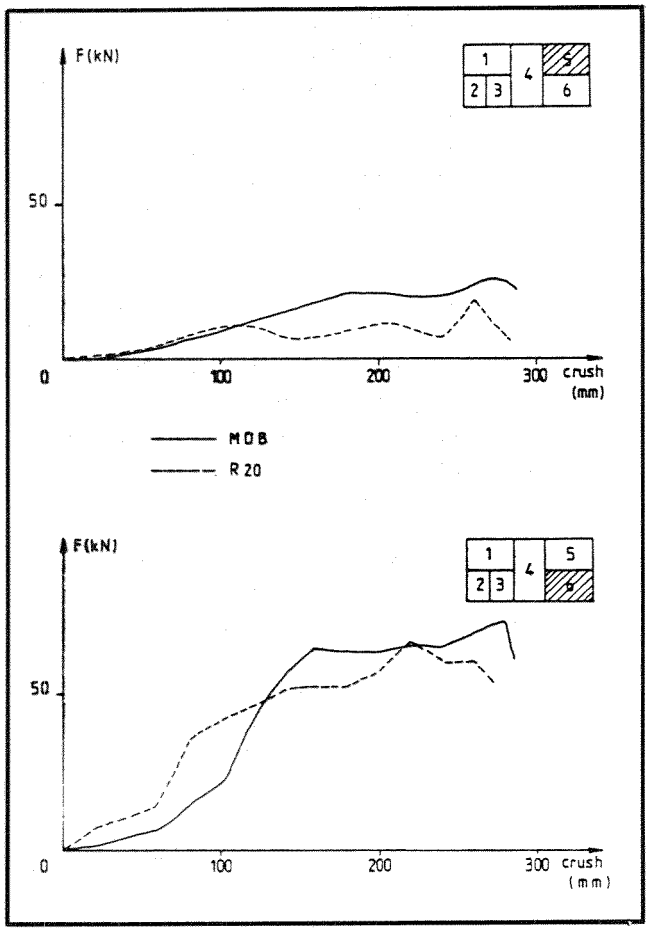


Figure 16. Comparison of F/D pulses—cells 5 and 6.

will have to be specified before the remaining faces may be used for the crash test. Lastly, it will not be possible to check afterwards (as it is the case for the dummies) that the deformable face used was actually meeting the requirements desired in the specification.

e) In any case, it is also important to specify the validity of the tolerance zone required; does a 6% variability of stress at a 200 mm collapse yield sufficiently close results in a MDB-to-car collision?

COMPARISON OF THE CAR-TO-CAR AND MDB-TO-CAR COLLISION TESTS

Description of the Procedure Used

First, two experimental crashes (A and B) have been performed in the car-to-car configuration, so as to provide a tentative evaluation of the reproducibility of this type of test. The results of these tests were also compared with results from previous tests in order to support the validity of the conclusions.

During these experimental collisions, the following major parameters were recorded:

a) Initial test conditions: vehicle masses and attitudes, and position of occupants relatively to different points in the passenger compartment.

b) Results relating to the structure of vehicles:

- Impacting vehicle: map of deformations on front section;
- Impacted vehicle: map of deformations on body side, inside and outside; outstanding deformations of the structure involved in the crash: floor to bodyside joints; A, B and C posts.

c) Dummies on board of impacted vehicle: impact zones of the various portions of the body: head, thorax, pelvis.

d) Measurements on the structure:

- Impacting vehicle: longitudinal, right side and left side decelerations;
- Impacted vehicle: transversal accelerations at non-deformed points of the inside of the impacted shell.

e) Measurements on the dummies: for each body portion (head, thorax, pelvis): times of possible contacts with adjacent shell; X, Y and Z accelerations. We used dummies of the Part 572 type although they are obviously not suitable for lateral impacts. We

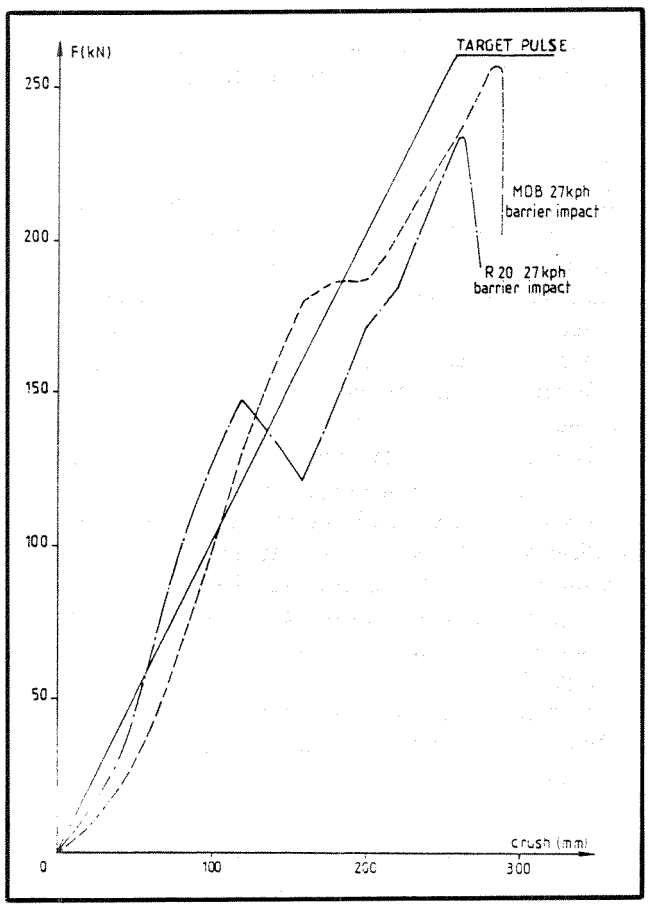


Figure 17. Comparison of total F/D pulses.

	RENAULT	CCMC (5)	UTAC (4)	CEVE (9)	NHTSA (3)
width (mm)	1520	1550	1400	1500	1676
depth (mm)	400	400	/	500	831
height (mm)	540	490	410	500	559
ground clearance (mm)	250	300	350	250	280
height of separation between upper and lower part (mm)	550	545	/	500	/
deformable face mass (kg)	13,5	25	/	/	/
M.D.B total mass (kg)	1306 *	950	915	950	1560
energy absorption method	phenolic foam + aluminium honeycomb	polyurethane foam	/	/	aluminium honeycomb ($31 Ncm^{-2}$)

Figure 18. Compared characteristics of various MDB.

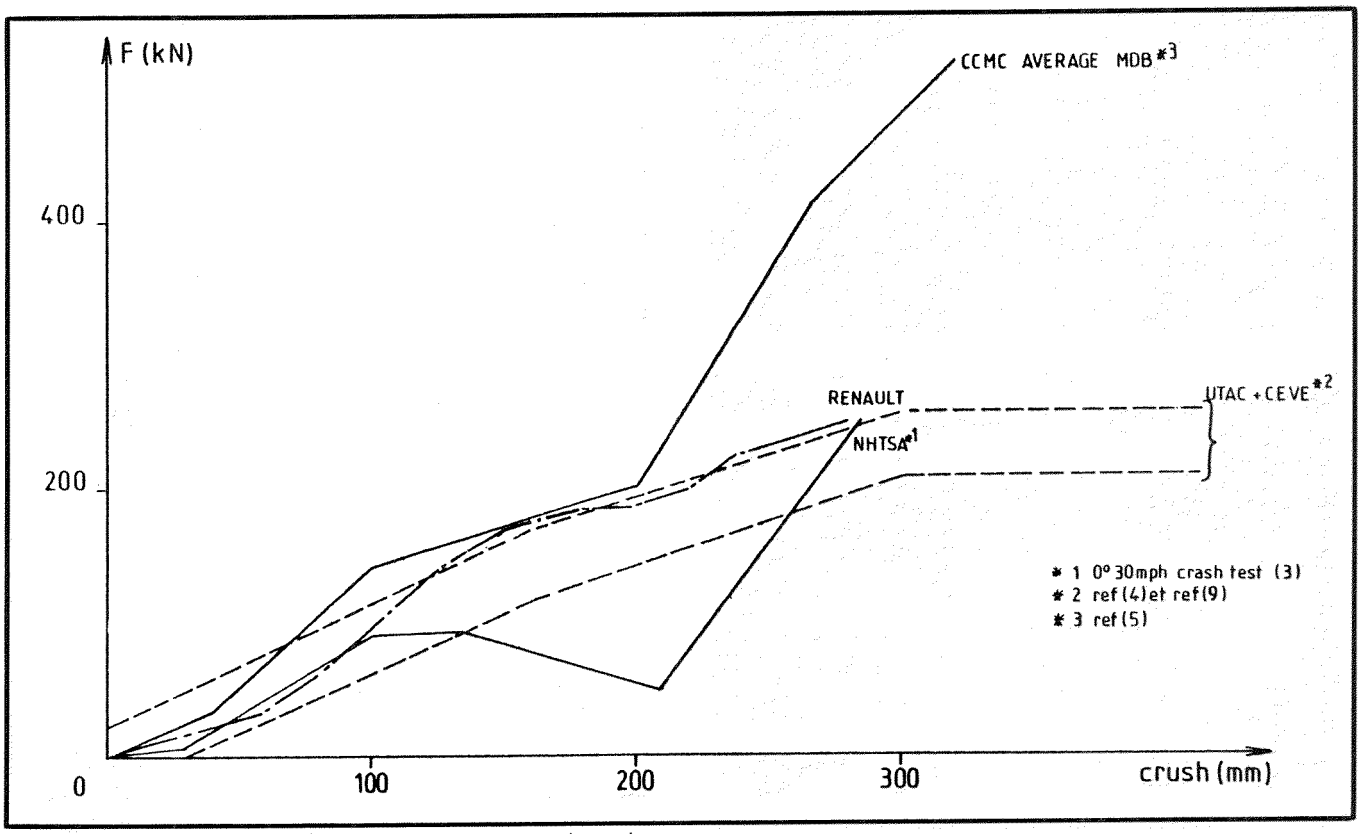


Figure 19. Comparison of total F/D characteristics (various MDB).

Test n°	Impact speed (kph)	Max. dynamic crush (mm)	Blocks 1 and 2 crush (mm)	Block n° 3 crush (mm)	Remarks
1	26,1	280	180	35	Resin envelope tearing (upper L and R ext.)
2	26,98	285	200	50	Resin envelope tearing (upper L and R ext.)
3	27,04	295	205	50	Resin envelope tearing (upper part)
4	27,05	280	190	45	Resin envelope tearing (upper and lower part)
5	27,33	290	195	50	Resin envelope tearing (upper and lower part)

Figure 20. Five tests against dynamometrical buffer. Comparison of results.

used them only as instrumentation supports to the sole end of allowing comparisons between the various tests.

The results of collisions A and B were averaged and the deviations recorded. Then, an MDB type collision (N° 1) was performed. All the values provided by these three tests were compared. However, for the purpose of clarity, only the major comparisons have been entered in this study.

Compared Results of Collisions A, B and 1

a) Initial test conditions:

These are shown in Figure 23. They relate to the mass and attitude of the impacting and impacted vehicles, the impact speeds, and the initial placement of dummies.

b) Measurements on the structure:

A chart of the inside and outside collapses of the

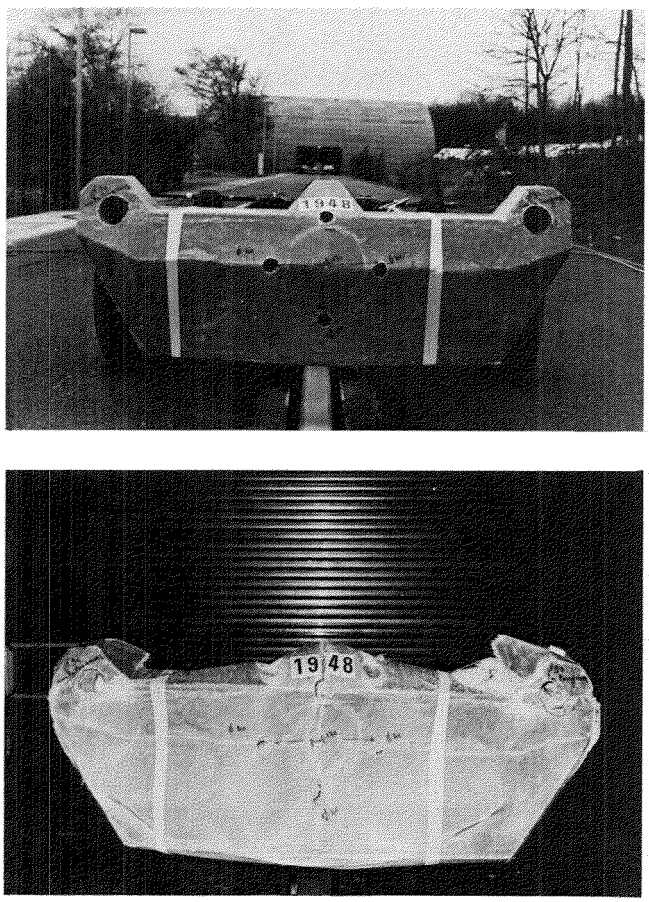


Figure 21. Pictures of deformable faces (before and after tests).

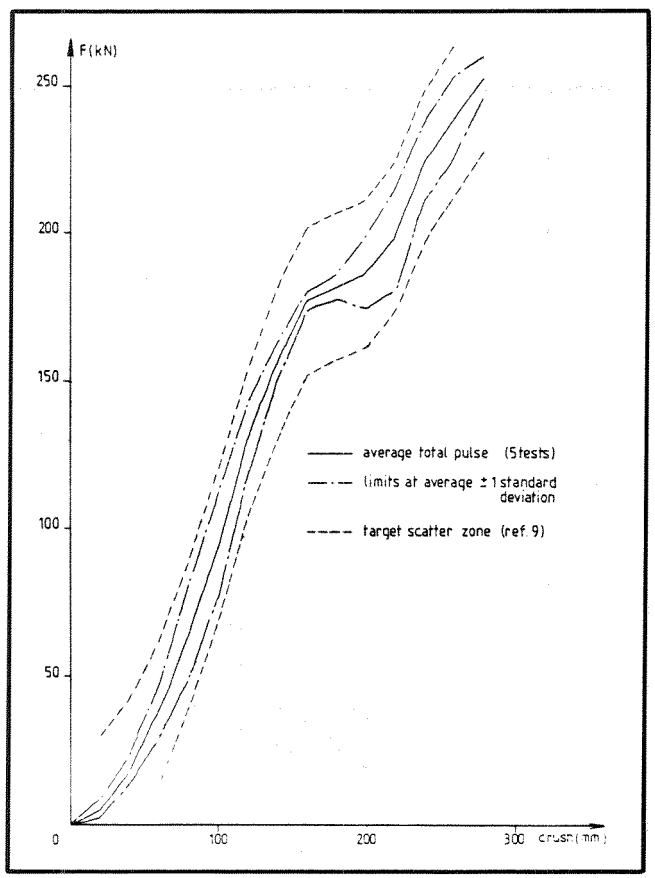


Figure 22. Observed scatter—five tests against dynamometrical buffer.

Parameter	Observed average	Max. deviation obtained
Striking vehicle mass (kg)	1310	±10
Struck vehicle mass (kg)	1445	±10
Struck vehicle attitude (mm) F	660	±10
R	520	±10
Impact speed (kph)	50	±0.2
Dummy placement (mm)		all measurements ±5mm

Figure 23. Initial conditions of tests A, B and 1. Comparative table.

bodysides, at the level of the front and rear R points, is shown in Figure 24. Figure 25 shows the deformation of the front door in a vertical plane close to the front R point. Figure 26 shows a deformation in a horizontal plane at the level of the window sill. Figures 27 and 28 show horizontal deformations at the level of the pelvis and at the level of the door sill upper part, respectively.

It appears that:

—The behavioral characteristic of the vehicle impacted by the MDB is nearly identical to that obtained in a car-to-car collision.

—The differences found in the collapses are low in the upper part of the side structure but significantly greater in the lower part, which evidences a greater stiffness in this area.

This finding is furthermore supported if we consider that these upper-part collapses are obtained with a considerable intrusion into body side, at a level where resisting forces are significant due to catenary effect.

Intrusion	Test #1	Average tests A and B	Deviations tests A and B
Front R point (int) (mm)	325	298	±12
Rear R point (int) (mm)	190	210	±10
Front R point (ext) (mm)	424	408	±18
Rear R point (ext) (mm)	292	366	±48

Figure 24. Compared intrusions at "R" point.

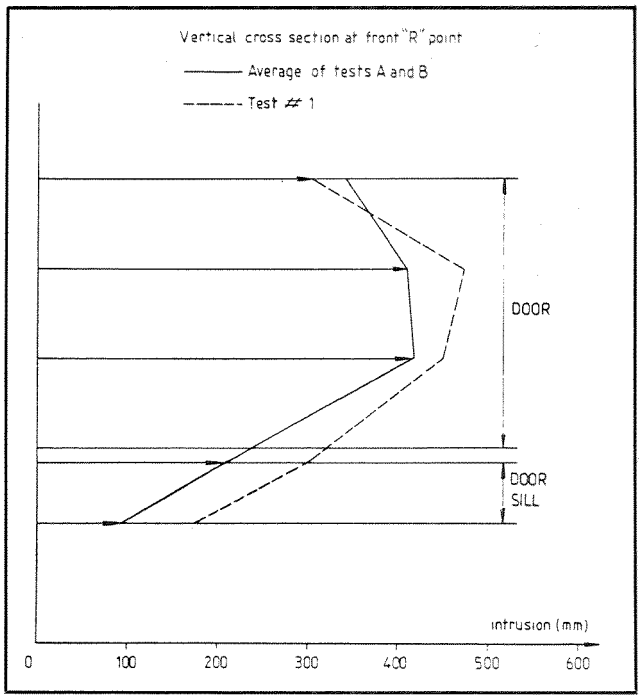


Figure 25. Deformations of front door. Vertical cross section.

c) Dynamic measurements—Relating to structure:
A thorough comparison of the curves brings out two important facts:

—A significant difference in the acceleration laws recorded on the impacted vehicle, on opposite side to impact (Fig. 29). This results probably from the different behavior—as is stated above—of the door sill.

—A similarity in shell velocities at times of impacts against the dummy, as regards both the thorax and the pelvis. It can be seen, from the values reported in Figure 30, that these do not differ by more than 10%.

Also, the time-sequence of the impact is in correct conformance: contact times at shoulder and pelvis do not differ by more than 5%.

d) Results for dummies:
Figure 31 summarizes the results obtained on the front dummy in collisions A, B and 1. The following conclusions may be drawn:

—At head level: No significant difference in results in spite of the maximum acceleration values shown. No head-to-structure impact was observed in all three tests.

—At thorax level: The significant difference found in maximum deceleration levels is due essentially to the shoulder-impact localization, i.e.:

- ahead of the B-post in the case of MDB-to-car crash (test N° 1),
- on the B-post in the case of car-to-car crash.

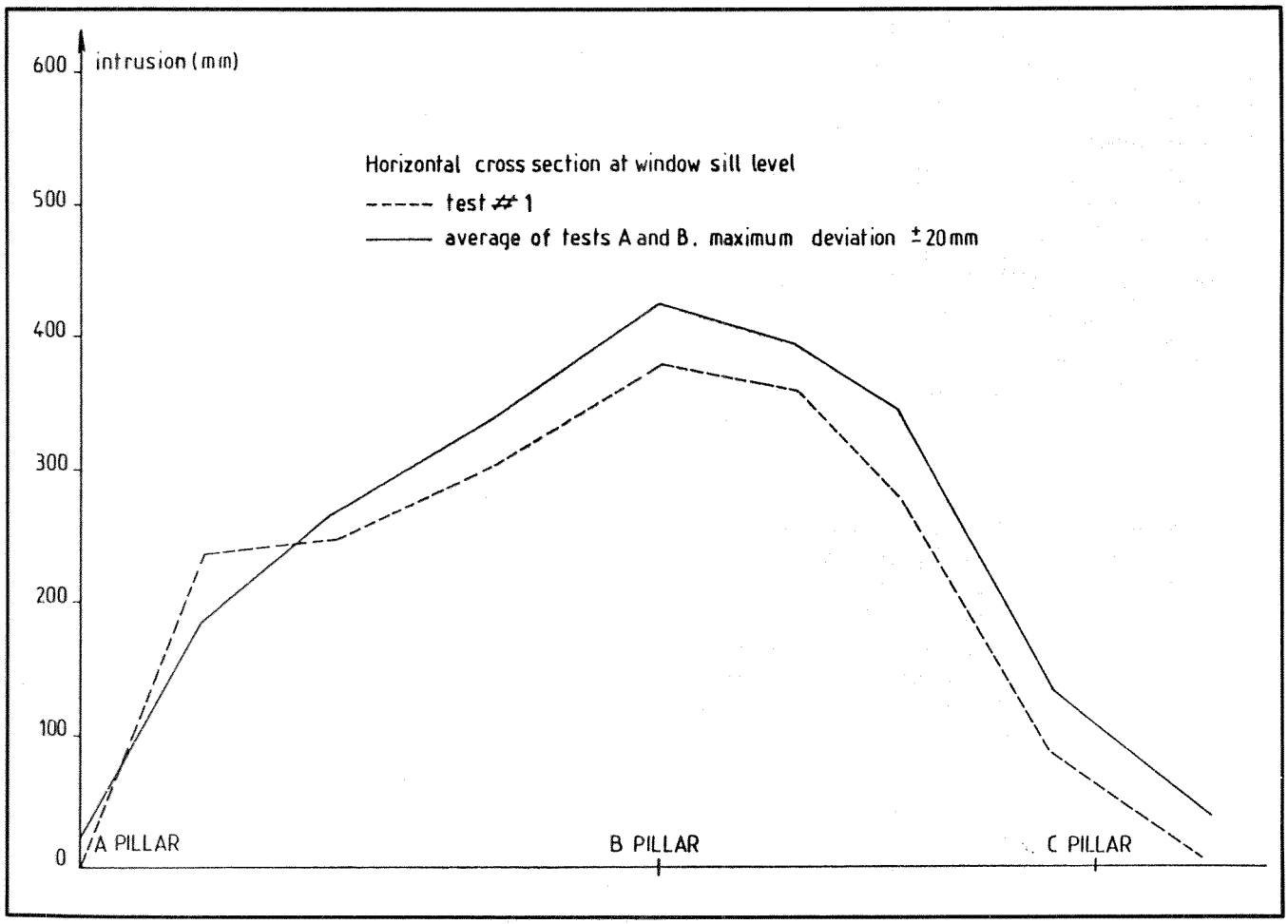


Figure 26. Deformations at window sill level.

However, even in the latter configuration we observed, on previous tests, occurrences of B-post avoiding by the shoulder. Maximum deceleration level is then brought down to values close to 60g. This random occurrence, due for a large part to the fact that dummy Part 572 is not realistic, is not therefore to be considered in this analysis.

Thorax transversal velocity variation on the other hand, exhibits an appreciable discrepancy in the two configurations. The value of 11.8 ms^{-1}, as obtained in test, is significantly larger than for tests A and B where an average value of 10 ms^{-1} was recorded. This clearly shows that shell stiffness and equivalent mass—when contacting the thorax—are larger in the MDB-to-car impact than in the car-to-car impact.

—At pelvis level: the most divergent results were measured on this body segment. All values are much higher in the MDB-to-car configuration than in the car-to-car configuration. The transversal velocity variation, increased by 50%, particularly evidences an excessive stiffness in the lower part of the moving deformable barrier, which was already indicated by the more extended deformations on the impacted vehicle lower structure.

Discussion

The above results clearly indicate that the method applied to obtain a realistic simulation of the impacting vehicle front section, is somewhat inadapted. The deformable face obtained by this method will have to be further modified.

In particular, we believe that a weight-reduction of the rigid section of the barrier would be desirable, this to allow in particular for:

—The uncoupling of certain elements (occupants, etc. . . .) which is not correctly simulated by the (too simple) model proposed;

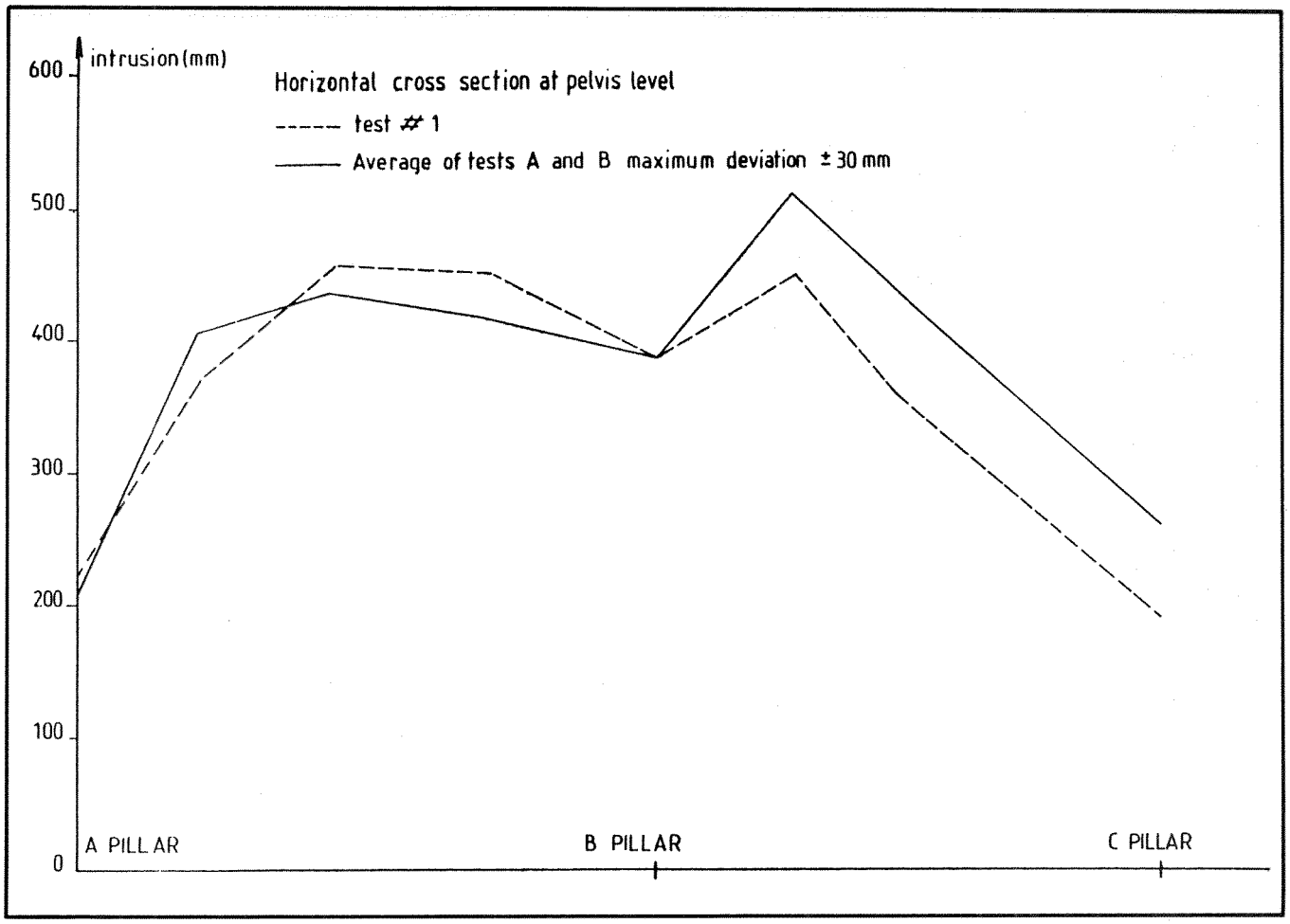


Figure 27. Deformations at pelvis level.

—The mass of material which builds up at the vehicle/vehicle interface, this being significantly higher in this case than in the MDB-to-vehicle collision.

Lastly, we see (which confirms the results previously obtained) that the final intrusion into the impacted vehicle is only a rough indicator of how severe the crash is for the occupant. One may in particular refer to thorax behavior, described above, comparatively with shell deformations observed at this level.

A discussion of the reproducibility aspect of the contemplated test procedure, in spite of some defects indicated above, would be interesting. This is discussed hereafter.

REPRODUCIBILITY OF MDB-TO-CAR TESTS

This aspect was studied by using five identical MDB-to-car tests. These collisions, numbered from 1 to 5, were planned in such a way that initial conditions would be as similar as possible. We used to this effect deformable faces from a single manufacturing batch.

An investigation of reproducibility using deformable faces manufactured at different times will remain to be performed.

Comparison of Results—Collisions 1-5

a) Initial conditions: All important test parameters are kept within the limits indicated in the table of Figure 23. Average initial speed of the MDB was 50,23 km/h with a standard deviation of .11. Temperatures recorded on test site were in the range 20-30°C.

b) Measurements relating to structure:

A table for body side inner and outer collapses, at the level of front and rear R points, is given in Figure 32. Figures 33, 34 and 35 show the deformations on a horizontal section at thorax level, at pelvis level, and on door sill upper part, respectively.

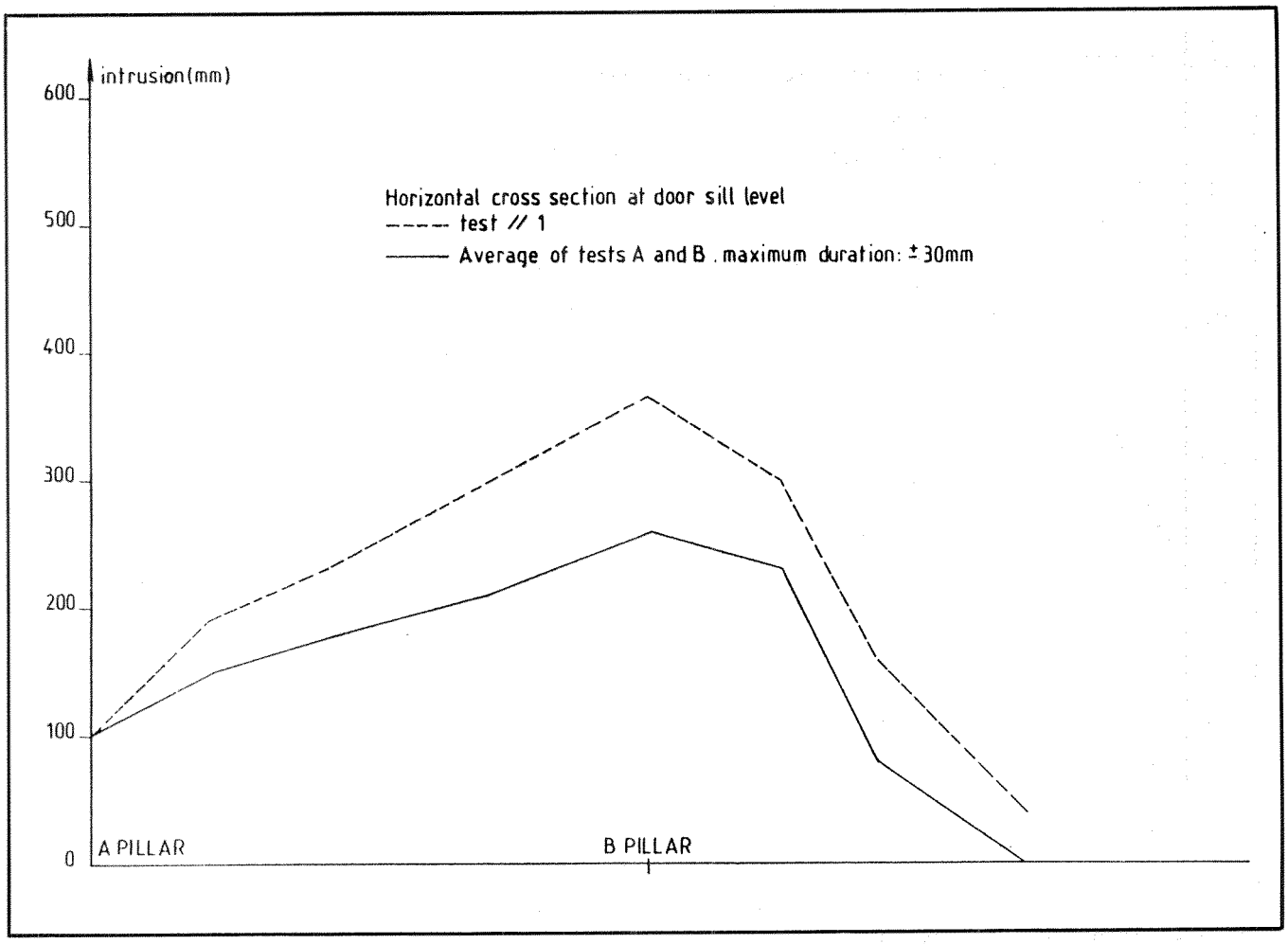


Figure 28. Deformations at door sill level.

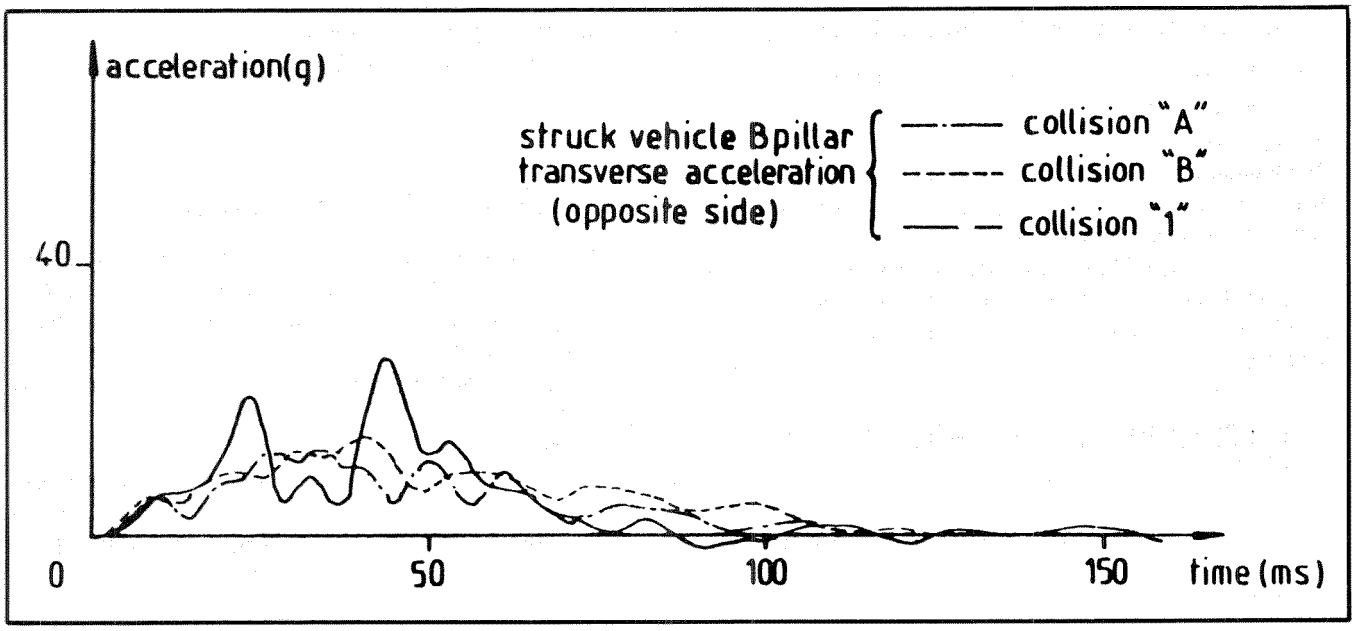


Figure 29. Comparison of passenger compartment transverse accelerations.

Wall speed at impact against front dummy (m/s)	Average (tests A and B)	Test 1	Deviation tests A and B
Chest level	9,4	10,5	0,4
Pelvis level	10,5	11	0,5

Figure 30. Comparison of wall/dummy impact velocities.

The variability, confined within 3% approximately at the front R point, can be considered as remarkably low.

c) Dynamic measurements—Relating to structure:

The table in Figure 36 shows the averages, standard deviation, and variability measured on the shell adjacent to the dummy at times of contacts with the different portions of the dummy. The variability found is somewhat less satisfactory in this case, with an order of magnitude of 10%. One must however remain careful for interpreting these measurements since they were made with accelerometers located near the impact point, whose measuring axes may be subjected to considerable variations once the deformation goes further than its first stages.

In a first approximation, we shall consider the differences found as acceptable.

Body area	Parameter	Test #1	Average tests A and B	Deviation tests A and B
Head	Max. decel. (g)	38	65	5
	Time > 80 g (ms)	0	0	/
	HIC	250	370	50
Chest	Max. decel. (g)	60	105	0
	Time > 60 g (ms)	0,8	6,6	0,15
	Time > 50 g (ms)	14,1	9,3	1
	Transverse ΔV (ms^{-1})	11,8	10	0,5
Pelvis	Max. decel. (g)	121	68	2
	Time > 60 g (ms)	13	4,6	0,4
	Time > 50 g (ms)	15	7,9	0,4
	Transverse ΔV (ms^{-1})	14,5	9	0,5

Figure 31. Comparison of front dummy results.

Intrusions	Average tests 1 to 5	Standard deviation tests 1 to 5	Variability %
Front R point (int) (mm)	326	10.8	3
Rear R point (int) (mm)	181	25.1	13.7
Front R point (ext) (mm)	440	11.4	2.6
Rear R point (ext) (mm)	286	6.5	2.2

Figure 32. Compared intrusions at "R" points.

d) Results relating to dummies:

A table of the results obtained during tests 1 to 5 will be found in Figure 37.

This table covers the major dummy parameters.

—At head level: No essential difference. No impact was recorded during the collision. Maximum decelerations remain mutually consistent. However,

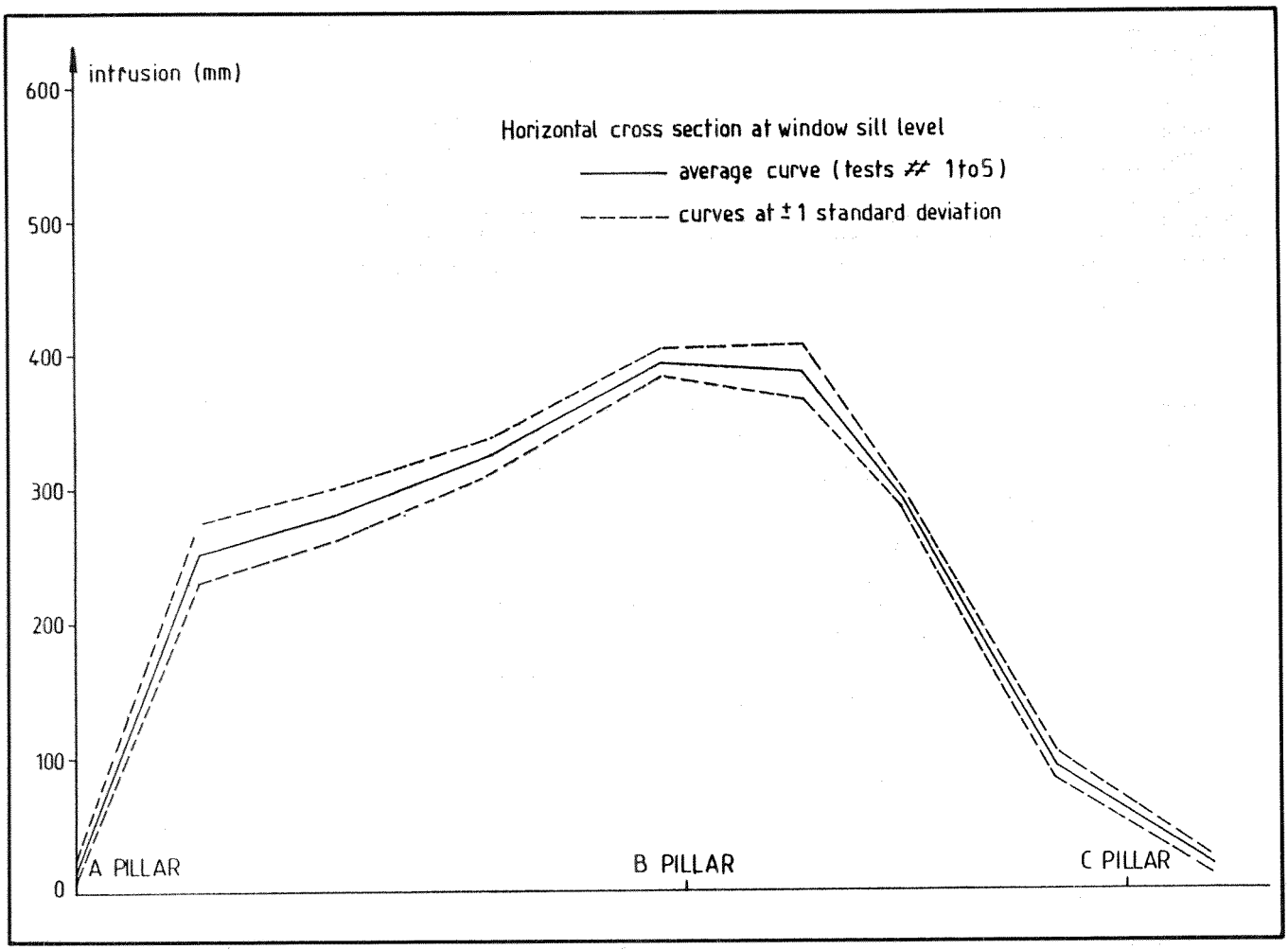


Figure 33. Deformations at window sill level.

as for the frontal crash, the redhibitory sensitiveness of parameter HIC is confirmed. Its variability is of almost 20%.

—At thorax level: As a whole, the results remain correctly grouped, with a variability of less than 10%. This is particularly true for transversal velocity variation, whose standard deviation is only .2 ms^{-1} for a measured average of 11.6 ms^{-1}.

—At pelvis level: A satisfactory consistency is obtained for all results.

Discussion

The first results obtained by using deformable faces from a same manufacturing batch are encouraging. The spreadings observed remain acceptable, in terms of both the deformations found on vehicles, and the values measured on dummies. Of course, these conclusions will have to be confirmed when the following is made available:

—a dummy capable of being used for lateral impact, and

—criteria as to the performances to obtain on such dummies.

This study did not confirm the risks which could have been rightly feared, concerning in particular:

—The variability induced by the deformable face, a test tool relatively ill-known to this day.

—The variability which could result from the lateral structure of the impacted vehicles themselves. It must be reminded that the number of structural components involved in the deformation process is significantly lower for a lateral impact than for a frontal one where a change in the behavior of one part of the structure may be relatively masked out in the final result.

Needless to say that the reproducibility of deformable faces manufactured at different times will remain to be studied.

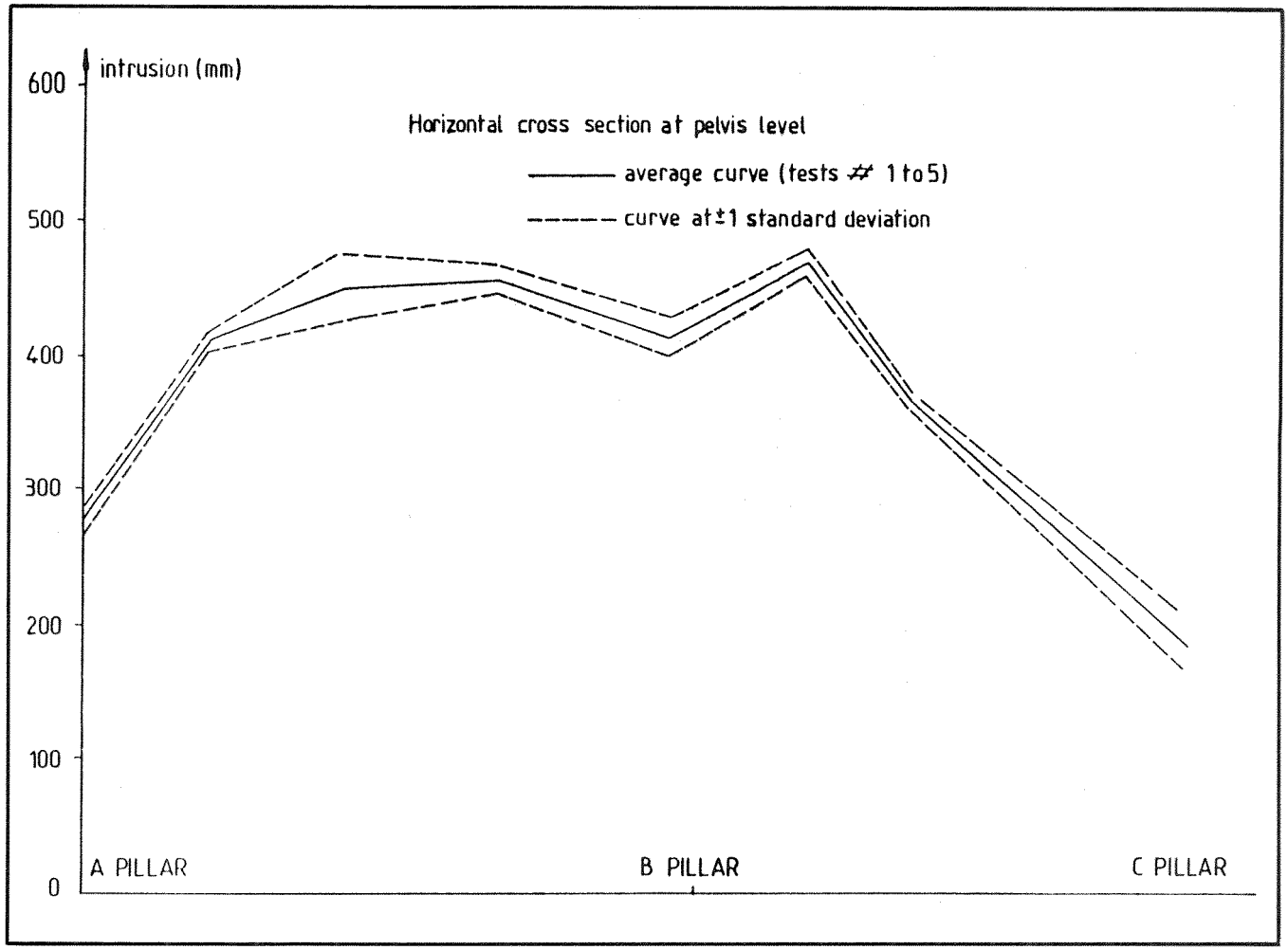


Figure 34. Deformations at pelvis level.

CONCLUSION

The results obtained in this preliminary study, generally confirm the feasibility of the lateral impact test procedure simulating the impacting vehicle by a moving deformable barrier.

However, a detailed study of the approach to use for developing the deformable face will have to be completed. We have shown that merely reproducing on the dynamometric buffer, the stress-collapse performance of the vehicle to be simulated could result in a too-severe test tool, from the double point of view of its mass and of its stiffness.

Some modifications seem necessary in that respect, even if this entails a higher sophistication of the moving deformable barrier assembly.

This is all the more supported if the following considerations are added:

—Such a test procedure makes it impossible to improve a basic parameter governing the lateral impact severity i.e., the stiffness of the impacting vehicle front section; and

—The economic implications of such a process are of an extremely large magnitude (10), especially when they are considered in the present context of scarce and expensive energy.

Finally, it is clear that these several issues make it essential to provide for an extensive cost/benefit analysis.

LIST OF REFERENCES

1. Side impact insights from General Motors Field Accident Data Base. R. Mehta et al.—8th ESV conference—Wolfsburg—October 1980.
2. Side collision. E. Franchini—7th ESV conference Paris 1979.

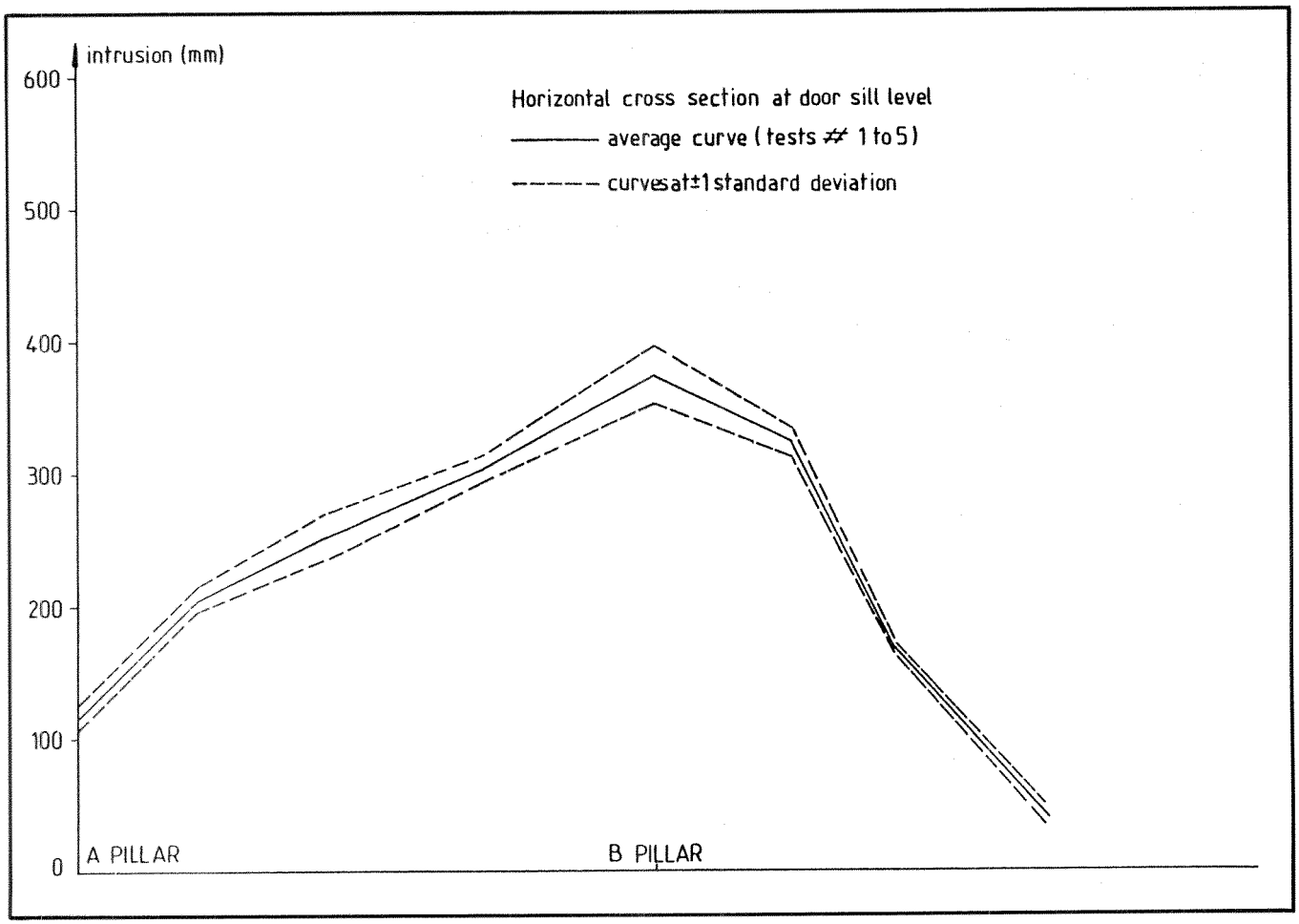


Figure 35. Deformations at door sill level.

Wall speed at impact against front dummy (m/s)	Average tests 1 to 5	Standard deviation tests 1 to 5	Variability %
Chest level	12.2	1.04	8.5
Pelvis level	12.41	1.12	9

Figure 36. Tests 1 to 5. Wall/dummy impact velocities.

3. Development of a Deformable Side Impact Moving Barrier. Sol Davis—Carl Ragland—8th ESV conference—Wolfsburg—October 1980.
4. Le choc latéral: vers un essai normalisé. R. Dargaud—Colloque SIA 17/18 mars 1982—Paris.
5. Report on CCMC Mobile Deformable Barrier Development (CW/25/81). Bruxelles—November 81.
6. Development of Protection Systems in Lateral Impact. J. Provensal et al.—SAE Paper 790710—SAE Passenger car meeting. June 1979.
7. Absorption d'énergie par déformation des coques à parois minces. J. Provensal—Revue Française de Mécanique—N° 75—1980.
8. Proposal for test evaluation of compatibility between very different passenger cars. P. Ventre—4th ESV conference—Kyoto 1973.
9. EEVC Working Group N° 6—Structures—Final Report. March 1982.
10. Occupant Protection in Lateral collisions: Special Features of Renault EPURE. J. Provensal—7th conference—Paris 1979.

Body area	Parameter	Average tests 1 to 5	Standard deviation tests 1 to 5	Variability %
Head	Max. decel. (g)	39,6	2,07	5,2
	Time > 80 g (ms)	0	/	/
	HIC	206	36	17,5
Chest	Max. decel. (g)	67,4	6,4	9,5
	Time > 60 g (ms)	5,76	2,8	48,6
	Time > 50 g (ms)	12	1,6	13,3
	Transverse ΔV (ms^{-1})	11,6	0,2	1,7
Pelvis	Max. decel. (g)	123	2,9	2,3
	Time > 60 g (ms)	12,2	0,8	6,8
	Time > 50 g (ms)	13,6	0,9	6,5
	Transverse ΔV (ms^{-1})	14,1	0,36	2,5

Figure 37. Tests 1 to 5. Front dummy results.

The Reconstruction of Two Side Impact Accidents by Performing Moving Car-to-Car Crash Tests

ARNOLD K. JOHNSON
National Highway Traffic Safety Administration

CHARLES E. STROTHER, J. FAVORS, ROGER LENARD and J. AXTELL
Minicars, Inc.

ABSTRACT

This report documents the reconstruction of two real world car-to-car side impact accidents for which detailed accident investigation reports were available. The accident reconstructions were made under controlled test conditions, and the accuracy of each reconstruction was evaluated by comparing the damage to the vehicles in the reconstruction to that of the vehicles in the accident. The objective was to reproduce side impact crash environments for which a known injury severity occurred to an accident victim. A dummy specially designed to predict injury in side impact was seated in the same position as that of the accident victim. The dummy's accuracy in predicting injury severity could then be compared to the injury severity of the accident victim. The accuracy of such injury severity predictions will be presented in future reports by the National Highway Traffic Safety Administration (NHTSA) concerning development of dummies for side impact. This report concerns mainly the accuracy of the side impact accident reconstructions and the problems in attaining the accuracy. The degree of injury severity of the accident victims is also reviewed.

INTRODUCTION

This report documents the reconstruction of two real world car-to-car side impact accidents. These accidents, based on accident investigation reports from the National Crash Severity Study (NCSS) (1), were reconstructed under controlled test conditions. The accuracy of each accident reconstruction was evaluated primarily by comparison of damage to each vehicle with the corresponding damage recorded in the accident investigation report.

The objective was to reproduce by accident reconstruction side impact crash environments for which a known injury severity occurred to an accident victim. This ob-

jective, however, was only an element to fulfill the larger objective to develop a dummy for side impact which reliably predicts injury severity for living humans.

A dummy, especially developed by the Association of Peugeot-Renault (APR) to predict injury severity in side impact crash environments (2) (3) (4), was seated in each accident reconstruction in the same location as that of the accident victim whose injury severity was known. By this procedure it was possible to compare the injury severity predicted by the dummy to that of the accident victim.

The violence of the dummy's motion would approximate that of the accident victim. The more violent the motion, the greater the crash environment's injury potential. Measures of the degree of violence of the dummy's motion, and thereby measures by which to predict the injury severity of an impact environment were obtained by instrumenting selected mechanical responses of the dummy. The dummy's instrumented responses were those of a Part 572 dummy (5) plus an array of linear accelerometers (6), which was mounted to the chest, and a gage to measure lateral compression of the chest.

Accident reconstructions for which a known injury severity occurred to an occupant could be used to calibrate a dummy's mechanical responses so that the responses could be used to predict injury severity. The reconstructions, however, are expensive. As an alternative, efforts are being made to develop predictions of injury severity of lateral impact environments based on injury producing, controlled lateral impacts to unembalmed cadavers. The APR dummy was designed to have impact responses similar to those of the cadavers. Efforts are being made to correlate injury severity of the cadavers with selected instrumented responses which are common to both the dummy and the cadavers. The cadavers were instrumented like the dummy with the same array of linear accelerometers mounted to the chest, but not with a gage to measure lateral chest compression. Thus, it is primarily the responses of the array of linear accelerometers which are to be the basis for predicting side impact injury severity to the chest.

Although cadavers have the important feature that they can be injured, they have the drawback that they are not lifelike (lack of muscle tone, etc.). Whatever injury severity predictions may finally be developed based on side impacts with instrumented cadavers, the predictions must be in reasonable agreement with the injury severity of accident victims. If there should be significant disagreement, then an appropriate adjustment will have to be made to the predictions. The two accident reconstructions were conducted to provide a check on the reliability of any predictions of injury severity in side impact that may be derived based on tests with cadavers.

The instrumented responses of the dummy and its ability to predict injury severity will be reported by NHTSA later in conjunction with the ongoing efforts to develop injury criteria for side impact. This report concerns only the reconstruction of the two accidents.

SELECTION OF THE TWO ACCIDENTS THAT WERE RECONSTRUCTED

The National Crash Severity Study accident investigation files of the NHTSA were reviewed by NHTSA staff for candidate accidents to reconstruct for which one car impacts the side of another car. Much of the information in the reports is subjective based on reports from those involved in the accident and from the police reports. More objective information are photographs of damage to each vehicle and the specific injuries to occupants from which is assessed an AIS injury severity number. It is difficult to assess accurately the initial conditions of the vehicles (e.g., velocities, angle of impact, initial strike point on the struck vehicle, etc.) at the initiation of impact.

The accident reports contain essentially no information concerning an occupant's position and posture at the initiation of the vehicle's being laterally impacted. Some thought was given by the NHTSA staff to use a program such as the Calspan Crash Victim Simulator (7) (8) (9) (10) to study the sensitivity of an occupant's response as a function of his location at different distances from the impacted side of the vehicle. It was decided, however, to avoid such an effort at this time and to minimize uncertainty in location and posture by considering accidents in which:

1. The driver was the injured occupant of interest.
2. The driver was seated in a bucket seat in a smaller size car.
3. The lateral impact was in the region near the driver.

One of the pairs of accidents chosen was a 1965 Pontiac Catalina impacting laterally a 1978 Toyota Celica Liftback, and the other accident was a 1972 Chevrolet Malibu impacting laterally a 1969 Volkswagen Beetle. Both target vehicles have smaller than average interiors. Their small interiors helped to reduce the uncertainty of the driver's position at the instant of impact.

As stated, the dummy was that of the Association of Peugeot-Renault, and its size was that of a 50th percentile male. It would be ideal, of course, to choose accidents for which the driver was also approximately the size and weight of a 50th percentile male, whose weight is 164 pounds and whose height is 67 inches. This is not practical, however, due to the limitations of the accident data. For the Pontiac/Celica accident, the driver of the Celica was a 120 pound female whose height was 63 inches (age 45 years). In respect to the Malibu/Beetle accident the driver of the Beetle was a 155 pound male whose height was 70 inches (19 years). Thus, in the Beetle, whose interior was the smaller, the driver was the closer to the size and weight of the APR dummy. Age, physical health,

weight and other human factors may affect injuries sustained in a specific accident.

The accident investigation reports for each of the two accidents are reviewed in the next two succeeding sections.

REVIEW OF THE 1965 PONTIAC CATALINA/1978 TOYOTA CELICA ACCIDENT INVESTIGATION REPORT*

In this accident the Pontiac impacted the side of the Celica in the region near the driver. Figure 1 is a copy of an actual data sheet from the accident investigation report which documents the damage to the laterally impacted Celica. It will now be reviewed.

The data recorded near the top of Figure 1 are self-explanatory. Elsewhere the accident investigators have shaded regions of the vehicle to indicate the general location of damage. The depth of shading approximates the depth of damage. It is clear that two separated damaged areas occurred, one at the side of the extreme front of the left front fender and a second which extends approximately between the two axles on the driver's side.

It is the general policy of accident investigators to record on such a diagram the "direct dent" rather than the "direct dent plus the induced dent." The direct dent is that caused by direct contact with the impacting vehicle, and the induced dent is that which extends beyond the region of estimated direct contact. The point C1, in Figure 1, is the measurement closest to the rear of the vehicle and is at the estimated point where the direct dent starts. The point C6 is the measurement closest to the front of the vehicle and is at the end of the direct dent opposite to that of C1. The other four measurements of depth of dent are evenly spaced spaced between C1 and C6. The total length of the direct dent is L. Thus, the distance between each dent measurement is L/5. By this procedure, there is no guarantee that the maximum depth of dent will be at one of the points measured. The maximum could lie in between measurements. Another parameter shown in Figure 1 is D which is the location of the center of a dent from the vehicle's estimated center of gravity along the vehicle's profile. (See Reference (1) for more details.)

If a dent is short such as that near the front of the left front fender in Figure 1, then only four measurements of the depth of dent are made rather than six.

A review of Figure 1 indicates that four sets of depth of dent measurements were made for the larger of the two dents and by the differences in handwriting they obviously were not all recorded by the same investigator. Each set is designated by a subscripted "L" number, and they are now located in Figure 1 as follows:

L1: located near the bottom left
L2: located near the bottom right
L3: located just above columns L and C1
L4: located near the top center

The vehicle diagram indicates the location, however, of only L1, L2 and L3. It is the L4 set of measurements which is recorded (to the nearest inch) in the official data section near the bottom. They are clearly in approximate agreement with the set L3. It should be noted that the length of dent L3 is 101 inches while that of L4 is 107.5 inches. This difference might well reflect subjective differences between investigators as to where the direct dent begins and ends. Because the L4 set of measurements is recorded in the data section near the bottom, this is assumed to be the best set against which to compare dents in the reconstructed crashes. Someone on the investigation team judged this set as the best data.

The dent L1 has a length of only 10 inches, and, as is the policy, for this short distance only four depths of dents were measured rather than the usual six.

For the bullet Pontiac, the dent damage was confirmed to the front of the vehicle and the set of depth measurements to the nearest inch are listed below.

It must be carefully noted that the height of damage to each vehicle in Figure 1 is not given. For this particular accident no height was found recorded in the accident report. If one can assume for this accident (a) that the accident bullet car was not carrying an unusually heavy load or nose diving due to braking, (b) that the impacted vehicle was not undergoing a roll due to crash avoidance maneuvers and (c) that investigators took their measurements at the height where the maximum dent damage occurred, then it can also be assumed that the maximum depth of dents in the reconstructed accident occurred at the same height as in the accident. This was the assumption that had to be made.

The accident investigation report also provides measurements of interior intrusion. Intrusion of the A-pillar was 7 inches. The maximum intrusion of the door panel was 16 inches, and the accident report also records this as the point which was in contact with the occupant. This point was approximately the arm rest, and the accident report records the injury source for the chest injury as the arm rest.

We now review the data in the accident file concerning the driver of the Celica and the degree of injury severity that this occupant suffered. It is the degree of injury severity to this occupant which is of interest and against

Table 1. Depth of dent on the front of bullet Pontiac (inches).

L	C1	C2	C3	C4	C5	C6	D±
79	6	14	12	14	13	8	0.0

*This accident report is numbered as case 04902002 in the NCSS files.

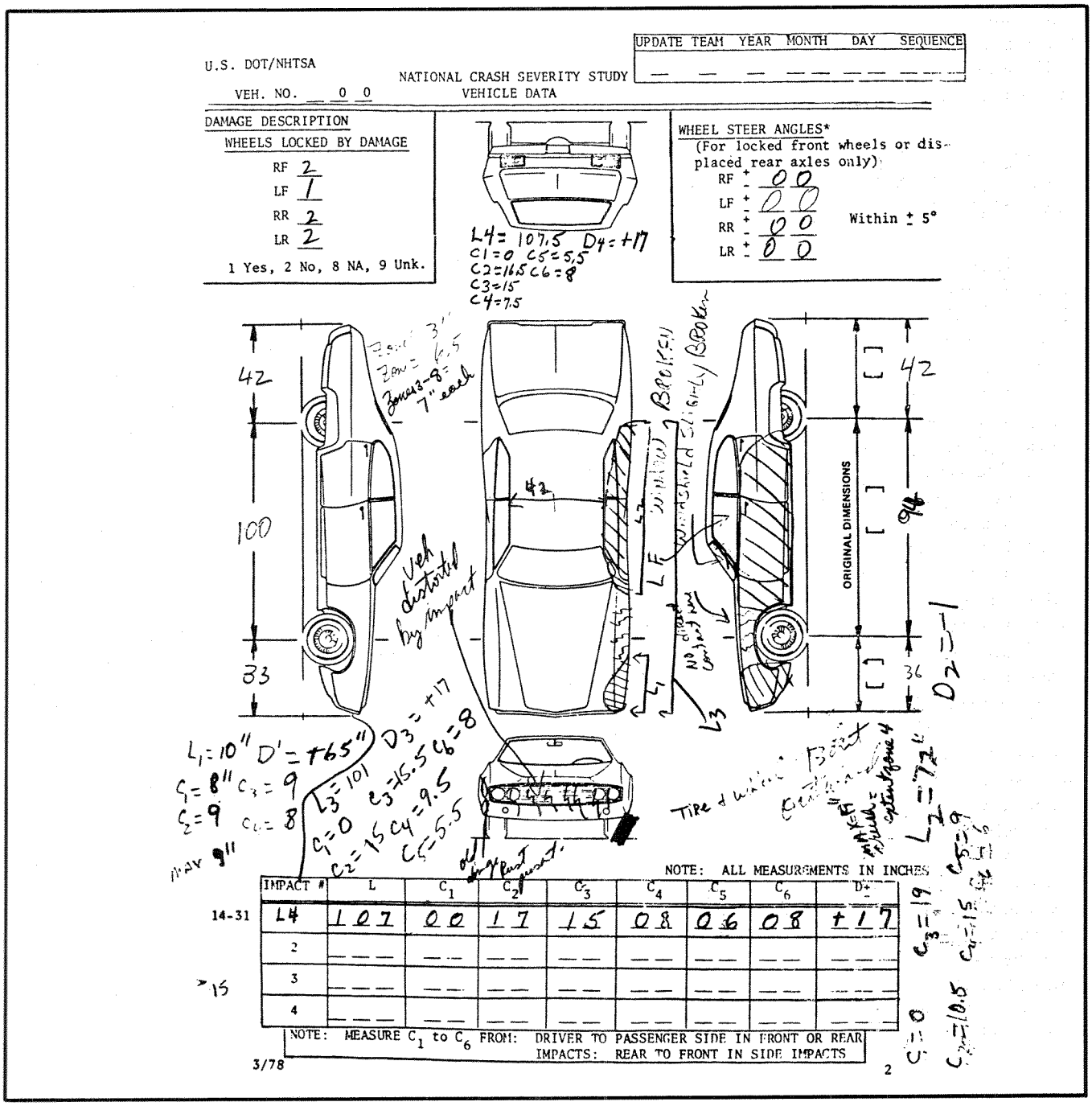


Figure 1. Actual data sheet from the accident investigation file concerning damage to the target 1978 Toyota Celica Liftback.

which predictions of chest injury severity will eventually be made.

The driver of the Celica was:

(1) 45 years of age
(2) 63 inches in height
(3) 120 pounds in weight
(4) female
(5) unrestrained

It is interesting to note that this occupant is listed as having been trapped. A photograph of damage to the accident Celica (Figure 12) shows the driver's door apparently being held in place by a segment of a seat belt. The upper hinge appears broken loose. It is likely this door was forced open to remove the trapped occupant, thereby inducing greater damage to the door area. (Figure 12 will be discussed in detail later.)

Although the driver suffered a basal head fracture with a severe concussion, rated as 4 on the Abbreviated Injury scale (AIS) (11), this report is principally interested in injuries to the chest, and it is these injuries that are reviewed.

The equations to predict chest injury severity do so in terms of AIS. Equations may yet be derived which predict chest injury severity in terms of the number of rib fractures. Thus this discussion of chest injuries will concentrate on injury to the chest assessed in terms of AIS and the number of rib fractures.

The injury record for the driver of the Celica shows bilateral injuries to the lung with the arm rest indicated as the source of injury. Although the primary impact was to the left side of the driver, the record shows three rib fractures on the right side and a fractured right clavicle. Only one rib was fractured on the impacted left side. Injuries to the right side of the chest cannot be attributed to a front seat passenger, because the driver was the only occupant. Involvement with the steering wheel during rebound from the door seems highly probable, especially since there were facial fractures. It is not clear how rib fractures occurred on the right hand side of the driver. There may have been an error in recording the injuries.

The accident investigation report gives the severity of chest injuries as AIS 4 and the number of rib fractures as 4.

REVIEW OF THE 1972 MALIBU/1969 VOLKSWAGEN BEETLE ACCIDENT INVESTIGATION REPORT*

In this section the Malibu impacted the side of the Beetle in the region near the driver. Figure 2 is a copy from the accident report which documents the damage to the Beetle. This figure for the laterally impacted Beetle will now be reviewed.

The data recorded near the top of Figure 2 are self-explanatory. Elsewhere the investigators have shaded regions of the vehicle to indicate the general location of damage, and the depth of the shading gives a rough estimate of the general depth of damage. It is clear that two separated dents occurred, one on the driver's side in a region centered near the driver, and a second at the right hand side of the rear bumper. The accident report records these separate damaged areas as due to separate impacts. However, the damage to the driver's side occurred first. It is assumed that the chest injuries were due to the initial impact against the region near the driver. The driver was ejected, and the degree to which the ejection may have aggravated his chest injuries is unknown but assumed negligible.

A review of Figure 2 indicates that a set of direct dent measurements was made on the Beetle for each of the two separated dents. The first row of dent measurements recorded near the bottom of the figure is for the larger dent on the driver's side, and the second row of measurements is for the smaller dent at the rear of the Beetle. Fortunately for this accident the height of the maximum depth of dent was recorded elsewhere in the accident report as 34" above the ground.

Table 2. Depth of dent on the front of bullet Malibu (inches).

L	C_1	C_2	C_3	C_4	C_5	C_6	D±
74	6	5	5	4	4	3	0

For the bullet Malibu, the dent damage was confined to the front of the vehicle, and the set of depth of dent measurements to the nearest inch listed below are taken from the accident report.

We now review the data in the accident report concerning the driver of the Volkswagen Beetle and the degree of injury that this occupant suffered. It is the degree of injury severity of this occupant which is of interest and against which predictions of injury severity will eventually be made.

The driver of the Volkswagen Beetle was:

(1) 19 years of age
(2) 70 inches in height
(3) 155 pounds in weight
(4) male
(5) unrestrained

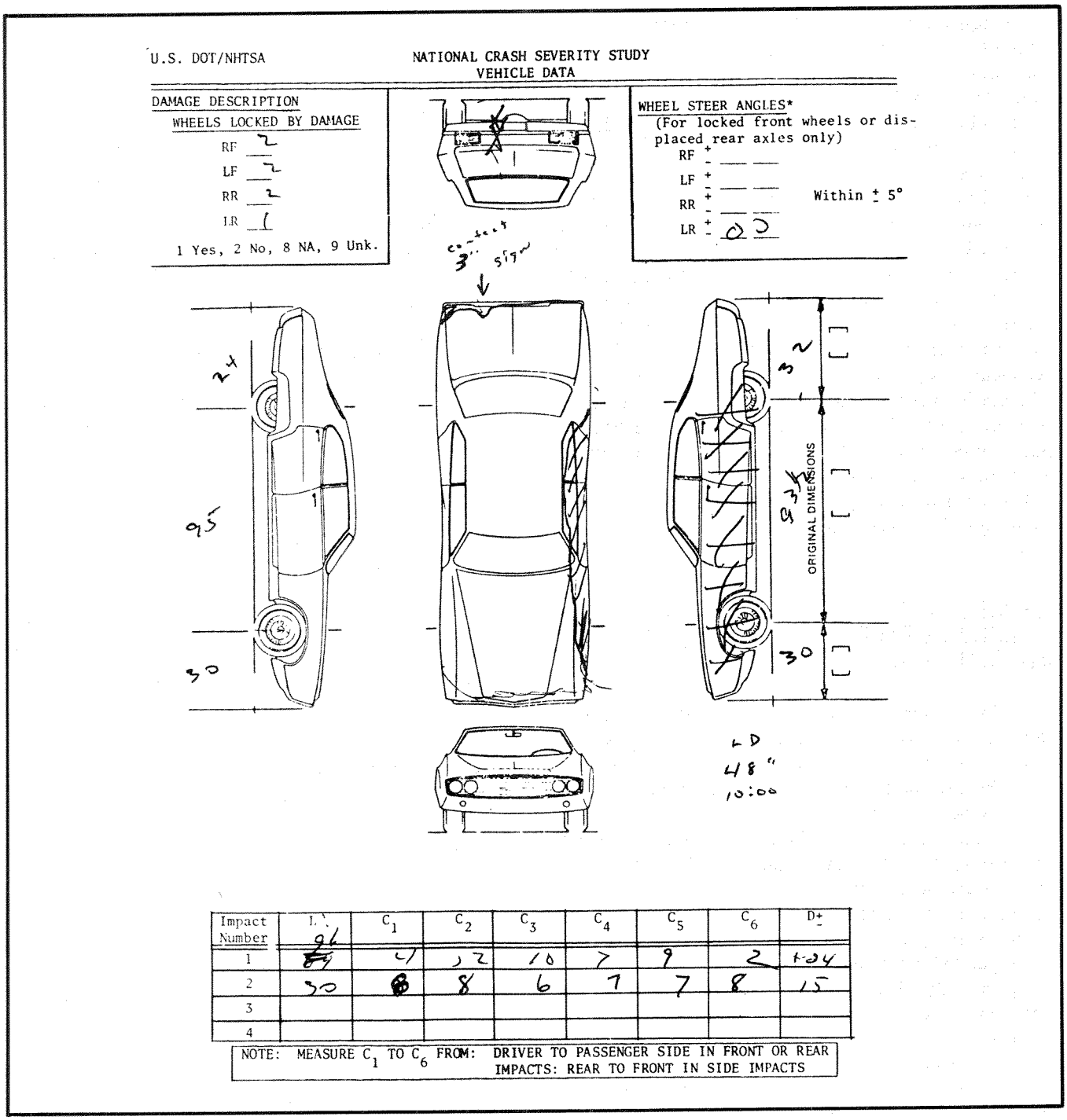
The driver's chest injuries, pneumothorax and ruptured spleen, were judged to be of severity AIS 3. There were no broken ribs.

GENERAL PROCEDURES USED TO RECONSTRUCT THE ACCIDENTS

Every effort was made to obtain cars similar to those in the accident. However, for two of the 1965 Pontiac Catalina/1978 Toyota Celica crashes it was necessary to substitute a 1966 Pontiac Catalina and a 1966 Pontiac Grand Prix because of difficulty in obtaining 1965 Pontiac Catalinas. The Pontiacs were used as bullet vehicles, and the structural strength of the substituted vehicles was judged to be equivalent for frontal impact to that of the 1965 Pontiac Catalina. Similarly for the 1972 Chevrolet Malibu/1969 Volkswagen Beetle, one of the three crashes used a 1970 Beetle and another used a 1971 Beetle. Side structural strength was judged for each of these vehicles to be equivalent to that of the 1969 Beetle.

The accuracy of the reconstruction of an accident depends upon how accurately one knows and can reconstruct the initial conditions for both vehicles and all occupants at the moment of impact. The initial conditions for the vehicles are many: the speed of the laterally impacted target car; the speed of the bullet car; the angle of impact between the two cars; the skidding of each car; the weight of cargo; possible pre-impact braking; etc. Important additional information is the type of pavement and its condition.

*This accident report is numbered as case 6710079 in the NCSS files.



Impact Number	I.[illegible]	C_1	C_2	C_3	C_4	C_5	C_6	D±
1	~~84~~ 96	4	12	10	7	9	2	1-04
2	30	8	8	6	7	7	8	15
3								
4								

NOTE: MEASURE C_1 TO C_6 FROM: DRIVER TO PASSENGER SIDE IN FRONT OR REAR IMPACTS: REAR TO FRONT IN SIDE IMPACTS

Figure 2. Actual data sheet from the accident investigation report concerning damage to the target 1969 Volkswagen Beetle.

Some of the information of the occupants and vehicle is recorded in the accident report. The initial conditions for the vehicles have to be inferred from damage to each vehicle, possible skid marks, final rest position, etc.

Only a limited number of vehicle initial conditions can be controlled. For this program they were (a) the speed of the impacting bullet vehicle, (b) the speed of the laterally impacted target vehicle, (c) the angle of impact between the two vehicles and (d) the respective initial point of impact of each vehicle. The crash test set up required that the velocities of the two vehicles be in the ratio of small whole numbers. This restriction fortunately caused no problems in obtaining good reconstructions in terms of vehicle damage.

First the accident report was reviewed for information to make a rough estimate of the crash's initial conditions. Next this rough estimate of initial conditions was used as input for a series of computer accident simulations

using a program entitled SMAC (12). SMAC was used on a trial and error basis to search for a set of initial conditions for which SMAC's prediction of damage to each vehicle seemed reasonably close to that recorded in the accident report.

The set of conditions for which SMAC was judged to estimate best the vehicle damage was then used for the initial car-to-car controlled crash. The degree and type of damage that occurred to each vehicle in the car-to-car crash test was used as the basis for judging how to modify the initial conditions for the next crash in the series. Each series consisted of three car-to-car crashes.

The procedure used to reconstruct the accidents is discussed in detail in the sections which follow. First we review the Minicar's crash test facility.

CAR-TO-CAR CRASH TEST FACILITY

The Minicars car-to-car crash test facility can tow and guide two 5,000 lb vehicles up to 100 mph closing velocity. It can be used for tests of one moving car impacting at various angles and velocities the side of another moving car.

As shown in Figure 3, it employs two rails to guide vehicles as they approach the central impact point. One rail is 1,300 feet long and is fixed in location. Another rail is 300 feet long and can be oriented at any angle from 15 to 165 degrees relative to a fixed rail. Side impacts at various angles can thus be accommodated.

Parallel and adjacent to the 1,300 foot fixed rail is a continuous loop cable which is driven by engines (not shown) connected to a winch through an automatic transmission. Power is transmitted to the vehicle on the other rail by a cable connected between the two vehicles. The vehicle on the 1,300 foot rail pulls the vehicle on the other rail. It is necessary, however, that the connecting cable must be continuously in tension. To maintain tension, the car powered by the driven cable must undergo a constant acceleration up to the crash speed. Use of such a connecting cable kept in tension assists in attaining an accurate impact point on the target vehicle. Just prior to impact the one vehicle is decoupled automatically from the power cable, and the second vehicle is decoupled automatically from the cable connecting the two vehicles. The two vehicles crash into each other with their own kinetic energy, and their post-crash trajactories are a function of their respective kinetic energies and crash forces.

The ratio of the velocity of the vehicle on one track to that of the vehicle on the other track is determined by various pulley systems that can be used. For example, the path followed by the cable connecting the two vehicles in Figure 4 is such that the velocity of the vehicle attached to the power cable is twice that of the vehicle being pulled by the connecting cable. This was the cable arrangement used for the Chevrolet Malibu/VW Beetle, with the Beetle

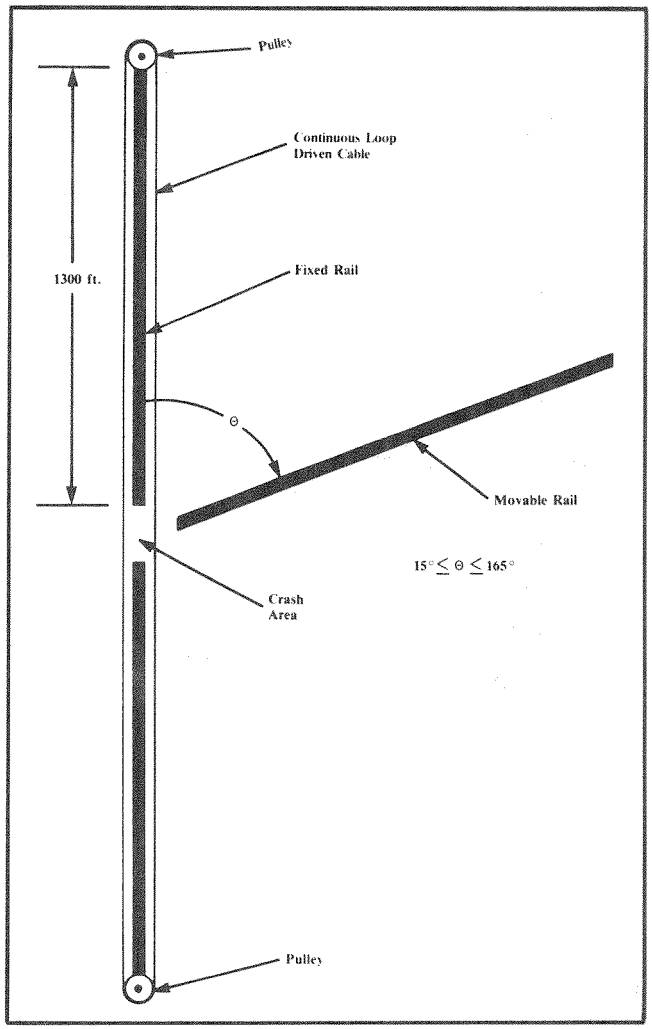


Figure 3. Schematic of the Minicars, Inc., car-to-car crash test facility.

attached to the power cable. Its velocity was twice that of the Malibu.

Due to dynamic stretch of the cable connecting the two vehicles, the ratio of the two velocities was not exactly an integer. To assure accurate measurement of each vehicle's velocity, a velocity trap was used for each vehicle to measure its velocity after decoupling from its respective cable just before the initiation of impact.

In each of the two series to reconstruct two different accidents, it was the target car, the Celica in one case and the Beetle in the other, which was coupled to the driven cable and whose velocity was controlled by controlling the cable's speed.

The amount of dynamic stretch that actually occurs in the cable connecting the two vehicles is a function of the acceleration to the crash speed of the vehicle coupled to the driven cable and the weight of the other vehicle that the cable is pulling. The effect of cable stretch on the velocity ratio is negligible. However, cable stretch can cause a significant error in the strike point on the target

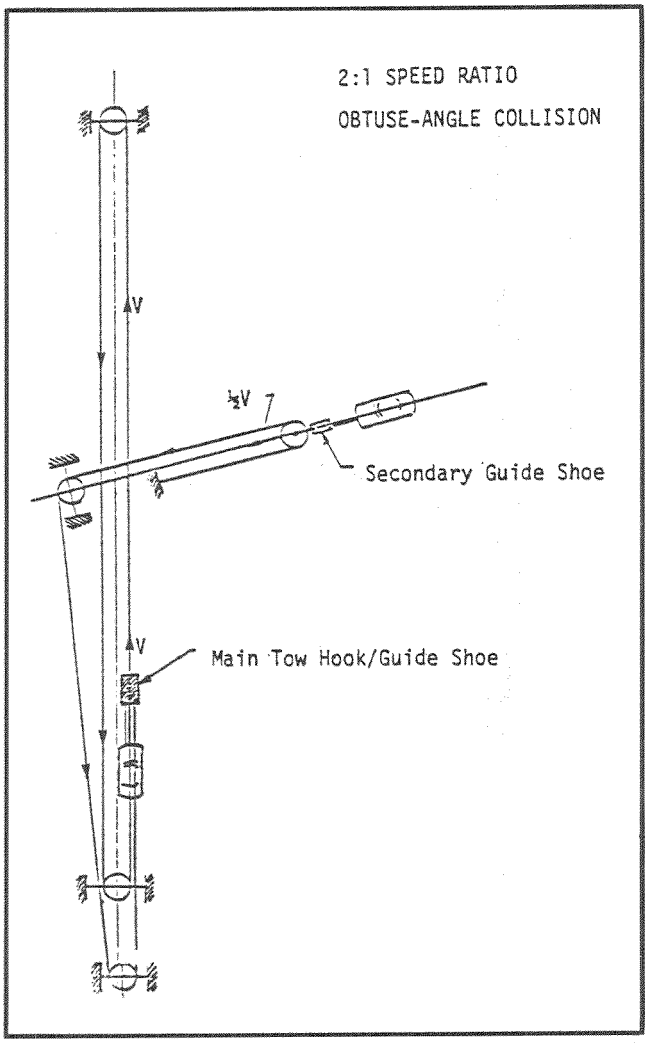


Figure 4. Schematic of Minicars, Inc., crash test facility to show how power is transmitted by cable to the two crash vehicles so that the velocity of the vehicle attached to the driven cable is twice that of the other vehicle.

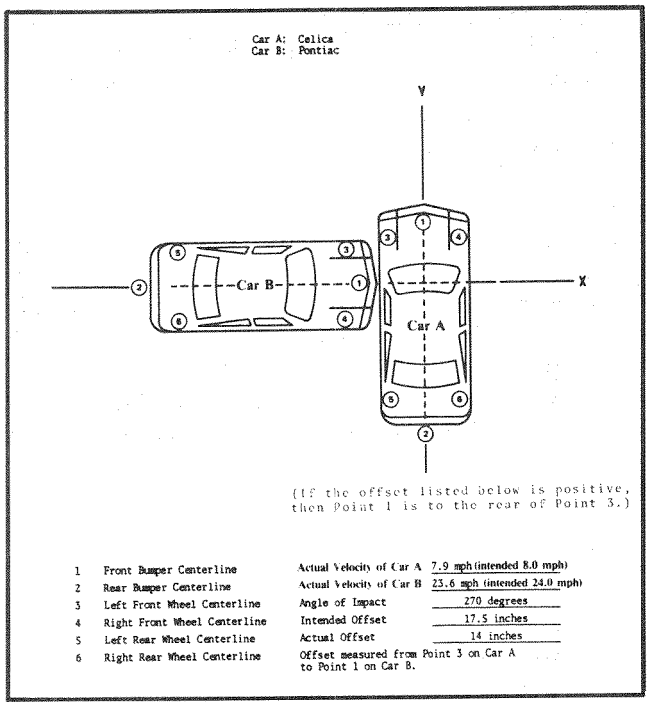


Figure 5. Crash configuration and impact parameters for the First Pontiac/Celica accident reconstruction.

vehicle. An error in the strike point of less than 6 inches can have a large effect on the degree of vehicle damage. This is especially true if the target vehicle is small, and large structural changes occur over a short distance (e.g., the Volkswagen Beetle which was one of the target vehicles). Thus, it was necessary to run two or more preliminary crashes of two vehicles of approximately the same weight and size as those to be crashed. The first preliminary test established the deviation of the actual strike point from that intended. An adjustment, usually of several inches, was then made in the length of cable connecting the two vehicles to compensate for and thereby reduce this error due to dynamic stretch. A second preliminary crash was then conducted to confirm that proper compensation had been accomplished. The goal was to be within plus or minus 3 inches of the intended strike point.

THE SERIES OF ACCIDENT RECONSTRUCTIONS BETWEEN A 1965 PONTIAC AND A 1978 CELICA

Based on the information in the accident investigation report and a series of simulated crash reconstructions using SMAC, it was decided for the first car-to-car accident reconstruction that the angle of impact should be perpendicular against the driver's side. The geometry is shown and the intended and the actual crash parameters are listed in Figure 5.

Figure 6 is a pre-test view of Celica for the first car-

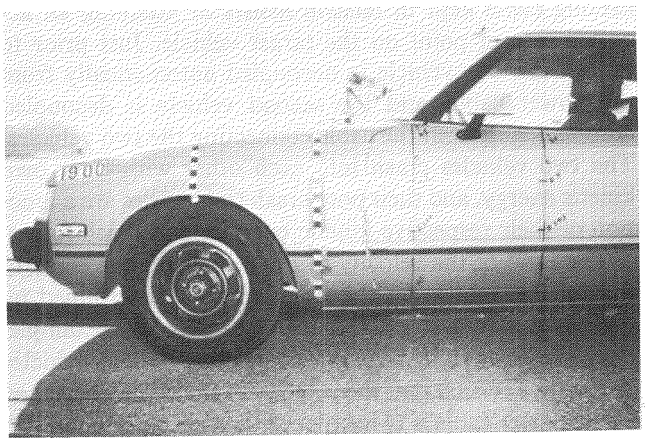


Figure 6. Pre-test view of Celica's left side for the first car-to-car accident reconstruction.

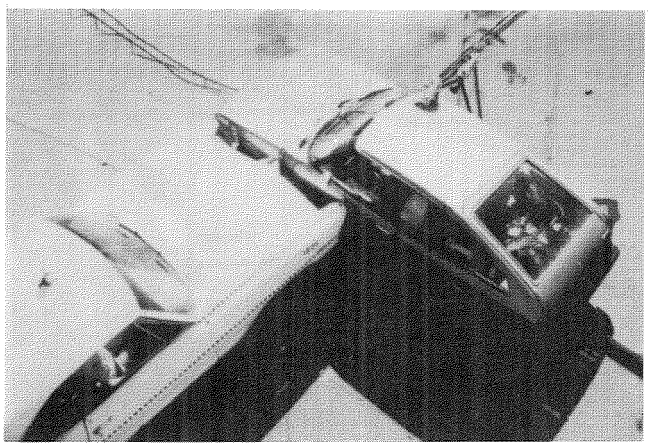


Figure 7. Overhead view of the pre-test positions for the first Pontiac/Celica car-to-car accident reconstruction.

to-car crash test. It shows vertical marking tapes pasted to the left side of the Celica. One tape is above the front axle, which is used as a reference point. The other tape is 16.5 inches to the rear of the front axle and marks the intended initial impact point for the first car-to-car accident reconstruction. This distance is defined at the bottom of Figure 5 as a "positive offset" because the intended impact point is to the rear of the front axle. Figure 6 also shows the dummy seated in the driver's position.

Figure 7 is a pre-test view of the two vehicles brought together and touching each other at the intended point of impact.

The Celica was coupled to the driven cable, and thus it was the Celica's speed that was controlled by the cable's speed. The cable connecting the Celica to the Pontiac passed through a pulley system by which the Celica pulled the Pontiac at a speed three times that of the Celica. It was necessary to change the driven cable's speed and the length of the connecting cable in order to change the initial impact speeds and impact point from one test to the next in order to obtain improved damage comparability with that recorded in the accident report. The cable's pulley system remained unchanged for the series of three accident reconstructions.

The actual velocities and the actual offset listed near the bottom of Figure 5 are different from the intended values. As discussed in the preceding section, the difference in offset (i.e., initial strike point) can generally be attributed to the variability of the stretch of the cable connecting the two vehicles.

Figure 8 shows the matrix of the points at which depth of dent measurements were made. Some of these points can be seen marked on the door in Figure 6.

As stated at the beginning of this report, the accuracy of the accident reconstruction is judged in terms of impact damage to the two vehicles. The maximum depth of dent of the target Celica of this first accident reconstruction was 6.8 inches, whereas Figure 1 shows a maximum of 17 inches.

Figure 9 documents for this first reconstruction of this series the damage to the target Celica. Damage to the bullet Pontiac is documented in Figure 10. For compar-

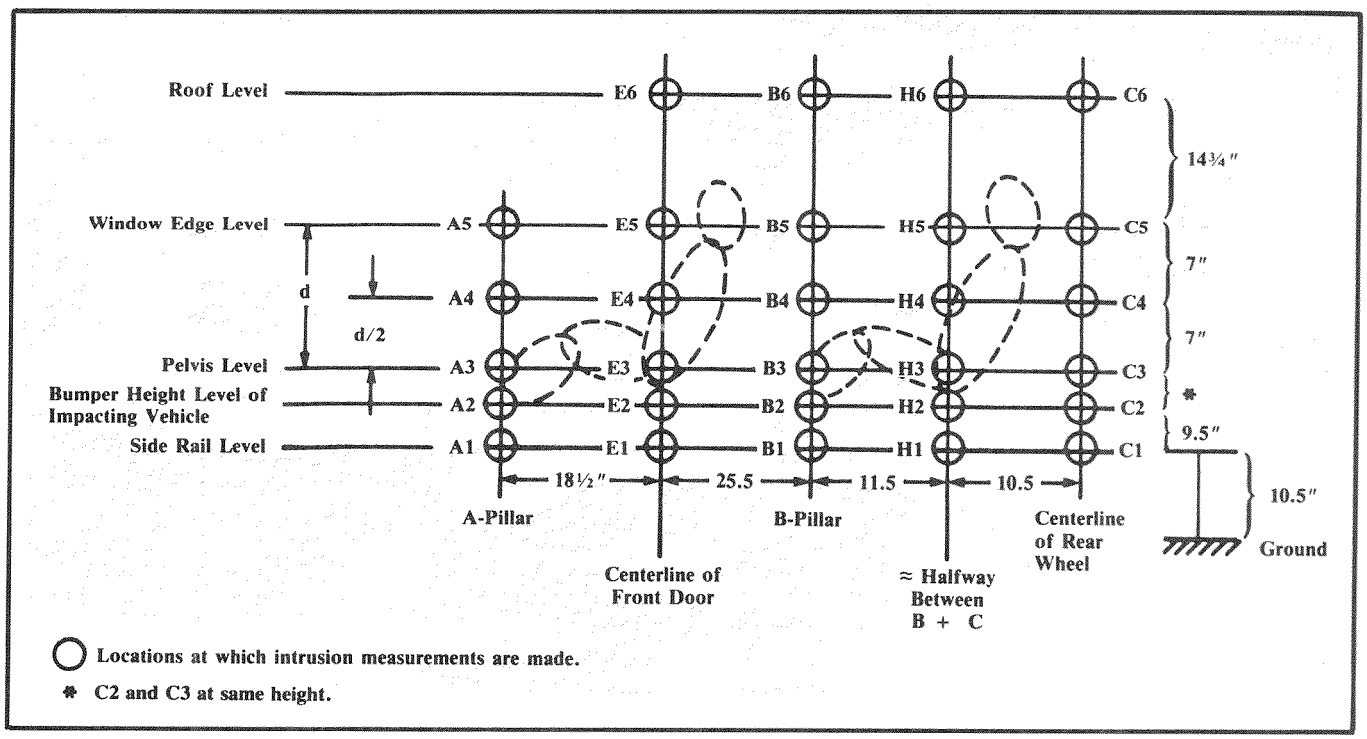


Figure 8. Matrix of points on the impacted side of the Celica at which depth of dent measurements were made.

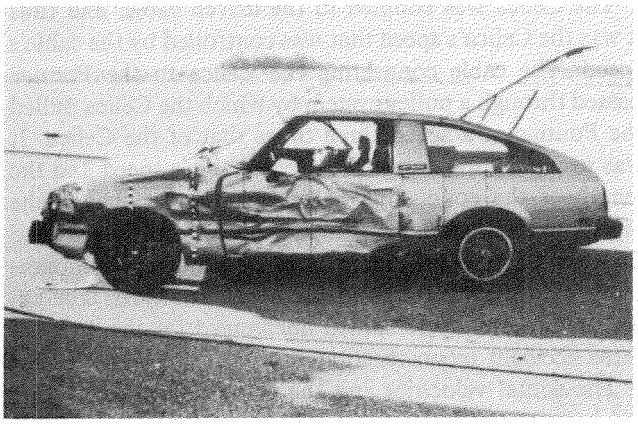


Figure 9. A view of the damage to the left side of the target Celica after the first car-to-car accident reconstruction.

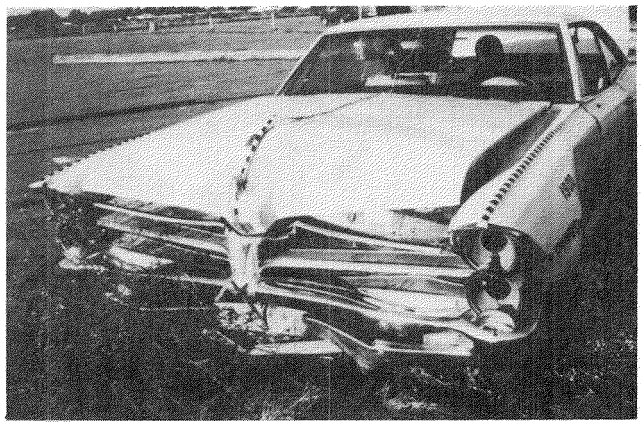


Figure 10. A view of the damage to the front of the bullet Pontiac after the first car-to-car accident reconstruction.

ison, reference is made to Figures 11 and 12 which show damage to the accident Celica. Figure 13 shows damage to the accident Pontiac.

It was clear by both measurement and view of the damage that the impact was not as severe as that for the accident vehicles. However, it was felt that the required increase in impact damage for the next reconstruction could be obtained by increasing the velocity of the bullet Pontiac with the corresponding increase in the Celica's velocity remaining (because of the cable system) one-third

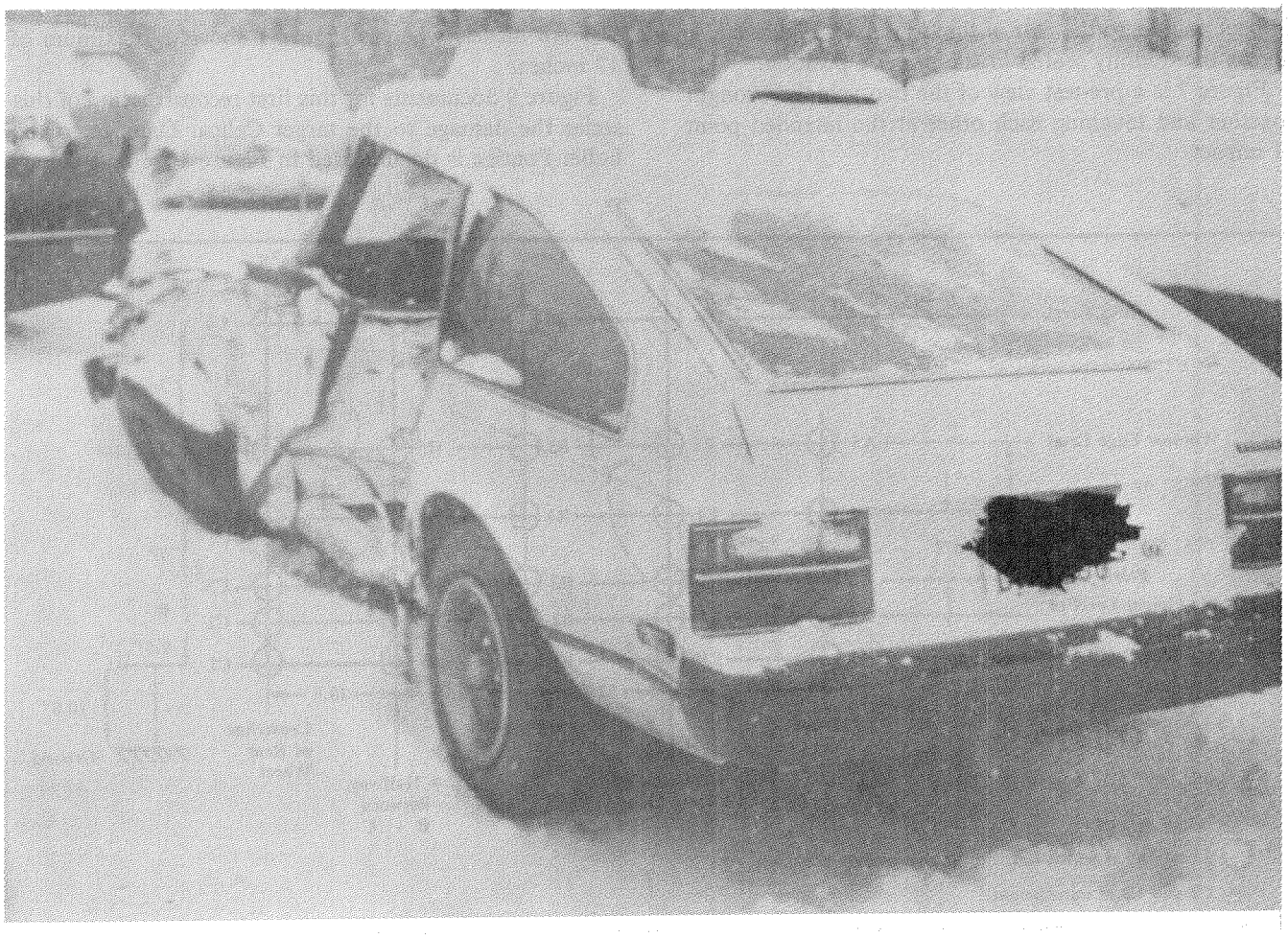


Figure 11. A photograph of damage to the accident Celica.

Figure 13. Another view of damage to the accident Pontiac.

REVIEW OF THE NUMERICAL DATA PERTAINING TO THE THIRD AND FINAL-PONTIAC/CELICA ACCIDENT RECONSTRUCTION

This section presents the numerical data of the third and final Pontiac/Celica accident reconstruction. This is considered the best reconstruction of the series of three.

An APR dummy was seated in the driver's position in the target Celica. Two lap belted Part 572 dummies were in the bullet Pontiac, one in the driver's position and the other in the front seat occupant's position.

Table 3 summarizes the test condition of the Pontiac and the Celica.

Figure 8 specifies the matrix of locations at which dent measurements were made. Table 4 records the measurements. However, the maximum depth of dent occurred at a point not located on the matrix. Figure 18 provides additional information on the depth of dents, including the location of the maximum dent of 16 inches. This maximum compares well with the 17 inch maximum recorded in the row of dent measurements at the bottom of Figure 1.

Table 3. Summary of the test condition of the Pontiac and Celica for the third and final Pontiac/Celica accident reconstruction.

	Pontiac	Celica
Vehicle manufacturer	General Motors	Toyota
Make/model	Grand Prix	Celica GT Liftback
Model year	1966	1977
Vehicle Identification Number	266576C141179	RA42001528
Number of engine cylinders	8	4
Engine cylinder displacement	398 in^3	133 in^3
Transmission	3 speed/auto	5 speed/man.
Type of front seat	Bench	Bucket
Number front seat occupants	2	2
Body style	2-door sedan	2-door hatchback
Total test weight with required dynamics	4220 lb	2850 lb

Figure 12. Another view of damage to the accident Celica. (Arrow near the rear wheel indicates the point assumed to be that of the most rearward extent of the direct dent.)

that of the Pontiac. It was decided that neither the offset of 17.5 inches nor the perpendicular angle of impact needed to be modified. It was difficult, however, to decide what the velocity of the Pontiac should be. Since the next reconstruction would be the second in a series of three, it was decided to choose a velocity that would probably be too high. Then for the third and final reconstruction the velocity would be chosen by interpolating (based, of course, on damage severity) to a velocity between those of the first two reconstructions. By engineering judgment the Pontiac's velocity for the second reconstruction was chosen to be 31 mph.

Figure 14 is similar to Figure 5 and shows the geometry and lists the intended and actual crash parameters for the second Pontiac/Celica accident reconstruction. (The cable system was the same as for the first reconstruction of this series.) The maximum depth of dent for the target Celica was 11.5 inches which was considerably less than the 17 inch maximum dent of the accident Celica. Figure 15 shows damage to the Celica after the second reconstruction. The damage does not compare well with the way damage is distributed on the accident Celica. Poor comparison was attributed to the offset being 26.25 inches instead of the desired 17.5 inches. The reason for so large an error is unclear and difficult to explain by cable stretch. The length of cable connecting the two cars may have been in error. The figures show a lot of damage to the Celica even if the maximum dent was only 11.5 inches. As can be readily seen in Figure 15, two large separated dents occurred. The amount of kinetic energy expended to form them was felt to exceed that of the damage of the accident Celica. Thus, it was felt that the Pontiac's velocity was too high. Figure 16 shows damage to the Pontiac.

For the third and final reconstruction of this series, the desired velocity of the Pontiac was 29.5 mph. Figure 17 is similar to Figures 5 and 14 and shows the geometry and lists the intended and actual crash parameters for the third reconstruction. The results of this third and final reconstruction are the closest in agreement with the accident and are discussed in detail in the sections immediately following.

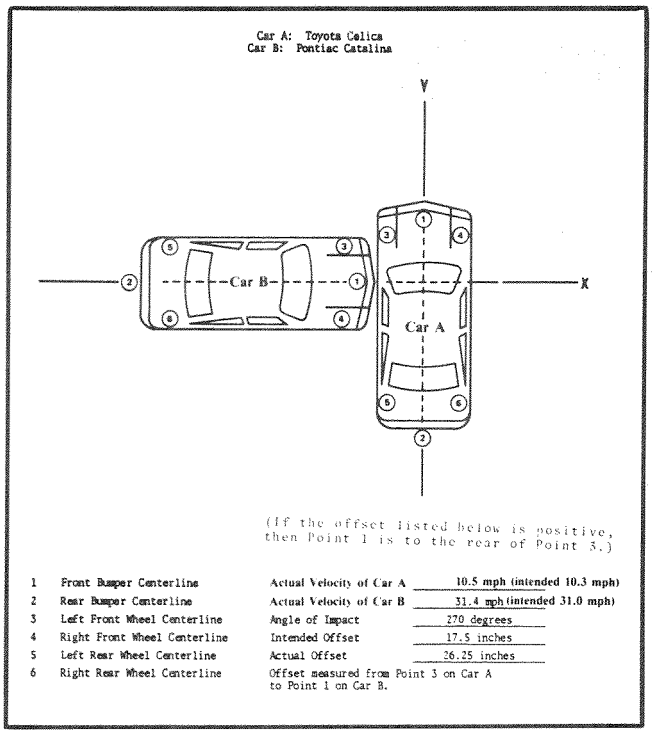


Figure 14. Crash configuration and impact parameters of the second Pontiac/Celica accident reconstruction.

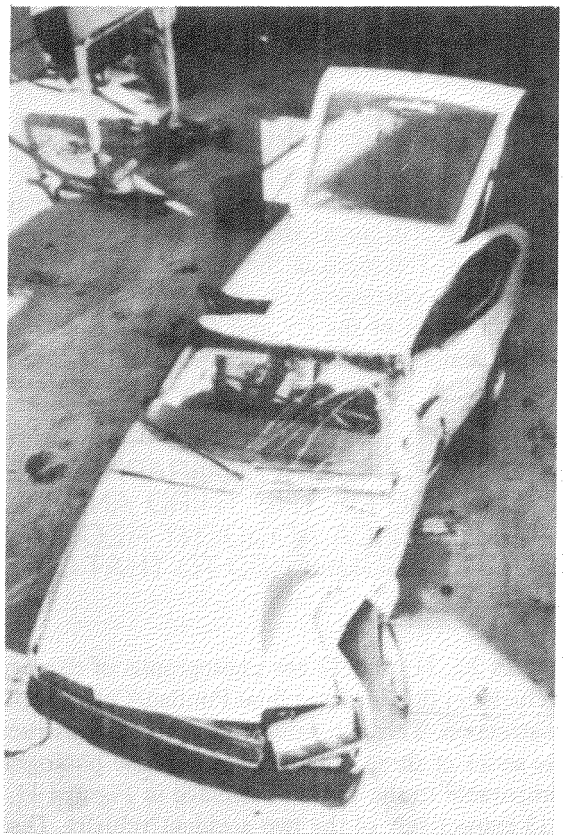


Figure 15. Another view of damage to the target Celica after the second Pontiac/Celica car-to-car accident reconstruction.

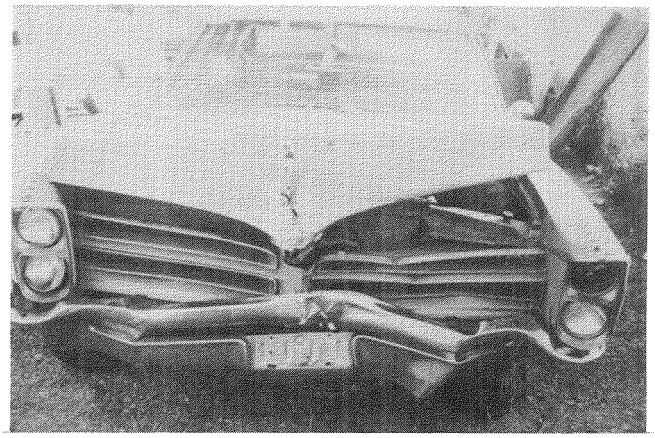


Figure 16. A view of damage to the bullet Pontiac after the second Pontiac/Celica car-to-car accident reconstruction.

Figure 19 compares the dent damage graphically of the accident and reconstruction Celicas. The two points listed as "not measured pre-test to establish a reference point" are the two rearward dents shown in Figure 18. The other points for the reconstruction are points H_3, B_3, E_3, and A_3 from Table 4. It should also be recognized that the depth of dent measurements made on the accident Celica have the same uncertainty as these two points, because the accident investigators had no pre-impact measurements. The matrix of dent measurements in Figure 8 is

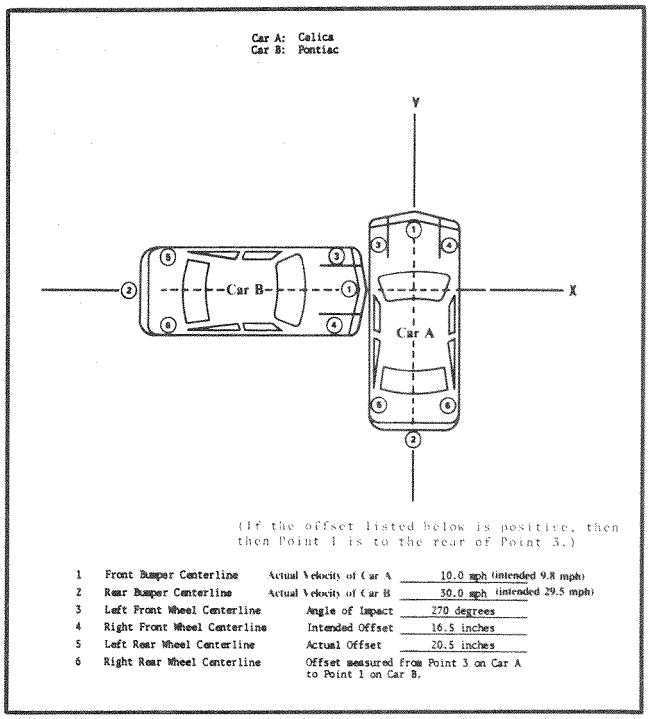


Figure 17. Crash configuration and impact parameters of the third and final Pontiac/Celica accidental reconstruction.

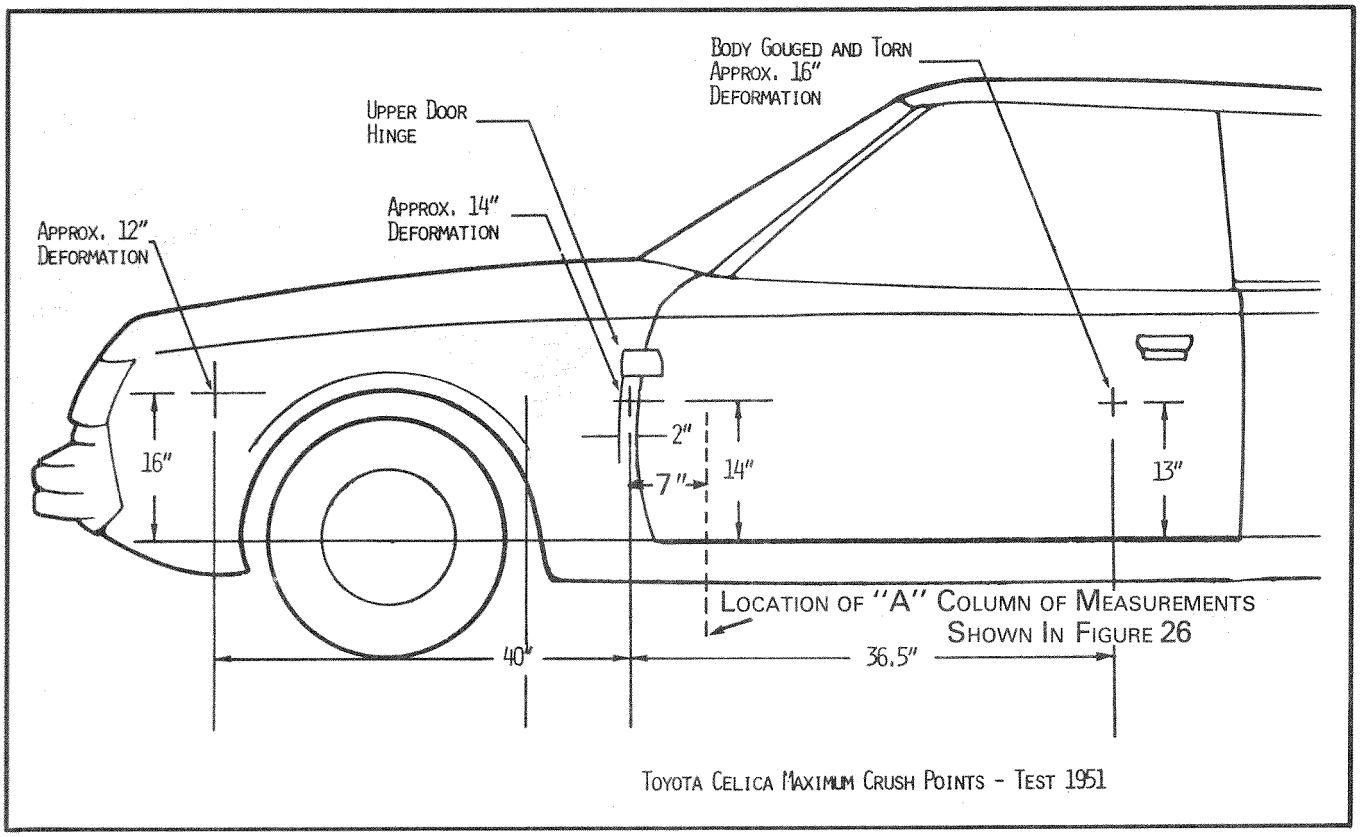


Figure 18. Location of the maximum dent of 16 inches on the target Celica on the third and final Pontiac/Celica car-to-car accident reconstruction.

restricted to the compartment area and thus the measurements were not made as far forward as for the accident Celica. In retrospect this was unfortunate.

Table 4. Depth of dent measurements on the target Celica on the third and final Pontiac/Celica reconstruction.

Location*	Depth of dent (inches)	Location	Depth of dent (inches)
A1	2.5	E1	2.85
A2	7.75	E2	11.5
A3	7.75	E3	11.5
A4	7.50	E4	11.0
A5	3.75	E5	8.9
B1	2.35	E6	0.0
B2	3.75	H1	N/A
B3	3.75	H2	0.0
B4	5.25	H3	0.0
B5	4.50	H4	0.75
B6	0.40	H5	1.1
C1	N/A	H6	0.0
C2	N/A		
C3	N/A		
C4	0.0		
C5	0.0		
C6	N/A		

*See Figure 26 for definition of locations of depth of dent measurements.

Measurements of the bullet Pontiac indicated that the impact reduced its total length at the centerline by 9.25 inches. The accident report indicates that the damage is symmetrically distributed about the Pontiac's longitudinal centerline. The mean of the dents at stations C3 and C4 would then correspond to the dent at the centerline above. The mean of the C3 and C4 dents is 13 inches. This is reasonable agreement with 9.25 inches.

REVIEW OF THE PHOTOGRAPHED VEHICLE DAMAGE OF THE THIRD AND FINAL PONTIAC/CELICA ACCIDENT RECONSTRUCTION COMPARED TO THAT OF THE ACCIDENT

Figures 20, 21, and 22 are photographs of damage to the vehicles in the third and final Pontiac/Celica accident reconstruction. This is considered the best reconstruction of the series of three. The damage in these photographs is comparable to the views of damage in Figures 11, 12, and 13 respectively of the two accident vehicles. Discussion of each pair of corresponding photographs follows.

Figures 11 and 20 show respectively, from the same angle of view, damage to the accident and to the recon-

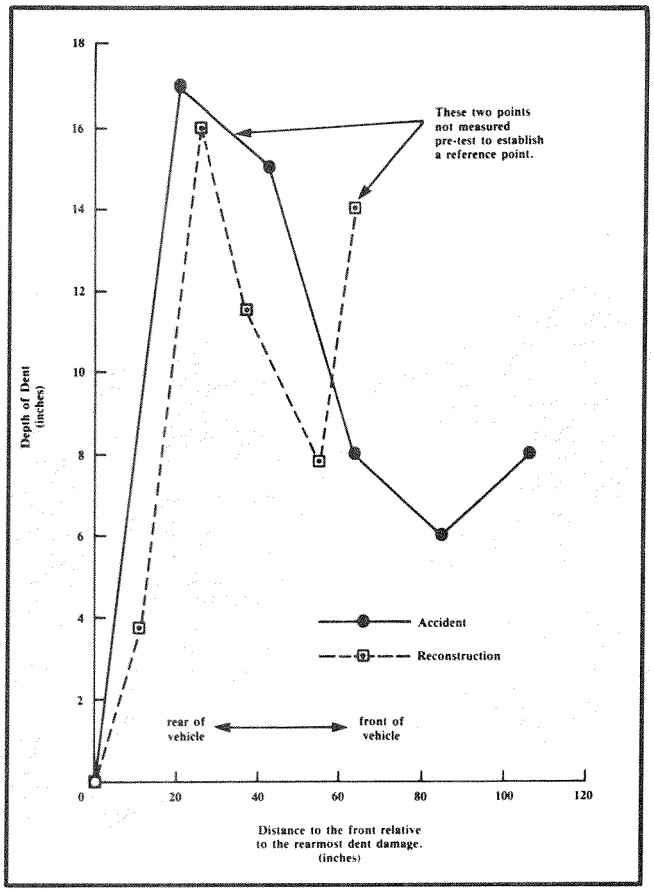


Figure 19. Graph comparing dent damage of the accident Celica and the Celica of the third and final accident reconstruction.

struction Celica. Figures 12 and 21 are a similar pair of photographs but from another view. As can be seen in both pairs of photographs, the angle of the left front wheel relative to the chassis is reversed in the accident photographs from what it is in the reconstruction. It is believed that the angle in the photographs 20 and 21 of the reconstruction is correct; the angle attained in the accident investigation photograph is believed to be a result of towing from the accident scene. The door of the Celica in the accident photographs appears to be held in place with a segment of a seat belt, and the upper door hinge seems to have been torn loose. It is possible that the door had to be pried open or off at the accident scene in order to remove the victim. In the reconstruction photographs of the Celica the door's sheet metal is torn at the point of maximum indentation; such a tear does not appear in the corresponding accident photograph. The point of maximum indentation in the accident Celica appears at approximately the same distance forward of the door handle, but perhaps three inches lower than in the reconstruction photograph. The dent appearing to be located lower in the accident may be due to the Pontiac's nose diving in response to panic braking. This also would explain what appears to be greater indentation to the sill area in the accident vehicle. Panic braking was not simulated in the reconstruction. The left front headlight was reoriented slightly in the accident, but not in the reconstruction. In the accident more severe damage occurred to the B-pillar near the window sill than in the reconstruction.

In terms of similarities, the accident investigation report (Figure 1) lists the maximum dent in the Celica as 17 inches while that measured in the reconstruction was 16 inches, a value that is within experimental error. Comparing the depth of dent in the two photographs is obviously difficult, especially since the door may have been pried open or off, but the photographs do not contradict the assumption that they are almost equal. The accident report shows (See Figure 1) a short part of the fender directly above the left front wheel not dented, and this is supported by the photographs of both the accident and the reconstruction Celicas. Both Celicas had damage near the left front corner of the hood with more severe damage occurring in the reconstruction. The accident Celica shows the hood raised slightly, but this may be due to its being raised after the accident in order to provide routing of the belt which appears to be holding the door in place. The indentation to the left front fender of each vehicle seems comparable, and the indentation on both vehicles extends back to a point slightly forward of the rear axle. The left side of each windshield underwent similar shattering.

Reference is made to Figures 11 and 20. Clearly the B-pillar in the accident was twisted more than in the reconstruction. The lack of shadows in the accident photographs make comparisons of damage near its front difficult to compare with that of the reconstruction. The depth of dent in the door area appears greater for the accident than for the reconstruction. But this may be due to the accident Celica possibly having its door pried loose to free the occupant.

We now discuss the damage to the bullet Pontiac as shown in the two corresponding photographs, Figures 22 and 13. It is clear that in the accident there was considerable damage to the accident Pontiac's left front fender, but much less to that of the reconstruction Pontiac. Bending of the hood is different in the two photographs. There appears to be greater damage to the left side of the reconstruction Pontiac than to that of the accident. Yet the amount of kinetic energy expended in damage appears to be comparable. Various explanations could be offered for the differences in damage. As stated earlier, the accident Pontiac may have been nose diving due to panic braking. The angle of impact was assumed to be 90°, but a slight deviation from this orientation could make a difference in damage. Speculations such as these could have been investigated if more than three pairs of vehicles had been available for crash testing.

This section completes the review of the third and final Pontiac/Celica accident reconstruction.

Figure 20. A view of damage to the target Celica in the third and final Pontiac/Celica car-to-car accident reconstruction.

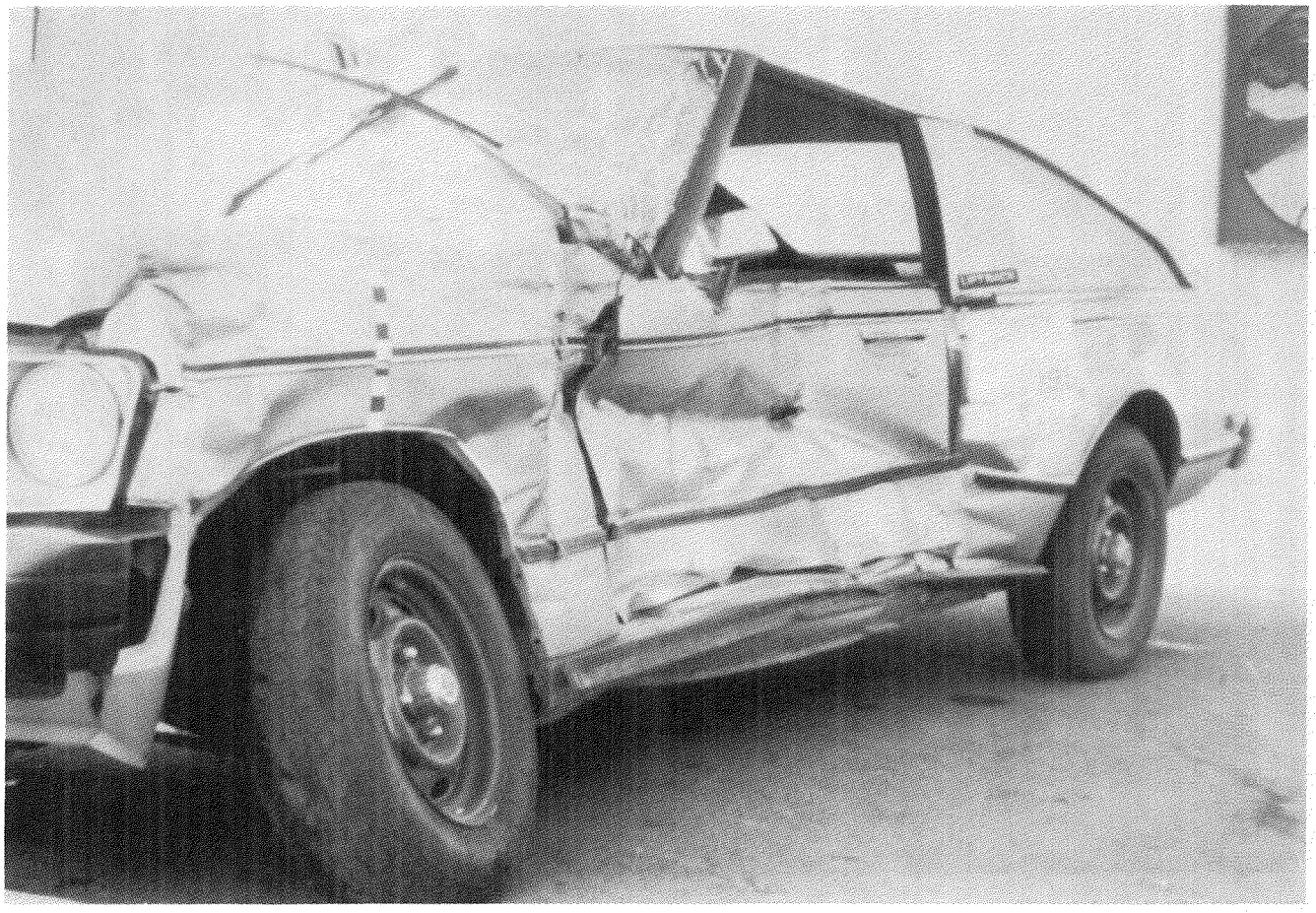


Figure 21. Another view of damage to the target Celica in the third and final Pontiac/Celica car-to-car accident reconstruction.

Figure 22. A view of damage to the bullet Pontiac in the third and final Pontiac/Celica car-to-car accident reconstruction.

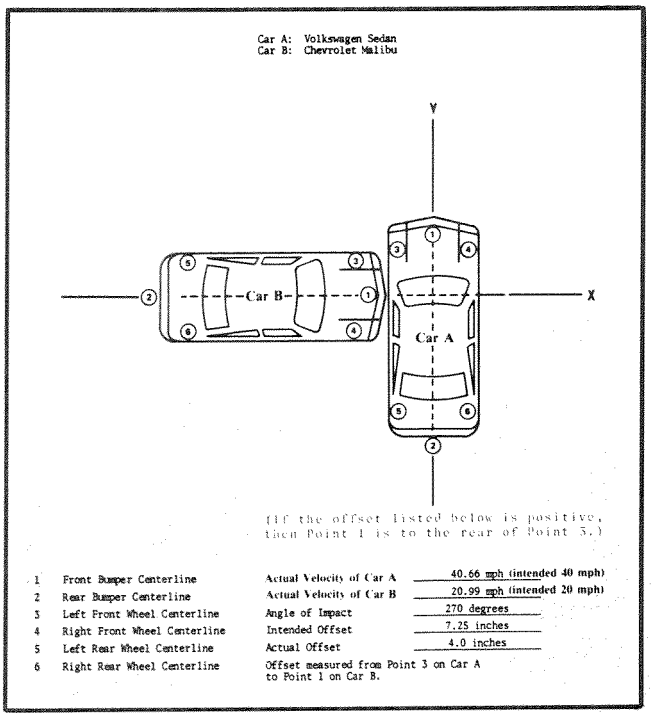


Figure 23. Crash configuration and impact parameters of the first Malibu/Beetle accident reconstruction.

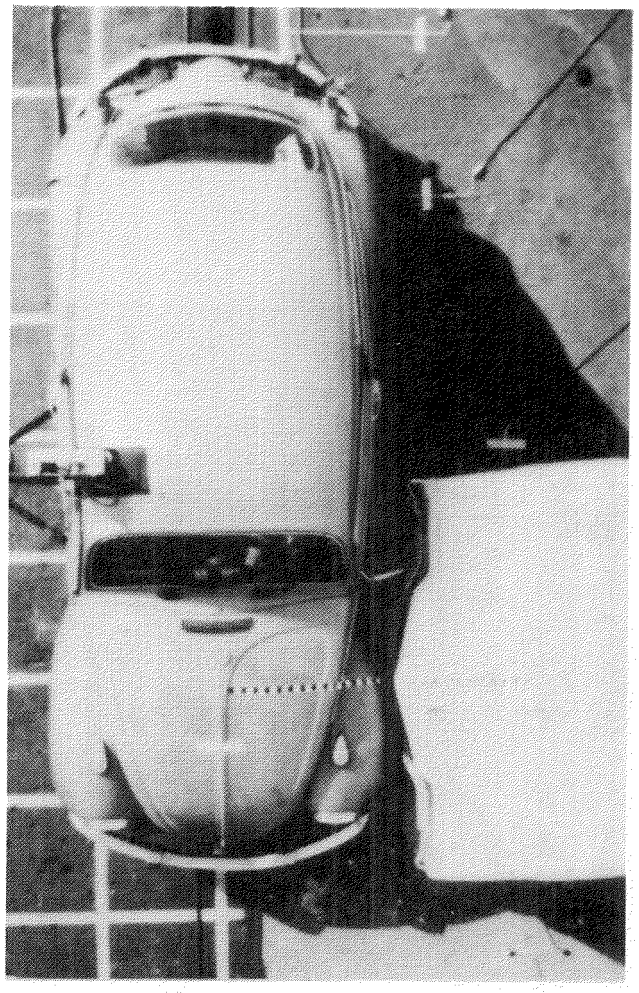


Figure 24. A view of the pre-test vehicle positions for the first Malibu/Volkswagen Beetle car-to-car accident reconstruction.

THE SERIES OF ACCIDENT RECONSTRUCTIONS BETWEEN A 1972 CHEVROLET MALIBU AND A 1969 VOLKSWAGEN BEETLE

Based on the information in the accident investigation report and the results of a series of simulated crash reconstructions using SMAC, it was decided for the first car-to-car accident reconstruction that the angle of impact would be perpendicular against the driver's side. The geometry is shown and the intended and the actual crash parameters are listed in Figure 23.

Figure 24 is a pre-test view of the two vehicles touching at their intended points of contact. These points are marked with tape which can be seen.

The cable system used to connect the two vehicles was such as to provide the bullet Malibu with a velocity one-half that of the target Beetle.

The actual velocities and the actual offset listed near the bottom of Figure 23 are different from the intended values. As already discussed the difference in offsets can generally be attributed to the variability of cable stretch.

As stated at the beginning of this report, the accuracy of the accident reconstruction is judged in terms of impact damage to the two vehicles. Figures 25 and 26 are photographs showing respectively damage to the accident target Beetle and the accident bullet Malibu. In Figure 25 the door is lying face down preventing view of the damage. More significant than damage to the door, there is a large hole in the side due to the B-pillar's being bent into the form of a V. Judgments as to how well damage severity was duplicated was based mainly on damage to the B-pillar. The photograph of Figure 27 documents for this first reconstruction of this series the damage to the target Beetle. Damage to the bullet Malibu is documented in the photograph of Figure 28. For comparison, reference is made to Figures 25 and 26 which document respectively damage to the accident Beetle and damage to the accident Malibu.

It was clear by view of the damage of the first reconstruction that the impact was too severe with too much damage to the B-pillar. A review of high speed motion pictures revealed that the bending of the B-pillar was caused by the front point of the Malibu first denting the area ahead of the B-pillar and then engaging and bending the B-pillar. For the second test of this series it was decided by engineering judgment to reduce the speed of the Beetle from the 40.7 mph of the first reconstruction

Figure 25. A view of damage to the target Beetle of the accident.

Figure 26. A view of damage to the bullet Malibu of the accident.

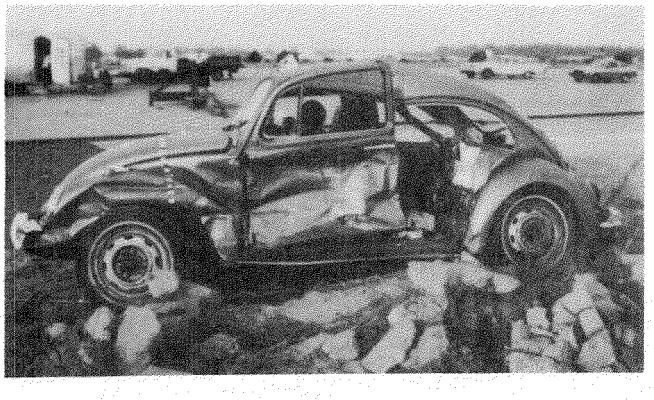


Figure 27. A view of damage to the target Volkswagen Beetle after the first Malibu/Beetle car-to-car accident reconstruction.

to 35 mph with the speed of the Malibu being reduced to 17.5 mph (one-half that of the Beetle). The offset was kept at 7.25 inches and the angle of impact was kept perpendicular.

Figure 29 is similar to Figure 23 and shows the crash geometry and lists the intended and the actual crash parameters for the second accident reconstruction of this series. Note that the actual offset recorded in Figure 29 is 11.75 inches instead of 7.25 inches. This error was sufficient to cause the Malibu to fail to engage (and thereby fail to bend) the B-pillar. See Figure 30.

The results of this second reconstruction obviously provided little insight on how to improve the third and final reconstruction of this series, except to stress the importance of engaging the B-pillar. To help ensure engagement, the intended offset for the third reconstruction was changed from 7.25 inches to the rear of the front axle to 2.75 inches to the rear of the front axle. Second thoughts in terms of engineering judgment caused the intended

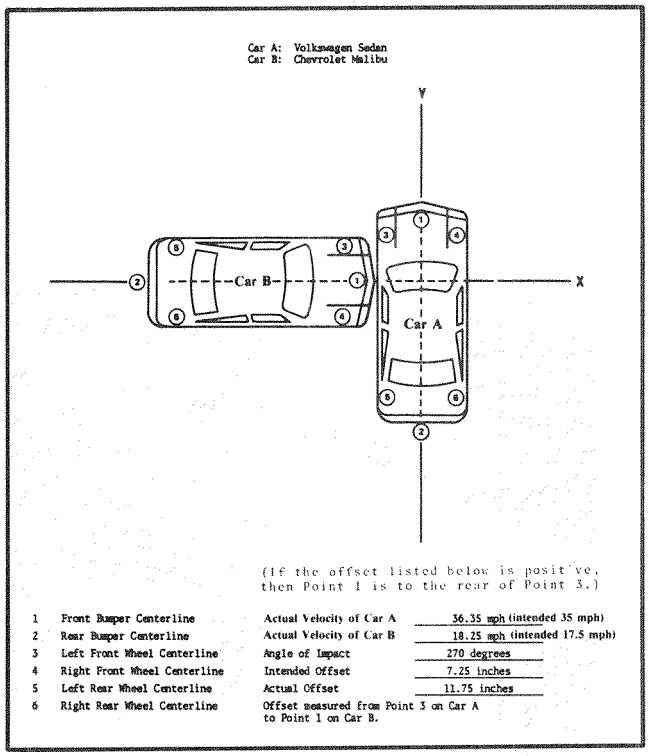


Figure 29. Crash configuration and impact parameters of the second Malibu/Beetle car-to-car accident reconstruction.

velocity of the Beetle to be reduced slightly from 35.0 mph on the second reconstruction to 34.5 mph for the third reconstruction. The intended speed of the Malibu, of course, was reduced to one-half that of the Beetle, 17.25 mph.

Figure 31 is similar to Figures 23 and 29 and shows the crash geometry and lists the intended and actual crash parameters for the third and final reconstruction of this series. The actual offset was 4.25 inches forward of the front axle instead of 2.75 inches to the rear of this axle

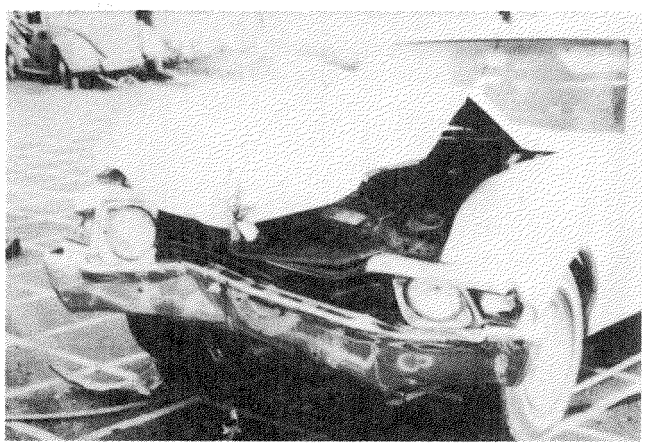


Figure 28. A view of damage to the bullet Malibu after the first Malibu/Beetle car-to-car accident reconstruction.

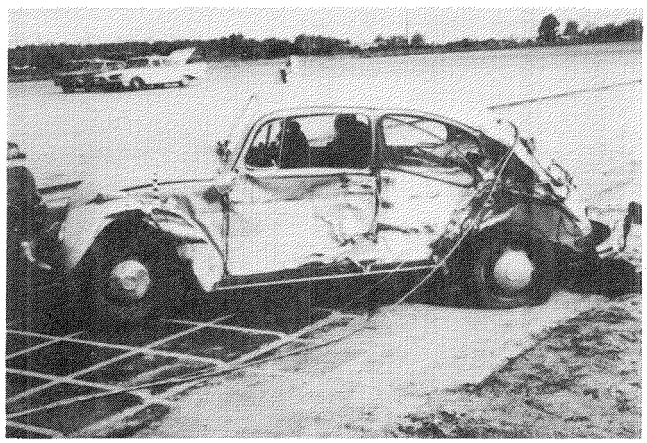


Figure 30. A view of the damage to the target Beetle after the second Malibu/Beetle car-to-car accident reconstruction.

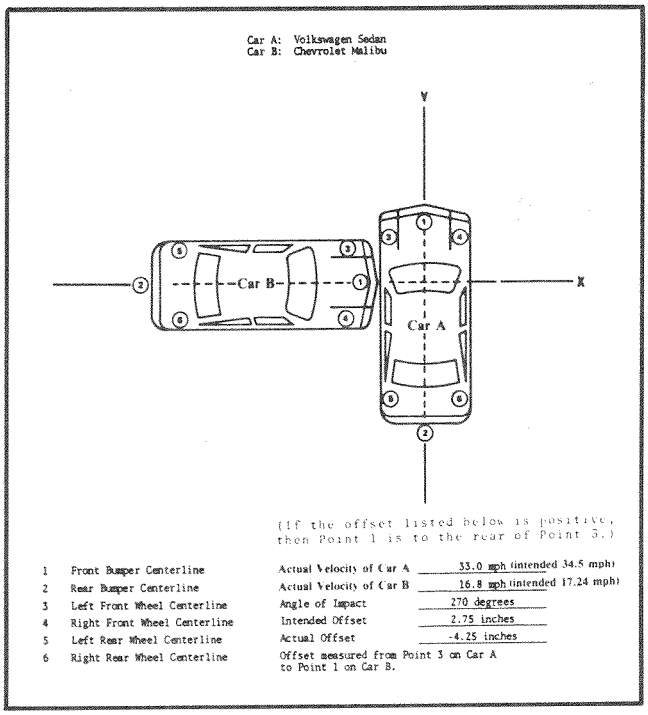


Figure 31. Crash configuration and impact parameters of the third and final Malibu/Beetle car-to-car accident reconstruction.

as intended. This error was perhaps beneficial because the crash damage, especially the bending of the B-pillar, was similar to that of the accident Beetle. The results of this third and final reconstruction are discussed in detail in the next session. It is considered the most accurate of the three.

Before ending this section, however, some comments are appropriate about the difficulties in reconstructing this particular Malibu/Beetle accident. First the Beetle's speed of approximately 35 mph on the third reconstruction was such that a late arrival of the Malibu of only one millisecond would cause the actual offset to be an additional ¾ inches farther to the rear of the Beetle. Because of the Beetle's small size, it has large structural changes over short distances, thereby enhancing the possibility of large changes in impact damage caused by small changes in offset.

This particular accident was selected for reconstruction, because the driver was 19 years of age and not too much smaller than that of a 50th percentile male. Also the Beetle's small interior reduced the possibility that the accident driver's position could not be accurately assumed. Nevertheless, it is clear from the problems on this series of accident reconstructions that it is best when possible to choose side impact accidents for which the target vehicle has a low velocity, perhaps not more than 15 mph. In general, the smaller the target vehicle, the lower its velocity should be.

REVIEW OF THE NUMERICAL DATA PERTAINING TO THE THIRD AND FINAL MALIBU/BEETLE ACCIDENT RECONSTRUCTION*

This section presents the numerical data of the third and final Malibu/Beetle accident reconstruction. This is considered the best reconstruction of the series of three.

An APR dummy was seated in the driver's position in the target Beetle. Two lap belted Part 572 dummies were in the bullet Malibu, one in the driver's position and the other in the front seat occupant's position. Table 5 summarizes the test condition of the bullet Malibu and the target Beetle.

Figure 32 specifies the matrix of locations at which depth of dent measurements were made on the target Beetle. Table 6 reports these measurements. Some of the measurements along the B-pillar were obtained by angling the ruler slightly. This was necessary, because the B-pillar was displaced backward and bent into the shape of a V.

Table 6 reports the maximum depth of dent to be 11.75 inches, while from Figure 2 from the accident report the maximum is given to be 12 inches. Considering that the damage to the Beetle was so severe that the door was torn off, one has to put at least a plus or minus 2 inch uncertainty on the 12 inch value from the accident report. The door must have been temporarily put back into its approximate position in order to measure the dent.

*See Figure 32 for definition of locations.

Table 5. Summary of the test condition of the Malibu and VW Beetle for the third and final Malibu/Beetle accident reconstruction.

	Malibu	Beetle
Vehicle manufacturer	General Motors	Volkswagen
Make/model	Chevrolet Malibu Classic	VW/Beetle
Model year	1972	1971
Vehicle identification Number	37H2L532958	1112916245
Number of engine cylinders	8	4
Engine cylinder displacement	350 in^3	1200 cc
Transmission	3 speed/auto	4 speed/manual
Type of front seat	split bench	bucket
Number front seat occupants	3	2
Body Style	2-door coupe	2-door sedan
Total test weight with required dummies	3870 lbs	2100 lbs

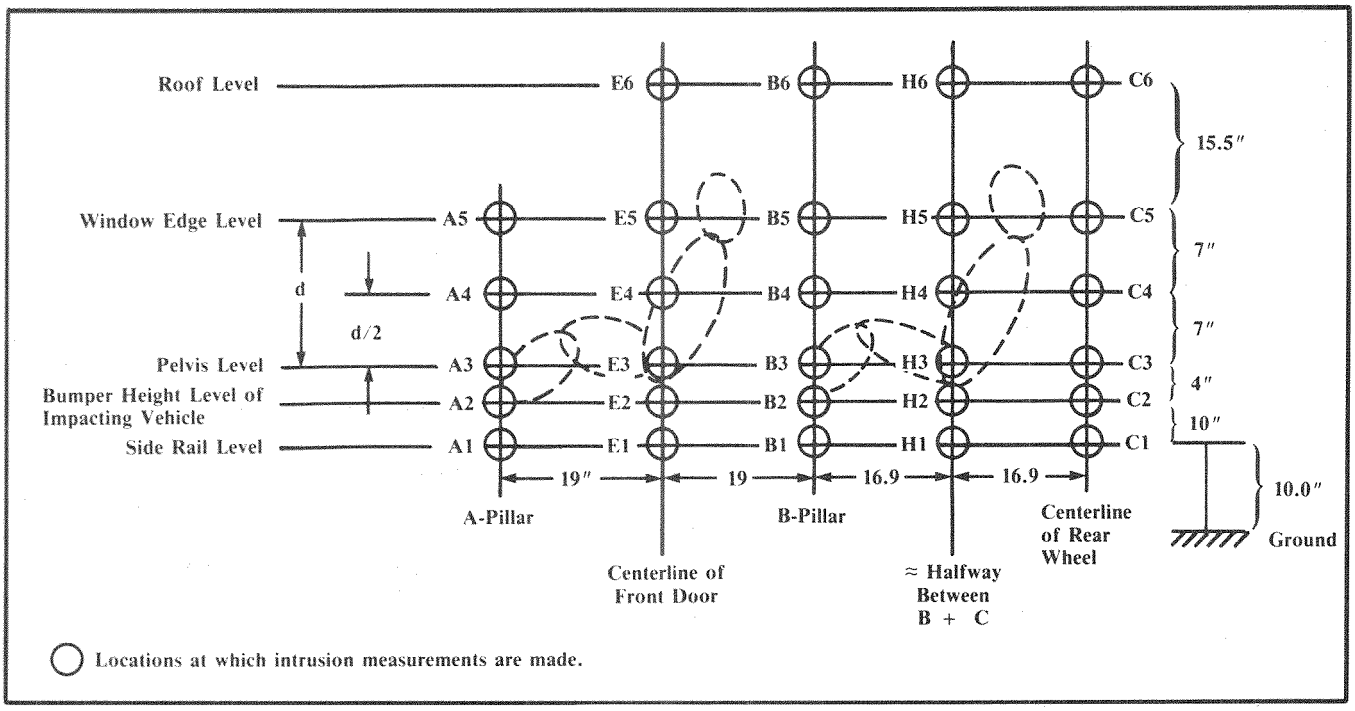


Figure 32. Matrix of points on the impact side of the Volkswagen Beetle at which depth of dent measurements were made.

It is difficult to compare the location of the maximum dent between the accident Beetle and the accident reconstruction Beetle. Reference is made to Figure 2, which locates the maximum dent on the accident Beetle at station C2. As discussed earlier each subscripted C is located the same distance from its neighboring C, and this distance is the total length of the direct dent divided by five. Figure 2 lists the length of the direct dent to be 96 inches. Thus the separation between each subscripted C is one fifth of 96 or 19.2 inches. Station C1 is the closest to the rear of the Beetle and C2 is 19.2 inches forward of C1. Station C1 is located at the rearmost point of the direct dent, and this point is difficult to judge on the accident Beetle shown in Figure 25. It is located near the displaced B-pillar. The location of the maximum dent at station C2 lies 19.2 inches forward of C1 and is almost certainly in the torn open area, but probably not too far from the undisplaced B-pillar. The maximum dent that was measured in the reconstruction was at the B-pillar.

The accident report gives the location of the maximum dent to be 34 inches above the ground. The maximum of 11.75″ for the reconstruction Beetle occurs at location B2 (see Table 6) which by Figure 32 is only 20 inches above the ground. Thus, there is a discrepancy of 14 inches. However, B3 is located 24 inches above the ground with a depth of dent of 11.5 inches, almost that of the maximum of 11.75 inches. Thus, the maximum does not appear to be a well-defined point.

Although there are uncertainties in comparing the maximum dent and its location, there appears to be better agreement when comparing damage from photographs as will be done in the next section.

Measurements of the bullet Malibu indicated that the impact reduced its overall length at the centerline by 3.25 inches. The centerline of the accident Malibu lies approximately midway between stations C3 and C4. The mean of the dents for these two stations is 4.5 inches. In

Table 6. Depth of dent measurements on the target Volkswagen Beetle after the third and final Malibu/Beetle reconstruction.

Location*	Crush (inches)	Location	Crush (inches)
A1	5.00	E1	4.50
A2	4.40	E2	7.35
A3	6.00	E3	9.65
A4	4.15	E4	8.85
A5	1.50	E5	2.25
B1	3.25	E6	0.40
B2	11.75	H1	2.00
B3	11.50	H2	1.20
B4	10.50	H3	0.25
B5	6.25	H4	1.00
B6	1.85	H5	1.25
C1	0.75	H6	1.20
C2	1.00		
C3	N/A		
C4	3.50		
C5	2.00		
C6	N/A		

*See Figure 32 for definition of locations.

summary the change in length of the reconstruction Malibu is 3.25 inches while that of the accident Malibu is 4.5 inches; this is a good comparison.

COMPARISON OF THE PHOTOGRAPHED VEHICLE DAMAGE OF THE THIRD AND FINAL MALIBU/BEETLE ACCIDENT RECONSTRUCTION COMPARED TO THAT OF THE ACCIDENT

Figures 33 and 34 are photographs which document damage to the target Beetle after the third and final Malibu/Beetle accident reconstruction. These photographs should be compared with the photograph in Figure 25 which shows damage to the Beetle of the actual accident. Similarly Figure 35 is a photograph of damage to the bullet Malibu. This photograph should be compared with the photograph of Figure 26 which shows damage to the Malibu of the actual accident. A comparison is now made between damage to the vehicles in the accident reconstruction and the vehicles in the accident based on the above photographs. The damage to the Beetle will be reviewed first.

The damage to the door of the accident Beetle is hidden from view in Figure 25, because the door is off its hinges and lying face down against the ground. A review of the accident report indicates that the door was torn off during impact and not pried off to extricate the victim. Figures 33 and 34 are photographs of damage to the accident reconstruction Beetle. The two photographs show severe damage in the hinge area, but the door still remains attached. The door not being torn off during the accident reconstruction is, of course, a significant difference in results. Photographs of damage to the accident reconstruction Beetle show almost no damage to the sill. The door's position in Figure 25 of the accident Beetle hides most of the sill from view. But the slight part that is exposed appears to be undamaged. Both Beetles have similar damage in the area of the B-pillar. However, because of the separation of the rear side panel from the rear fender in Figure 33, the damage appears to be more severe in the reconstruction. All the damage in the reconstruction initiates at the left headlamp, whereas in the accident damage begins several inches to the rear of the lamp. The angle the B-pillar makes in the reconstruction is comparable to that of the accident. Both vehicles have

Figure 33. A view of the damage to the target Beetle after the third and final Malibu/Beetle car-to-car accident reconstruction.

Figure 34. Another view of the damage to the target Beetle after the third and final Malibu/Beetle car-to-car accident reconstruction.

a similar wrinkle of induced damage to the roof just above the B-pillar. It is clear by the point near the front where indentation begins that the initial strike point was forward in the reconstruction from that of the accident. This difference in strike point could explain differences in damage. In a small car such as the Beetle, significant structural changes occur over short distances.

Reference is made to Figures 35 and 36 which show damage to the Malibu in the reconstruction. It is difficult to judge damage to the bumper of the accident, shown in Figure 26, but the right part of the bumper appears damaged as in the reconstruction. Clearly the accident Malibu had more wrinkling of the right front fender than the reconstruction Malibu.

Although there are differences in damage between the accident and the reconstruction, there nevertheless appears to be good general comparison of the damage severity.

REVIEW OF THE CAR-TO-CAR CRASH TEST PROCEDURES USED TO OBTAIN MORE ACCURATE ACCIDENT RECONSTRUCTIONS

As stated at the beginning of this report, the accuracy of the accident reconstruction was judged primarily in terms of the damage to the two impacting vehicles. In each of the two crash reconstructions, that of the Pontiac/Toyota and that of the Malibu/Volkswagen Beetle, the results of each reconstruction series did not contradict the assumption, derived partly by SMAC computer reconstructions, that the angle between the accident vehicles' centerlines was 90°. The velocity ratios for each series were also adequate for the test series. In each series the problem was to decide, based on crash damage of the preliminary tests, the following:

1. The correct speed of the target vehicle (with the corresponding velocity of the bullet vehicle being a fixed ratio to that of the target vehicle).
2. The correct point on the target vehicle for initial impact (i.e., the correct offset as defined near the bottom of Figure 5).

It was not difficult to judge from damage whether the velocity of the bullet vehicle was too great or too small. However, it was difficult to decide the exact amount by which the velocity should be changed. For the most part the change was based on engineering judgment. Fortunately the velocity of the faster vehicle could be controlled to within plus or minus one and one-half miles per hour.

For the Pontiac/Celica crash, the first reconstruction was not sufficiently severe. The strategy used was to have the second reconstruction too severe and then be in a

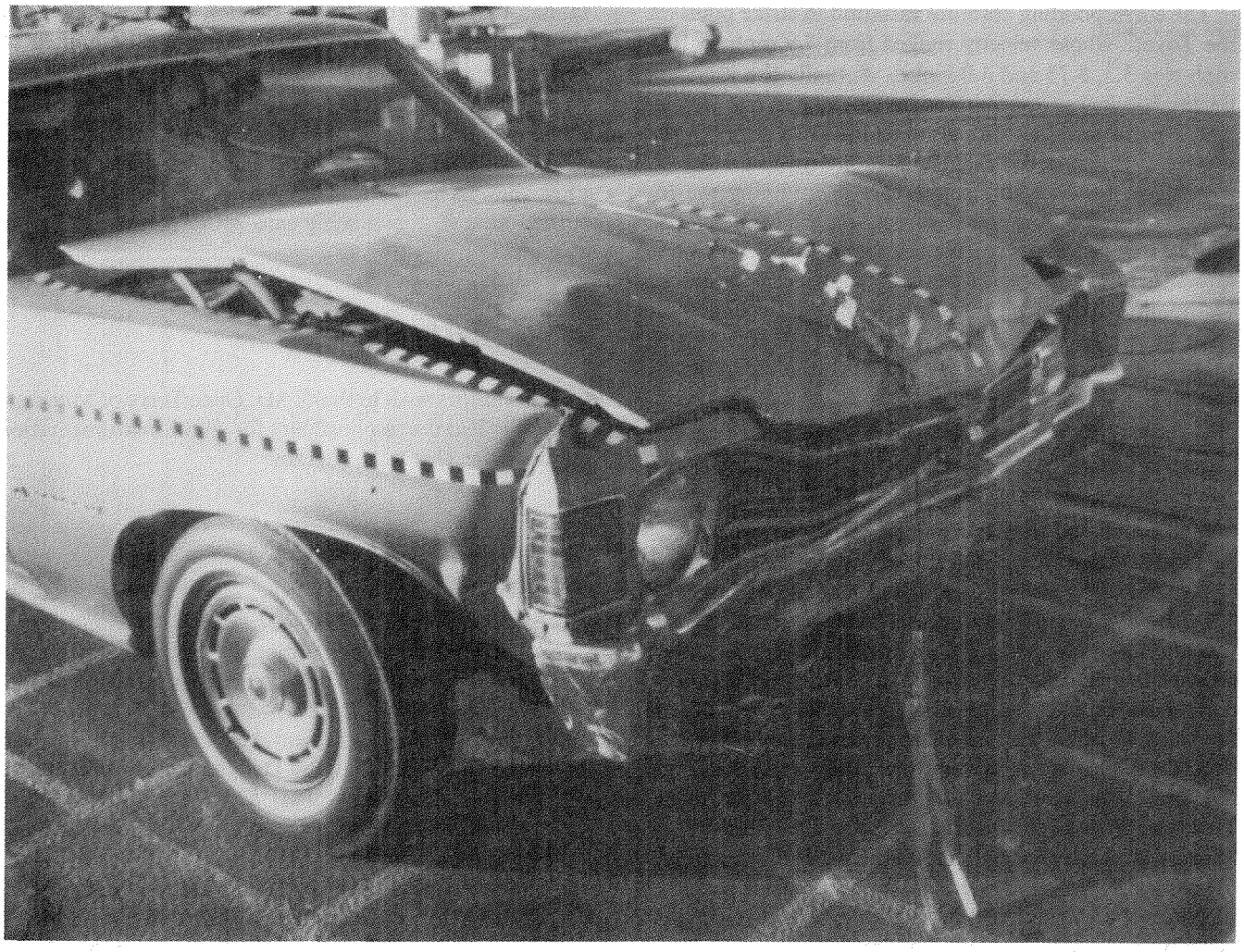


Figure 35. A view of the damage to the bullet Malibu after the third and final Malibu/Beetle accident reconstruction.

position for the third and final reconstruction to interpolate to a more appropriate crash severity. This seemed to be a wise procedure.

The most difficult of the two series to reconstruct was that of the Malibu/Volkswagen Beetle. The Beetle's velocity for the three tests of the series ranged from 33.0 mph to 40.7 mph. The velocity of the bullet Malibu was approximately one-half these velocities. A Beetle's velocity of 40.7 mph is equivalent to 0.7 inches per millisecond. An early or late arrival of the bullet Malibu of only one millisecond would cause a change in the initial impact point by 0.7 inches. The absolute differences in actual impact point to that intended were 3.2 inches, 4.5 inches and 7.0 inches. Although a correction was made to reduce the error due to the dynamic stretch of the cable which connected the two cars, there were still remaining errors. These remaining errors account for the above variation of the strike point on the target vehicle.

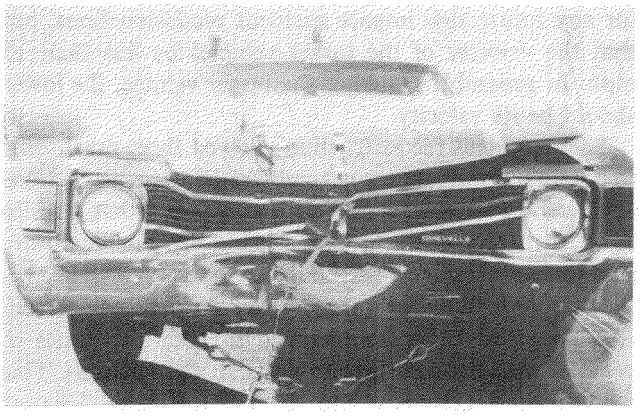


Figure 36. Another view of the damage to the bullet Malibu after the third and final Malibu/Beetle car-to-car accident reconstruction.

The corresponding absolute variation in strike point on the Toyota whose velocity ranged from 7.9 mph to 10.5 mph was 3.5, 8.75 and 4.0 inches. Actually the variation for the Beetle was less than for the slower moving Toyota. The Toyota variations are also attributed to errors in the dynamic stretch of the cable connecting the two vehicles. There clearly are significant errors in attaining the intended strike point at lower speeds. At the Minicars test facility it is necessary to give the target vehicle, which is attached to the power cable, a constant acceleration up to the intended velocity if slack in the connecting cable is to be prevented. Maintaining a constant acceleration up to a lower speed can be more difficult than for a higher speed.

CONCLUSIONS

It is concluded that the two accident reconstructions performed are excellent in terms of reproducing the damage sustained by the original vehicles of the accidents.

Of the two reconstructions, that of the Pontiac/Celica was the more accurate. This is attributed to the target Celica's low velocity of 10 mph. In contrast, in the other reconstruction the target Volkswagen Beetle's velocity on the third and final reconstruction was 33 mph. In addition, the Celica is larger than the Beetle and thus, does not have large structural changes over short distances. This lessens the Celica's change in damage severity as a function of slight changes in initial strike point. Attaining the correct strike point is crucial for an accurate accident reconstruction. The Beetle's smaller size and its higher velocity combined to make it more difficult of the two reconstructions to conduct.

Although a smaller car with bucket seats has the asvantage of minimizing the uncertainty in the position of the occupant, especially that of the driver, a clear disadvantage is large structural changes over short distances of the vehicle. Based on the limited testing in this report, it is concluded that small target vehicles still be considered for any future side impact accident reconstructions, but that the velocity of the target vehicles be less than 15 mph. In general the smaller the target vehicle, the lower should be its velocity.

Each accident reconstruction allowed three crash tests to obtain by trial and error good accident reconstructions by the third reconstruction. It is concluded that a series of at least three crash tests be used in any similar future side impact crash reconstructions.

It would be wise for a side impact accident reconstruction program to be conducted with about six pairs of vehicles used for six trial and error reconstructions. This many reconstructions would advance the state-of-the-art by permitting a more in-depth study of the factors which effect vehicle damage in side impact crashes.

It was extremely difficult to obtain 1965 Pontiac Catalinas and 1969 Volkswagen Beetles, and it is concluded that accident reconstructions in the future be limited to cars no more than eight years old. Before a selection of an accident is made, it is wise to determine how many of the cars involved in the accident were manufactured. The older cars can only be located at junk yards, and after they have been obtained by a junk yard, they are turned almost immediately into scrap metal after being stripped.

ACKNOWLEDGEMENT

The authors wish to thank Mr. Gene Terry of Minicars, Inc., who had the responsibility for all the instrumentation required for this test program.

REFERENCES

1. Partyka, Susan, "NCSS—The Analyst's Companion: A Description of the National Crash Severity Study Statistical Data File", Department of Transportation Report DOT-HS-805-871, May, 1981.
2. Fayon, A., *et al.*, "Presentation of a Frontal Impact and Side Impact Dummy Defined from Human Data and Realized from a 'Part 572' Basis," Seventh International Technical Conference on Experimental Safety Vehicles, June, 1979.
3. Stalnaker, R. L., *et al.*, "Modification of Part 572 Dummy for Lateral Impact According to Biomechanical Data," Twenty-Third Stapp Car Crash Conference, October, 1979.
4. Fayon, A., *et al.*, "Development and Performance of the APR Dummy (APROD), "Eighth International Conference on Experimental Safety Vehicles, October, 1980.
5. Part 572—Anthropomorphic Test Dummy (Occupant Crash Protection), pp. 20449-20456, *Federal Register*, Vol. 38, No. 1477, August 1, 1973.
6. Melvin, J. W., *et al.*, "Experimental Application of Advanced Thoracic Instrumentation Techniques to Anthropomorphic Test Devices," Seventh International Technical Conference on Experimental Safety Vehicles, June, 1979.
7. Fleck, J. T., *et al.*, "An Improved Three Dimensional Computer Simulation of Vehicle Crash Victims: Vol 1—Engineering Manual," U.S. Department of Transportation Report No. DOT-HS-801-507 (PB No. 241-692), April, 1975.
8. Fleck, J. T., *et al.*, "An Improved Three Dimensional Computer Simulation of Vehicle Crash Victims: Vol 2—Model Validation," U.S. Department of Transportation Report No. DOT-HS-801-508 (PB No. 241-693), April, 1975.

9. Fleck, J. T., *et al.,* "An Improved Three Dimensional Computer Simulation of Vehicle Crash Victims: Vol 3—User Manual," U.S. Department of Transportation Report No. DOT-HS-801-509 (PB No. 241-694), April, 1975.
10. Fleck, J. T., *et al.,* "An Improved Three Dimensional Computer Simulation of Vehicle Crash Victims: Vol 4—Programmer's Manual," U.S. Department of Transportation Report No. DOT-HS-801-510 (PB No. 241-695), April, 1975.
11. "The Abbreviated Injury Scale—1980 Revision", published by the American Association for Automotive Medicine, Morton Grove, Illinois 60053.
12. McHenry, R. R., "Development of a Computer Program to Aid the Investigation of Highway Accidents", NTIS No. PB 208-537, December, 1971.

The Effectiveness and Performance of Current Door Beams in Side Impact Highway Accidents in the United States

CHARLES JESSE KAHANE, Ph.D.
National Highway Traffic Safety Administration

ABSTRACT

Federal Motor Vehicle Safety Standard 214 sets static strength requirements for the doors of passenger cars sold in the United States since January 1, 1973. The requirements have led to the installation of longitudinal reinforcement beams inside the doors.

Standard 214 has reduced the fatality risk in side impacts with fixed objects by approximately 23 percent and has reduced hospitalizations by 25 percent. In collisions with fixed objects, the standard has reduced both ejection and nonejection casualties. The beam enables the car to take a more glancing trajectory, resulting in a wider, shallower damage pattern and a generally less severe collision.

In angle collisions with motor vehicles, Standard 214 has reduced hospitalizations by about 8 percent and has had little or no effect on fatalities. The standard has been effective in reducing door intrusion when the impact is centered on the compartment; in such impacts, the nearside occupant's risk of torso and leg injury is significantly reduced. The standard appears to have little effect on other types of injuries in multivehicle crashes, nor does it enable a car to take a more glancing trajectory in these crashes.

INTRODUCTION

During the 1960's, the American motor vehicle manufacturers conducted side-impact research and crash-testing. They developed a longitudinal beam, installed inside the door, for protection in side impacts. The National Highway Traffic Safety Administration promulgated Federal Motor Vehicle Safety Standard 214, which specifies minimum static strength requirements for the doors of passenger cars sold in the United States after January 1, 1973. The door beams were installed in all passenger cars, accompanied, in some models, by minor local reinforcements of the pillars. Beams were installed in some cars as early as model year 1969, in others as late as January 1973.

It is United States Government policy, as outlined in Executive Order 12291, for Federal agencies to review the benefits, costs and impacts of major existing regulations, based on the actual performance of production vehicles. A comprehensive evaluation of Standard 214 was completed in 1982 (1). This paper summarizes the evaluation's findings on the effectiveness of Standard 214 and its analyses of how beams perform in crashes. It discusses the implications of the evaluation results for current side impact research.

THE SIDE IMPACT SAFETY PROBLEM

A large corpus of accident analysis and crash testing, much of it presented at earlier ESV conferences, has identified the principal injury mechanisms in side impacts: 1. Nearside occupants' torso injuries due to contact with the car's intruding side structure when it is struck in the compartment area by another motor vehicle. 2. Other side structure contact torso injuries (farside occupants, impacts not centered on the compartment, fixed object collisions) where intrusion is less likely to be a major contributing factor. 3. Head injuries due to side structure contact. 4. Ejection. 5. Contact with frontal components (dashboard, steering wheel, etc.).

It is of critical importance to know, in quantitative terms, the relative frequency of the injury mechanisms in highway accidents. Mehta, Pearson and Wilson presented the distribution of fatal and life-threatening injury mechanisms in General Motors accident data at the 8th ESV conference (2). Here are the distributions of fatalities (based on the Fatal Accident Reporting System, FARS) and hospitalizations (based on the National Crash Severity Study, NCSS) that would be occurring in side impacts if Standard 214 had not been promulgated:

	Percent of fatalities and hospitalizations	Percent of fatalities
Vehicle-to-vehicle, nearside occupant, compartment-centered damage	27	40
Vehicle-to-vehicle, nearside occupant, not compartment-centered	15	
Vehicle-to-vehicle, farside occupant	31	18
Vehicle-to-object, nearside occupant, compartment-centered damage	10	25
Vehicle-to-object, nearside occupant, not compartment-centered	4	
Vehicle-to-object, farside occupant	13	17

Throughout this report, a "compartment-centered" impact is defined to be a car in which the midpoint of the damaged area is no more than 45 inches to the front or 15 inches to the rear of the midpoint of the car; this restrictive definition is used to exclude collisions which only peripherally damage the passenger compartment and in which side structure intrusion is relatively unimportant.

The distribution of individual injuries resulting in fatality or hospitalization was the following:

	Percent of serious injuries
Torso, arm or leg injuries due to contacting side structure—nearside occupants, vehicle-to-vehicle crashes centered on compartment	17
Torso, arm or leg injuries due to contacting side structure—other persons	18
Head injuries due to contacting side structure	14
Exterior objects (mostly ejection)	8
Frontal interior components (dashboard, etc.)	30
Other (especially non-contact injuries)	13

The injury mechanism which has been most widely researched—torso injury due to contact with intruding side structures—may be the largest single cause of serious nonfatal injuries but, as shown above, it only accounts for a fraction of all side impact casualties. Moreover, Mehta's accident analysis suggests that this injury mechanism is superseded by head injuries due to side structure contacts and by ejection as a cause of fatal lesions.

EFFECTIVENESS OF STANDARD 214

The primary evaluation objective was to determine the number of lives saved and hospitalizations prevented as a result of Standard 214, based on statistical analysis of highway accident data. An important guideline for the analysis was to isolate the effect of Standard 214 from the effects of other safety standards that are beneficial in side impacts and from the effects of other changes in side structure design (especially the shift from genuine hardtops to pillared hardtops, which took place in the mid-1970's in the United States). Typically, these other safety standards and side structure changes took place 3 or more model years before beams were installed, or 3 or more years afterwards.

Therefore, where possible, the accident analyses were limited to cars of the last model year without beams and the first year with beams or, at most, cars of the last 2 years without them and first 2 years with them. In the analyses that involved a wider range of model years, various statistical techniques were used to identify and remove the effect of factors, other than Standard 214, that affected side impact injury risk.

A second guideline for the analysis was to consider single-vehicle and multivehicle side impacts separately. because Standard 214 could be expected to affect side structure performance quite differently in impacts by objects or vehicles. Furthermore, in the multivehicle crashes, special attention is devoted to nearside occupants in compartment-centered impacts, since they are the type of person most vulnerable to contact with intruding structures.

Fatality Reduction

The Fatal Accident Reporting System (FARS), a census of traffic deaths in the United States since 1975, offers a unique opportunity to assess the fatality reduction of a standard independently of the serious injury reduction. The effectiveness of Standard 214 was estimated by comparing side impact fatalities in cars of the last model year without beams and the first year with them to a control group of frontal impact fatalities in these cars. These estimates were checked by comparisons involving cars of the last 2 years without beams and the first 2 years with them; also by regressions of side impact fatality risk by vehicle age and Standard 214 compliance.

Standard 214 reduced the risk of death in a single-vehicle side impact by a statistically significant 14 percent (confidence bounds: 7 to 21 percent). This amounts to 500 lives saved per year in the United States. The effectiveness was almost equally large for nearside and farside occupants. Moreover, in the preceding estimate, the definition of "single-vehicle side impact" included grade crossing accidents, rollovers with primarily side damage and complex off-road excursions. When the definition was restricted to side impacts with fixed objects, the effectiveness rose to 23 percent.

Standard 214 had no observed effect on fatalities in vehicle-to-vehicle side impacts (confidence bounds: −9 to +7 percent).

Serious Injury Reduction

The National Crash Severity Study (NCSS) is a large, statistically representative sample of towaway accidents involving passenger cars (3, 4). It contains nearly 1600 cases of passenger car occupants who were killed or hospitalized in side impacts; over 500 of them were in cars of the last 2 model years without beams or the first 2 years with beams. The large sample made it possible to apply statistical modeling techniques in a meaningful way and/or restrict the analysis to cars of the last 2 years without beams or first 2 years with them.

In single-vehicle side impacts, the best estimate of Standard 214 effectiveness appeared to be a 25 percent reduction of fatalities and hospitalizations (confidence bounds: 11 to 35 percent). In the NCSS analysis, the single-vehicle side impacts were explicitly defined to exclude rollovers and consisted overwhelmingly of fixed-object collisions. The "best" estimate of effectiveness represents a synthesis of various statistical procedures (multivariate analyses, estimates for restricted model year ranges, comparisons with a frontal control group), all of which yielded positive estimates of Standard 214 effectiveness.

In vehicle-to-vehicle side impacts, the best estimate of Standard 214 effectiveness was 8 percent (confidence bounds: −3 to +17 percent). For the subset of nearside occupants in impacts centered on the compartment, the effectiveness was 25 percent (confidence bounds: 6 to 38 percent). For all other persons in vehicle-to-vehicle side impacts (farside occupants; crashes not centered on the compartment), there was little or no injury reduction.

WHY IS STANDARD 214 EFFECTIVE?

The following 5 hypotheses on why Standard 214 may be effective are stated not as facts but as conjectures. They are tested by examining the effect of Standard 214 on vehicle damage patterns and on specific types of injuries in NCSS and, where possible, by a review of staged crashes. Hypotheses 1–3 have been mentioned elsewhere in the literature:

1. Crush resistance: beams slow down the rate of door intrusion, at least to some extent, because they increase the door's crush resistance. The post-Standard 214 door dissipates more energy in a shorter distance, causes the frontal structure of the striking vehicle to absorb a larger portion of the energy, allows a more rapid momentum transfer from the striking to the struck car and/or more effectively transmits loads to the vehicle's pillars (5, 6).
2. Deflection: in an oblique side impact, the beam acts like a highway guard rail to help the vehicle partially deflect the striking vehicle or object, resulting in a more glancing collision trajectory, spreading out the damage and reducing the depth, helping maintain the integrity of the door structure and possibly reducing overall collision severity (6, 7, 8, 9).
3. Sill override protection: the beam holds the striking vehicle down, forcing it to engage with the struck car's sill, rather than override it (5).
4. Greenhouse protection: the beam provides a strong horizontal component in the side structure above the sill. It prevents a car from partially "tipping over" into a fixed object and keeps the object away from the car's greenhouse area.
5. Door integrity protection: the beam helps the door maintain its basic shape during a crash, preventing it from being deformed to the point where hinges or latches fail. As a result, fewer occupants are ejected through the door area.

Side Impacts with Fixed Objects

The overwhelming majority of side impacts with fixed objects involve large trees, poles or other rigid, massive, immovable objects that extend from the ground to a point above the car's roof. Hypothesis 3 (sill override protection) does not apply. Hypothesis 1 (crush resistance) would appear to be of limited importance, since momentum transfer is not involved, the fixed object cannot be induced to absorb a significant portion of the energy and the car's sill and roof rails are immediately engaged and absorb most of the energy, not the doors. Thus, the significant reductions of fatalities and serious injuries could only be attributable to hypotheses 2, 4 or 5.

Hypothesis 2 (deflection) is strongly confirmed by the damage patterns in single vehicle crashes on NCSS. Standard 214 decreased the depth of crush by an average of 20 percent while increasing the width of the damaged area by an average of 20 percent. In other words, Standard 214 resulted in significantly shallower and wider damage patterns—evidence of a more glancing collision trajectory. Also, the percentage of cars in which damage was centered on the compartment decreased significantly (from 50 per-

cent to 38 percent) as a consequence of Standard 214: beams help to spread the damage from the compartment area to less vulnerable parts of the car. Finally, as a consequence of Standard 214, the Principal Direction of Force reported by NCSS investigators was, on the average, 9 degrees more oblique—i.e., the effect of beams on the damage pattern made it look as if the collision had been more oblique.

The result of this effect on damage patterns is to reduce not only intrusion but also the overall severity of the collision—e.g., the force levels and, possibly, the velocity change. As a result, the injury reduction need not be limited to nearside occupants' torso injuries. Indeed, on NCSS, nearside occupants' torso injuries due to side structure contact were reduced by 50 percent in post-Standard 214 cars but farside occupants' torso injuries also decreased by 23 percent. Head injuries due to side structure contact decreased by 25 percent and serious injuries due to contact with frontal components, by 27 percent.

Hypothesis 4 (greenhouse protection) is only weakly supported by the NCSS data. There was a nonsignificant 13 percent decrease in the incidence of greenhouse damage in Standard 214 cars; moreover, the reduction might be a consequence of hypothesis 2 (spreading damage away from the compartment area) rather than hypothesis 4. The significant reduction of head injuries for Standard 214, however, could be evidence in favor of hypothesis 4.

On both NCSS and FARS there were large, statistically significant reductions of occupant ejection in fixed object collisions as an immediate consequence of Standard 214. Hypothesis 5 (door integrity protection) cannot be denied. On NCSS, the incidence of occupant ejection through the door area dropped by 40–60 percent as a consequence of Standard 214 (while ejection through other portals was unaffected); the frequency of doors opening in crashes declined by 20–40 percent and the incidence of latch or hinge damage, by 10–20 percent. On FARS, fatal ejections in fixed object crashes decreased by 24 percent because of Standard 214 (while nonejection fatalities decreased by 22 percent). The reduction of ejection was the primary benefit for Standard 214 for farside occupants and a major benefit for nearside occupants.

For these reasons—significantly more favorable damage patterns, door integrity protection and, possibly, greenhouse protection—Standard 214 has been effective in side impacts with fixed objects. Moreover, the benefits are not limited to nearside occupants' torso injuries due to contacting the door but include a reduction of ejections, head injuries and farside occupants' injuries. Fatalities as well as nonfatal serious injuries are prevented.

Side Impacts by Another Vehicle

Standard 214 significantly reduced the depth of crush in the NCSS cases, by an average of 20 percent, when a car was struck in the side by another vehicle and the damage was centered in the compartment area. It had little or no effect on crush when the damage only peripherally included the compartment area. The crush reduction observed in the highway accidents on NCSS was about the same as what had been found by Chrysler and Kitamura et al. in staged crashes (10, 11).

The damage data from NCSS suggest that hypothesis 2 (deflection) was not a major factor in the vehicle-to-vehicle crashes. Unlike the fixed object collisions, the reduction in crush depth was not accompanied by an increase in the width of the damaged area. The percentage of cars with damage centered in the compartment area did not change as a consequence of Standard 214—i.e., the damage was not spread out to other areas. The Principal Direction of Force reported by NCSS investigators was, on the average, about the same for pre- and post-standard cars.

Thus, the significant reduction of intrusion is mainly attributable to hypothesis 1 (crush resistance) or 3 (sill override protection). On NCSS, the incidence of sill override decreased by about 20 percent as a consequence of Standard 214—confirming the evidence for hypothesis 3 that had been obtained by General Motors from staged crashes (5). Nevertheless, the overall incidence of sill override in pre-standard cars was relatively low on NCSS and, given a 20 percent reduction, only one-eighth of Standard 214's intrusion reduction can be attributed to sill override protection. The remainder must be attributed to hypothesis 1—crush resistance.

Since Standard 214 significantly reduced intrusion in vehicle-to-vehicle crashes without otherwise affecting the overall damage pattern or collision severity, it might be expected to mitigate primarily those injuries associated with door intrusion. This is precisely what happened on NCSS. Nearside occupants' torso injuries due to contact with the side structure declined by 33 percent in crashes where damage was centered on the compartment—accounting for almost the entire serious injury reduction for Standard 214 in vehicle-to-vehicle crashes. The standard had little or no effect on head injuries, on farside occupant's injuries, in crashes not centered on the compartment, or on injuries involving contact with frontal components.

The NCSS data do not support a firm conclusion on the effect of Standard 214 on ejection in vehicle-to-vehicle crashes. Ejection through the door area dropped by 10–50 percent and the frequency of doors opening in crashes declined by 20–40 percent—the lower reductions are based on cars of the first 2 years with beams vs. the last 2 years without them and they are not statistically significant. More importantly, ejection is a much less predominant injury source in multivehicle crashes (5 percent of serious casualties) than in fixed-object collisions (15 percent of serious injuries and 24 percent of fatalities). Thus, while Standard 214 appears likely to have reduced

ejections in vehicle-to-vehicle crashes, the effect accounts for only a small proportion of the overall benefits in these crashes.

In short, the benefits of Standard 214 in vehicle-to-vehicle crashes are mainly limited to a reduction of nearside occupants' torso injuries due to contact with intruding side structures. The reduction is mainly explained by the increased crush resistance provided by the beams. There has been a significant reduction of nonfatal serious injuries. But since torso injuries are relatively less predominant among fatalities (and head injuries much more predominant) and since the increase in crush resistance due to beams is probably of little consequence on energy dissipation in an extremely severe crash, the effect of Standards 214 on fatalities in vehicle-to-vehicle crashes is negligible.

CONCLUSIONS—AND IMPLICATIONS FOR CURRENT RESEARCH

The results on vehicle-to-vehicle crashes support a number of conclusions that are relevant to current side impact research. The principal conclusion is that existing production door beams have significantly reduced the type of serious injury that they were intended to reduce (nearside occupants' torso injuries due to side structure contact). The beams have performed as intended—reducing the depth of intrusion when the car is directly impacted in the compartment by another vehicle, primarily as a consequence of increased crush resistance. This is evidence that the structural approach to side impact protection will work in highway accidents involving human subjects. What is more remarkable is that existing production beams—which represent a far lower level of structural improvement than what has been furnished in experimental side structures—have nevertheless eliminated 33 percent of these injuries in highway accidents.

Despite the fact that existing beams have eliminated 33 percent of the injuries they were designed to mitigate, they have only reduced the overall injury risk in vehicle-to-vehicle side impacts by 8 percent and have had little or no effect on fatalities. The key point here is that the majority of serious casualties in highway accidents cannot be directly attributed to contact with intruding door structures—especially the large number of fatal head injuries. That point was clearly stated at the 8th ESV Conference by Mehta, Pearson and Wilson (2) and it is confirmed by the NCSS and FARS data. It sets limits on the benefits that can be obtained by structural strengthening unless accompanied by other improvements.

The current Standard 214 appears to have been partially effective in mitigating sill override in highway accidents even though it has only been designed for that purpose to, at most, a limited extent. Perhaps a substantial additional reduction of sill override could be achieved on the highway with relatively simple modifications of existing beams. For example, Hollowell and Pavlick reported at the 8th ESV Conference that considerable reductions of override and intrusion were obtained in crash tests by providing a load path from the beam to the sill (12).

The current door beams did not appear to significantly promote deflection of the striking vehicle in highway accidents—the effect that was prominently displayed in fixed-object crashes and also, to some extent, in General Motors' and Renault's staged crashes involving two vehicles (5, 7). The potential benefits of a deflecting action were not realized in vehicle-to-vehicle crashes. Could the beams be modified so as to deflect the striking vehicle in a highway accident?

Regarding side impacts with fixed objects, the principal conclusion is that the existing Standard 214 has significantly reduced fatalities and serious nonfatal injuries. It has accomplished these benefits because beams have promoted a more glancing, less severe collision and because the likelihood of ejection through the door area has been reduced. The ejection reduction may be an unforeseen consequence of the effect on damage patterns.

The benefits are not limited to a reduction of nearside occupants' torso injuries. Many other categories of injury, including head injury and ejection were mitigated. The annual savings of 500 lives make the current Standard 214 one of the most effective existing safety regulations in the United States. These benefits, and the mechanisms that led to them, should not be overlooked in the development of more sophisticated side impact protection.

REFERENCES

1. C. J. Kahane, "An Evaluation of Side Structure Improvements in Response to Federal Motor Vehicle Safety Standard 214." National Technical Information Service, 1982.
2. R. Mehta, J. L. Pearson and R. A. Wilson, "Side Impact Insights from General Motors Field Accident Data Base." 8th ESV Conference, 1980.
3. C. J. Kahane, R. A. Smith and K. J. Tharp, "The National Crash Severity Study." 6th ESV Conference, 1976.
4. J. Hedlund, "The National Crash Severity Study and its Relationship to ESV Design Criteria." 7th ESV Conference, 1978.
5. C. E. Hedeen and D. D. Campbell, "Side Impact Structures." Society of Automotive Engineers Paper No. 69003, 1969.
6. *Federal Register,* Vol. 35, April 23, 1970, p. 6513.
7. A. Burgett, Letter No. 15 to NHTSA Docket 2-6-GR, August 22, 1975.
8. M. Rodger, "Occupant Protection in Side Impacts." *Toward Safer Road Vehicles,* Transport and Road Research Laboratory, 1972.

9. J. E. Greene, "Occupant Survivability in Lateral Collisions," Vol. 1. National Technical Information Service, 1976.
10. S. L. Terry, Letter No. 13 to NHTSA Docket 2-6-NO2, July 14, 1970.
11. O. Kitamura, K. Watanabe and K. Matsushita, "An Experimental Study of Lateral Impact Protection." 8th ESV Conference, 1980.
12. W. T. Hollowell and M. Pavlick, "Status of the Development of Improved Vehicle Side Structures for the Upgrade of FMVSS 214." 8th ESV Conference, 1980.

A Mathematical Analysis of Side Impact Using the CAL3D Simulation Model

ARVIND J. PADGAONKAR and
PRIYARANJAN PRASAD
Ford Motor Company

INTRODUCTION

An earlier work of the authors (1) showed the feasibility of using the CAL3D occupant simulation model (2) as a combined structural and occupant model (simulating dummy) for investigating the various factors affecting dummy response in car-to-car side impact. That study was done using hypothetical stiffness values for the striking and the struck cars and for the dummy occupant's chest and pelvis. Further, the ability of the model to simulate car-to-car crashes with the relative structural stiffness of real cars was not evaluated. Also, dummy parameters used in the study were based on engineering judgment. Better dummy parameters based on cadaver tests are now available in the literature. Several car-to-car crash tests with experimental side impact dummies meeting the cadaver data have now been conducted. This study reports on an effort to simulate the results of one of these car-to-car crash tests at 48 kph with an improved setup of the CAL3D model reported in Reference 1. The results of various perturbation studies with the model are also reported.

It should be emphasized that all the data defining the occupant referenced in the text and figures in this paper describe the Side Impact Dummy developed at HSRI (3).

CRASH TEST FOR SIMULATION

The car-to-car crash test used for simulation was that of a 1550 kg car moving at 48 kph, impacting a stationary 1450 kg car on the driver's side. The longitudinal axis of the striking car was at 60 degrees from the longitudinal axis of the struck car. The point of impact was arranged so as to just miss the A-pillar of the struck car. An early version of the HSRI side impact dummy was seated next to the door being impacted. Both the cars were instrumented with accelerometers at various locations and the struck car door was fitted with in intrusion rod to measure door inner panel intrusion into the passenger compartment at the driver chest location.

The crash test resulted in approximately 488 mm of door inner panel intrusion at the chest level. The peak velocity of the door panel was estimated to be approximately 38 kph. The peak acceleration of the dummy thoracic spine was 106 G's at T12 and 82 G's at T1. The peak resultant head acceleration was 52 G's. It was observed that at the time of the dummy spine and chest peak acceleration the loads developed in the lap belt and the torso belt were negligible. (Figure 1). High speed movies showed that rotations of the cars were negligible during the crush phase of the impact. From the movies it could be seen that the driver side window shattered early in the crash sequence; as a result the driver's head did not make contact with the glass plane.

MODEL FOR SIMULATION

Based on the observations from the crash test it was believed that the simple collinear model used in the earlier study for the striking and the struck cars would be adequate. The restraint system and the windows did not need to be modelled. The resulting model is shown in Figure 2 and is described in Reference 1. Since the window has not been simulated, two finite planes are attached to

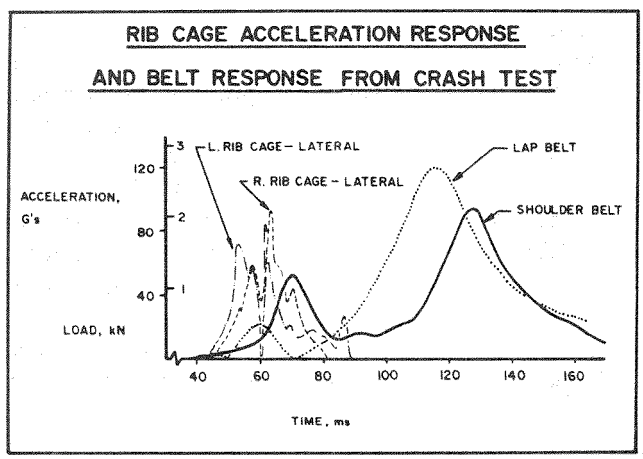


Figure 1.

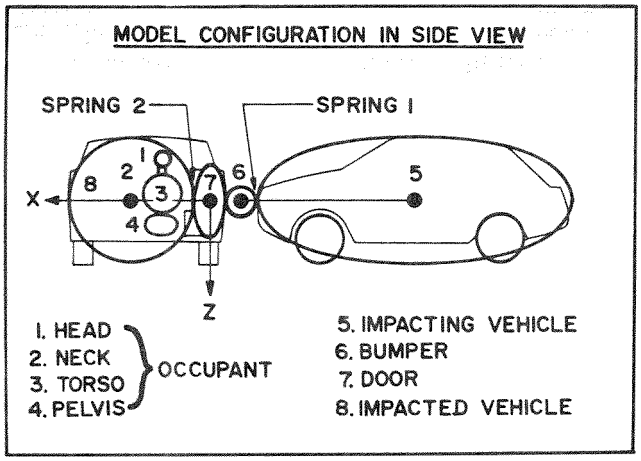


Figure 2.

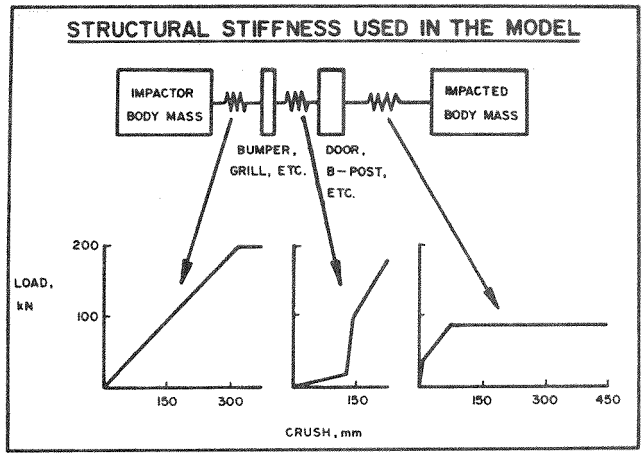


Figure 3.

the ellipsoid representing the door of the struck car. One plane extends up to the door belt line and interacts only with the chest contact ellipsoid. Another plane is offset 50 mm into the passenger compartment and interacts only with the occupant lower torso. This plane is offset 50 mm to simulate intrusion at the H-point level since post-test measurements show that intrusion at the H-point level is generally more than at the chest level due to bumper contact.

The occupant is modelled by four segments—the lower torso, upper torso, neck and head. The inertia properties of the lower torso includes parts of the femur masses and the pelvis. The lower legs were not simulated because their effect on head and chest response during the impact phase is believed to be negligible. The upper torso mass and moment of inertia are those measured from an HSRI side impact dummy. To avoid problems arising from contacts between ellipsoids and planes in the CAL3D model, the chest contact sensing ellipsoid has been offset towards the door by 112 mm from the spine. The inertia properties of the head and neck are those of a Part 572 dummy.

Table 1. Segment inertial properties.

Segment	Mass (kg)	Moment of inertia kg-m		
		x	y	z
Head	4.545	0.028	0.028	0.018
Neck	0.909	0.003	0.003	0.003
Upper torso	27.27	0.237	0.181	0.283
Lower torso	31.82	0.418	0.283	0.283
Impacting car body	1495.5	734.20	2938.000	2779.800
Bump., grill, assy.	52.3	25.43	80.12	79.33
Door, side str., etc	79.55	22.6	113.00	22.6
Struck car body	1319.5	757.0	3018.0	2859.0

The inertia properties used in the model are shown in Table 1.

Stiffnesses Used in the Model

The load-deflection properties of the various elements involved in simulating the structural responses of the two cars were determined by exercising a collinear, lumped mass model (4) configured similar to the structural model used in this study. A combination of stiffnesses producing acceleration and crush responses observed in the crash test of the two cars was selected for use in the CAL3D model. These stiffnesses are shown in Figure 3.

The lateral compliance of the HSRI side impact dummy was determined from a 24 kph sled test of the dummy into a rigid wall. It should be noted that no attempts were made to model the dummy hardware inside the chest, such as the hydraulic damper, and it was assumed that the stiffnesses determined from the test at 24 kph can be extrapolated to higher speeds. The stiffnesses used for the dummy chest and the lower torso are shown in Figure 4. Note from the figure that the first 52.5 mm of

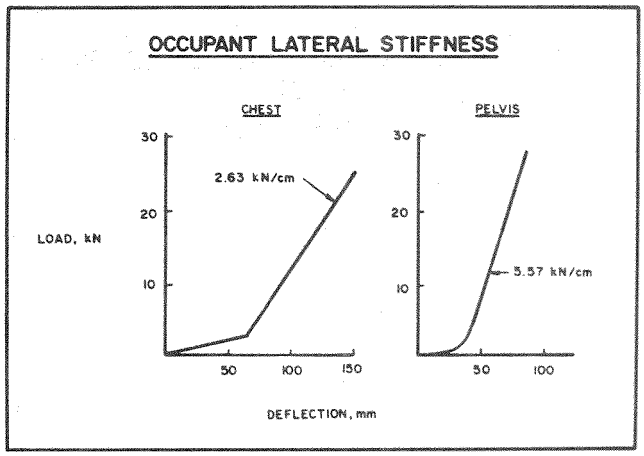


Figure 4.

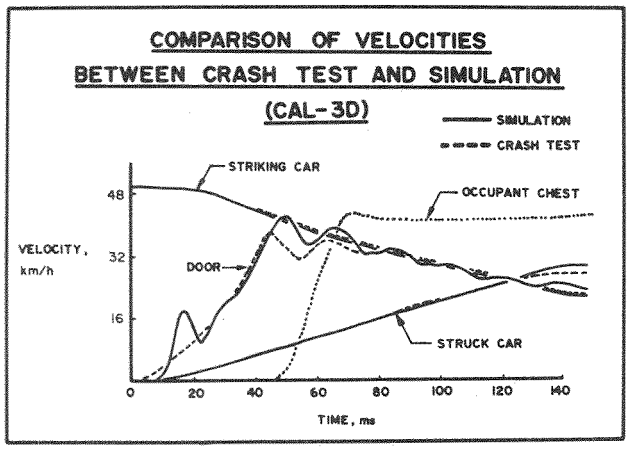


Figure 5.

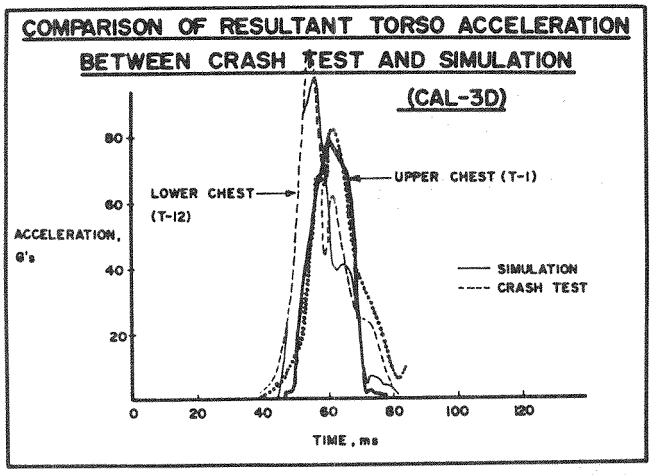


Figure 7.

chest compression represent the arm of the dummy which consists of very soft foam. For this study, the chest compression reported is the total compression minus the first 52.5 mm.

Results of the Crash Simulation

The velocity-time histories of the striking and struck cars, the door and the occupant chest are shown in Figure 5 and compared with those from the car-to-car crash test. It can be seen from the figure that the model results compare well with the crash test results in terms of the shapes and durations of the various responses. It is interesting that the common velocity reaches between the two cars in the test and the simulation are the same, showing that rotation and ground friction do not play an important role even at a 60 degree impact angle.

The door intrusion-time history predicted by the model compares very well with that observed in the crash test, and is shown in Figure 6.

The dummy spinal acceleration responses measured at T1 and T12 are shown in Figure 7. It can be seen from the figure that these responses in terms of timing, peak and shape have been predicted accurately within (6%) by the model. The difference in the timing of the peaks at T12 and T1 suggests large angular accelerations in the spine. The T1 acceleration response lags T12 response by approximately 6 ms which is due to the pelvis being struck earlier than the chest in the simulation and probably in the crash test. The pelvic response in the test was not measured, hence the model response cannot be compared with the test response.

Figure 8 shows a comparison of the dummy head resultant acceleration observed in the test and predicts an earlier and higher peak acceleration than observed in the test. Since the thoracic spine acceleration responses predicted by the model and the test agree closely, any difference between the test and the model predicted head response would be due to inaccuracies in the neck model. Since this neck model seems to predict longer duration, frontal impact response well, it is believed that the deformation mode in the dummy neck under a short duration high acceleration response requires a different neck

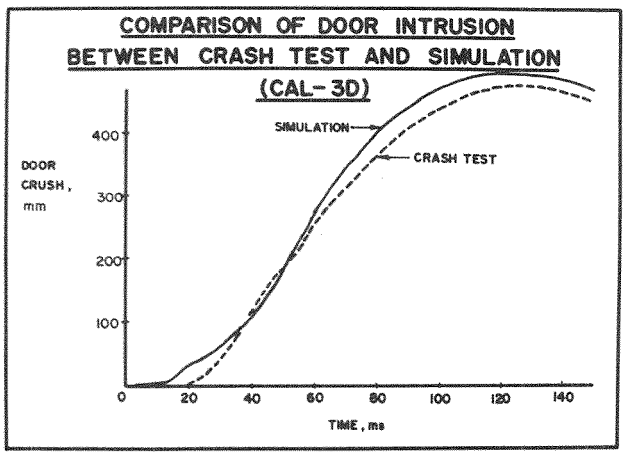


Figure 6.

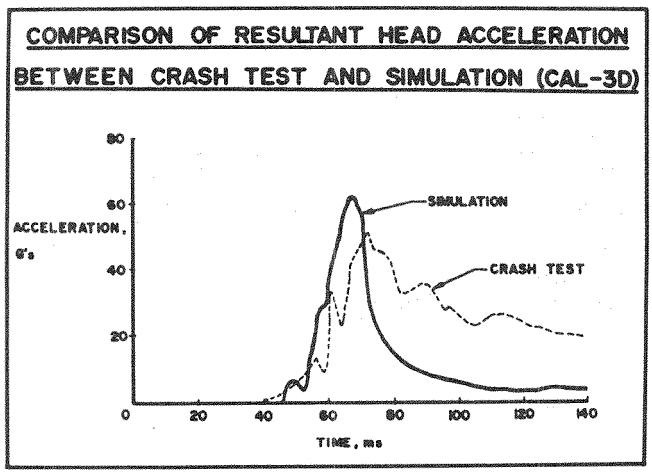


Figure 8.

Table 2. Effect of clearance.

Clearance (mm)	Peak head accn. (G)	Peak chest accn. T1 (G)	Peak chest accn. T12 (G)	Chest/door impact vel (km/h)	Chest/door common vel (km/h)	Door int. (mm)	Chest crush (mm)
25.4	57.7	59.3	59.0	17.0	40.23	469.9	81.28
50.8	59.7	64.0	64.5	12.83	39.11	474.98	83.82
76.2	66.6	66.3	67.0	20.12	39.91	485.14	88.90
101.6	67.6	71.6	81.9	23.23	40.23	492.76	91.44
127.00	65.5	78.4	94.6	28.62	39.43	500.38	91.44
152.4	65.1	80.5	103.0	33.47	39.91	505.46	91.44
165.1	63.7	80.2	100.0	35.2	39.43	505.46	88.9
177.8	64.3	78.3	98.9	37.03	39.43	505.46	88.9
203.2	63.1	72.7	92.1	42.79	38.62	502.92	83.82
228.6	62.5	69.0	87.7	46.18	38.3	502.92	81.28
254.0	62.8	65.1	85.2	46.27	37.34	502.92	83.82

BASE

model than what is currently used. Attempts at matching the test head response with the model by varying the neck joint stiffnesses were not successful. Perhaps a rigid neck with two articulations should be replaced by a deformable beam in the model.

PERTURBATION STUDIES WITH THE MODEL

The model response comparison with the car-to-car crash test was considered good enough to carry out perturbation studies with the model. The role of the initial door inner panel-to-occupant clearance, stiffness of the side structure of the car and a side impact bolster on occupant response were investigated by modelling exercises. The remainder of this paper describes the results of these exercises.

Effect of Clearance

The effect of clearance on occupant response was investigated by changing the occupant initial position in the model relative to the door from 25 mm to 250 mm. The results of these simulations are shown in Table 2 and Figure 9. It can be seen from the figure that as the clearance increases from 25 mm to 165 mm the spinal accelerations and chest crush increase. Beyond 165 mm clearance, the spinal accelerations and the chest crush decrease. The increase in spinal accelerations between 25 mm to 165 mm initial clearance is due to an increase in the relative impact velocity between the door and the occupant chest. Beyond 165 mm, even though the relative impact velocity is increasing, the common velocity reached between the chest and the door is decreasing and might account for the general decrease in the spinal accelerations and chest crush. This shows that the relative impact velocity as well as the common velocity are important in determining chest impact response. As a result, the entire door velocity-time history from the time of contact to the time of common velocity between the door and the chest is important.

The head acceleration response seems to be relatively insensitive to the initial clearance. It should however be pointed out that the side door window has been assumed to be shattered. If the window does not shatter as seen in the test and assumed in the model, the head response may show different trends.

It can be seen in Table 2 that the door intrusion is slightly affected by occupant clearance from the door. This shows that occupant impact can influence door kinematics as was hypothesized by Monk, et al. (5)

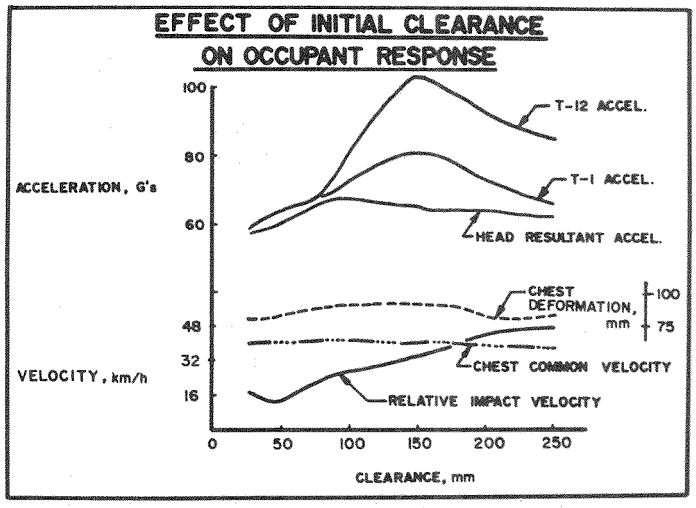


Figure 9.

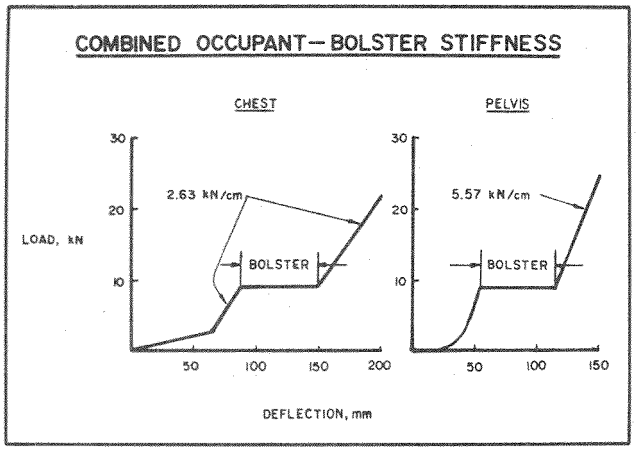


Figure 10.

Effect of Side Bolster on Occupant Response

B1. *Idealized Bolster Properties.* For the modelling exercises it was assumed that an ideal bolster would absorb energy at a constant force level and this force level would be below the human tolerance level. Currently, the human tolerance force level has not been established; however, a constant level of 8.9 KN was selected for the model based on cadaver test data from APR (6). At this level the model chest would deform 33 mm before crushing the bolster and even the softest chest in the cadaver population studied by APR would crush the bolster before exceeding proposed chest deformation tolerance limit. The resulting force-deflection property of the combined chest and bolster is shown in Figure 10.

B2. *Results of Bolster Runs in the Baseline Car.* Three model runs in the baseline car were made with a 25 mm, 50 mm and 75 mm of an idealized bolster interposed between the occupant and the door inner panel. The actual thickness of the bolster may be 15% to 25% greater than that of the idealized bolster due to material stackup. As a result of the installation of the bolster, the initial clearance between the occupant and the door was reduced by the thickness of the bolster used.

The results of these runs are shown in Table 3. It can be seen that with the addition of the bolster, the occupant response levels generally decrease. It is interesting to note that, in these simulations, 50 mm of bolster reduced chest deformation by only 10 mm when compared with the baseline car with no bolster. However, the addition of another 25 mm of bolster results in an additional 13 mm reduction in chest deformation.

Table 3. Effect of bolster.

Bolster thickness (mm)	Head accn. (G)	Peak chest accn.		Chest crush (mm)
		T1 (G)	T12 (G)	
0.0	63.7	80.2	100.0	88.90
25.4	61.1	75.0	93.1	86.40
50.8	55.1	68.1	85.3	78.70
76.2	47.9	57.3	73.8	66.00

Effect of Side Structural Stiffness

The side structural force-deflection characteristics in the baseline simulation were raised in steps of 10% to determine the effect of structural stiffness on occupant response. The results of these simulations are shown in Table 4 and Figure 11. As expected, as the side structural stiffness increases, the door intrusion into the passenger compartment decreases. There is a general trend towards reductions in peak chest and head accelerations, and chest deformation. It is found that doubling the baseline stiffness results in decreases of approximately 20 G's in the chest and head accelerations and approximately 22 mm chest deformation. The practicality of doubling the structural stiffness of the side of the car has not been addressed in this study.

It can be seen from Table 4 that only after a considerable amount of stiffening (80%) is the relative impact velocity between the door and the occupant reduced from the baseline case. Therefore, the reductions in occupant response levels below 80% stiffening are mainly due to the reductions in the common velocity reached between the door and the occupant.

The role of side structural stiffness alone in controlling occupant response levels can now be put in the proper perspective by comparing the results of this series of runs with the preceding series which only had an addition of a side bolster in the baseline car. These results are shown in Figure 12. It can be seen from the figure that the occupant response levels attained by doubling side structure stiffness, can be obtained by the inclusion of 75 mm of side bolster thickness on the door in the baseline car.

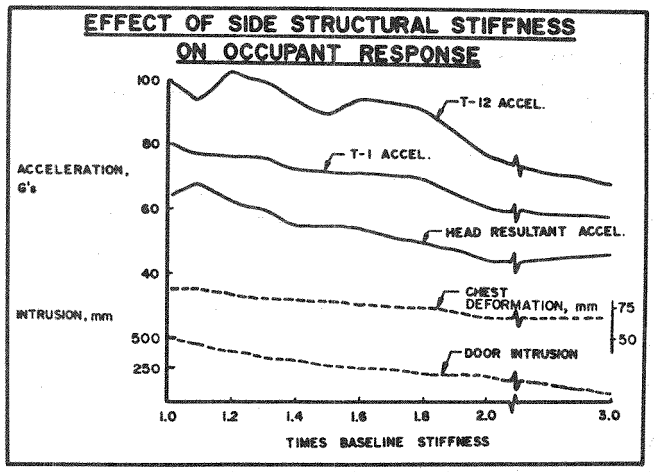


Figure 11.

Table 4. Effect of side structure stiffness on occupant response.

Side stiffness	Peak head accn. (G)	Peak chest accn. T1 (G)	Peak chest accn. T12 (G)	Chest/door impact vel (km/h)	Chest/door common vel (km/h)	Door int. (mm)	Chest crush (mm)
Base	63.7	80.2	100.0	35.20	39.43	505.46	88.9
+10%	67.2	76.7	94.3	36.04	40.23	441.96	88.9
+20%	61.9	76.6	103.0	36.76	38.30	391.16	83.82
+30%	59.7	75.7	98.7	37.13	37.34	347.98	81.28
+40%	54.8	71.7	92.9	35.85	34.76	322.58	78.74
+50%	54.3	71.1	89.3	35.13	34.12	287.02	78.74
+60%	53.2	70.5	94.5	35.76	33.31	259.08	76.20
+80%	48.7	68.2	91.1	33.94	31.38	218.44	73.66
+100%	43.6	59.9	75.4	30.49	28.97	172.72	66.04
+200%	46.0	57.4	67.1	21.57	29.77	27.94	66.04

Similarly the response levels reached by increasing the stiffness of the car between 40 and 80% can be attained by the inclusion of 50 to 75 mm of bolster on the door. This confirms that structural stiffening alone may not be an effective way to control occupant response levels.

Side Stiffness and Initial Clearance Effect on Required Bolster

The combined role of side structural stiffness, initial clearance and side bolster thickness on occupant response for the crash condition simulated, was next investigated through model exercises. The 8.9 KN constant force level bolster described in Section B1 was selected for these exercises. The variable of interest was the required bolster thickness without bottoming out, for the various side structure stiffnesses and occupant/bolster clearances. It should, however, be kept in mind, that the ideal bolster used in this model does not exist in practice due to material stackup when the bolster crushes. The actual bolster thickness required may be 15% to 25% greater than that predicted by the model to account for material stackup.

A series of simulations with varying levels of side structural stiffness and initial clearance from the bolster surface were made. The results of these simulations are shown in Tables 5 to 8. The composite result of these simulations is shown in Figure 13. It can be seen that for any given initial clearance, as the side structural stiffness increases, the required bolster thickness decreases for the crash condition studied (48 km/h, 60 deg. impact). Since the increase in structural stiffness and the addition of side bolsters probably entail weight and cost considerations, and occupant-to-door clearance affects interior packaging, Figure 13 can be used to trade-off one factor against another. With such trade-off studies it may be possible to evaluate various combinations of structural stiffness, bolster thickness and interior packaging.

CONCLUSIONS AND RECOMMENDATIONS

This study has shown the applicability of the CAL3D mathematical model as a combined structural and oc-

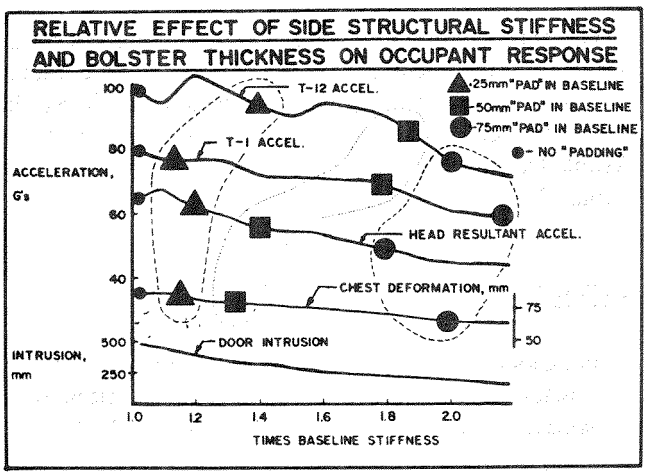


Figure 12.

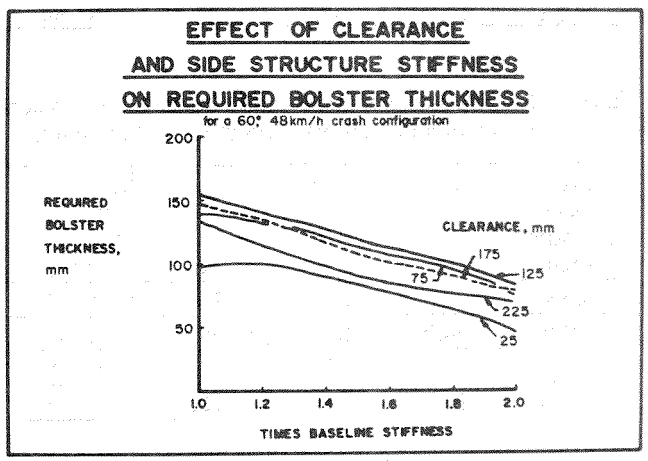


Figure 13.

Table 5. Required bolster thickness for base side structure (chest crush 33.8 mm).

Chest/ bolster clearance (mm)	Peak head accn. (G)	Peak chest accn.		Required bolster thickness (mm)
		T1 (G)	T12 (G)	
25.4	26.4	30.5	29.6	99.57
76.2	25.8	32.7	30.0	142.24
127.0	25.2	33.4	30.1	157.48
165.1	24.4	33.0	30.0	151.64
177.8	24.7	32.9	29.6	148.59
228.6	25.3	33.8	29.4	137.16

Table 6. Required bolster thickness for base + 20 percent side structure stiffness (chest crush 33.8 mm).

Chest/ bolster clearance (mm)	Peak head accn. (G)	Peak chest accn.		Required bolster thickness (mm)
		T1 (G)	T12 (G)	
25.4	25.6	31.0	29.3	101.6
76.2	25.5	33.1	29.1	134.6
127.0	24.4	32.8	29.9	142.2
165.1	24.2	33.4	29.7	137.2
177.8	24.1	33.5	29.6	137.2
228.6	25.8	33.8	29.2	114.3

Table 7. Required bolster thickness for base + 50 percent side structure stiffness (chest crush 33.8 mm).

Chest/ bolster clearance (mm)	Peak head accn. (G)	Peak chest accn.		Required bolster thickness (mm)
		T1 (G)	T12 (G)	
25.4	25.9	31.4	29.4	83.80
76.2	25.2	32.0	29.9	114.3
127.0	24.1	33.0	30.0	119.4
165.1	24.0	32.6	29.4	111.76
177.8	23.8	33.1	29.2	109.22
228.6	24.0	33.0	30.0	91.44

Table 8. Required bolster thickness for base + 100 percent side structure stiffness (chest crush 33.8 mm).

Chest/ bolster clearance (mm)	Peak head accn. (G)	Peak chest accn.		Required bolster thickness (mm)
		T1 (G)	T12 (G)	
25.4	27.3	31.9	29.6	45.72
76.2	24.9	32.7	29.4	76.2
127.0	24.5	32.7	29.7	83.82
165.1	24.8	32.3	29.8	81.28
177.8	24.5	32.7	29.6	78.74
228.6	25.1	33.1	29.5	71.12

cupant model to the simulation of car-to-car crash tests. The struck car in the simulation was stationary. Further development of the model should be aimed at simulating the condition where both cars are moving. It is believed that the structural part of the model can be enhanced and made more user friendly by incorporating generalized elastic-plastic spring algorithms of the type currently available in the Battelle (4) model.

It has also been shown that the side impact dummy spinal response can be simulated accurately; however a more detailed neck model should be developed to obtain better head acceleration correlations with actual test data in side impact.

The perturbation studies with the model show the relative effects of side structural stiffness alone and side bolster alone on occupant response parameters. The simulations indicate that the control of occupant response will be more effectively achieved by the use of side bolsters than by structural stiffening, at least for the combination of the striking and struck cars used in this study.

This study points to the existence of "trade-off" curves between structural stiffness, bolster thickness and occupant-to-door initial clearance as shown in Figure 13. If such relationships can be developed for the various side impact crash configurations, a wide range of combinations of structure and bolster can be studied.

The current study was done holding the striking car front-end stiffness constant. A previous study of the authors (1) and various other studies have shown the importance of the striking car front-end characteristics in influencing occupant response parameters. It is believed that if the front-end stiffness of the striking car is reduced, better compatibility between the colliding cars would be achieved, and hence would reduce the need for side structural stiffening and the required bolster thickness. Such an investigation can also be done by the model used in this study.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of the Vehicle Development Technology Office of Ford Motor Company for sponsoring this study and providing the crash test data used. The encouragement and support of Ashok Hargunani is particularly acknowledged for the initial phase of this project.

REFERENCES

1. Padgaonkar, A. J. and P. Prasad, "Simulation of Side Impact Using the CAL3D Occupant Simulation Model," Proc. 23rd Stapp Car Crash Conference, 1979, S.A.E., Warrendale, Pennsylvania.
2. Fleck, J. T., F. E. Butler and S. L. Vogel (1974), "An

Improved Three-Dimensional Computer Simulation of Motor Vehicle Crash Victims," Final Technical Report No., ZQ-5180-L-1, Calspan Corp.
3. Melvin, J. W., D. H. Robbins and J. B. Benson, "Experimental Application of Advanced Thoracic Instrumentation Techniques to Anthropomorphic Test Devices," Proc. 7th International Technical Conference on Experimental Safety Vehicles, 1979, U.S.D.O.T., NHTSA.
4. Herridge, J. T. and R. K. Mitchell, "Development of a Computer Simulation Program for Collinear Car/Car and Car/Barrier Collisions," Rpt. No. FH-11-7550-BCL G-0612-C. Prepared by Battelle Columbus Laboratories for the D.O.T. The version used in this study is an inhouse modification of the above program.
5. Monk, M. W., R. M. Morgan and L. K. Sullivan, "Side Impact Sled and Padding Development," Proc. 24th Stapp Car Crash Conference, 1980, S.A.E., Warrendale, Pennsylvania.
6. Tarrière, C., G. Walfisch, A. Fayon, J. P. Rosey, "Synthesis of Human Tolerances Obtained from Lateral Impact Simulations," Proc. 7th International Technical Conference on Experimental Safety Vehicles, 1979, U.S.D.O.T., NHTSA.

Vehicle Side Impact Structural Analysis

C. M. NI
Engineering Mechanics Department
General Motors Research Laboratories
Warren, Michigan

ABSTRACT

A computerized analytical technique, which includes the NONDRIS (NONlinear Dynamic Response of Integrated Structures) program and the structural models, has been applied to compute the structural response of space frames to static crush loadings and side impacts. As a first step toward full vehicle analysis, the vehicle is represented as a simplified space frame structure which can be modeled by beam elements, nonlinear stiffness elements, and concentrated masses. The analytical technique is used to compute deflections, force resultants, local section buckling of the beams, and fracture for the following cases: 1) side crush due to quasi-static loading and 2) side impact by a rigid barrier at impact speeds of 24 and 34 km/h.

To verify the analytical study, experimental space frame structures were fabricated and subjected to the aforementioned load conditions. Comparisons between measured and computed results indicate that total side crush, resisting force, and deformed profiles can be numerically predicted.

INTRODUCTION

Studies have shown that side impacts are second only to frontal impacts in terms of numbers of injuries [1,2]. For this reason, there is an increasing interest in side impact collisions and methods for reducing injuries which result from these collisions. Generally speaking, the knowledge of events during a frontal collision has developed to a comparatively high degree, yet side impacts are less understood. Side impact collisions usually involve a broad spectrum of factors such as: 1) the vehicle parameters (mass, structural design, and rigidity), 2) the point and angle of impact, 3) the impact speeds, 4) the vehicle interior design, and 5) the use of restraints. This paper will consider the structural deformation and the rigid body motion of the struck vehicle. The large structural deformation associated with side impact complicates the problem of predicting the response. Comprehensive analysis methods for assessing vehicle side impact are still absent in the literature largely because of the difficulties introduced by the lack of geometrical symmetry, the highly nonlinear plastic flow of metal, the large structural deformation, and the continuously changing contact surface.

Because of the extreme complexity of automotive vehicle structures and complicated material behavior involved in large plastic deformation of structural material, the analysis of the automotive structural response resulting from collision is a complex and challenging task. Much progress has been made in the area of vehicle impact analysis of automotive structures during recent years. Notably, the computer simulation technique for a one-dimensional mass-spring system has been developed and applied with great success in predicting dynamic response of automotive vehicles in a symmetric front or rear impact [3,4]. It should be pointed out, however, that applying this approach to two-dimensional or three-dimensional problems in an unsymmetric impact may lead to difficulty in determining analytically and experimentally the force-deflection curves of the structural components. This is because multi-axial plastic deformation of structural components is generally path dependent. Therefore, it is necessary to solve the symmetric and unsymmetric crush problems of automotive vehicles analytically so that their impact response can be predictively assessed in a more general and efficient manner.

An analytical technique has been used to predict the force-deflection curves of automotive frame-type com-

ponents with a three-dimensional configuration [5]. It should be noted that this analytical technique can only deal with a single structural component. Subsequently, extension of this technique to a two-dimensional frame system subjected to symmetric and unsymmetric impact loadings was made [6]. An analytical formulation is available in the literature [7] to predict the moment-rotation relationship of two-dimensional box beams in bending with local buckling as a dominating factor. In addition, the accordion-type buckling of box beams in pure axial compression was also studied [8]; in Reference 8, analytical formulas were derived to predict the mean crush load. Aside from the frame, an analytical technique was also developed for large deformation analysis of flat panel members [9].

Since the basic tools, as described in the preceding paragraph, have been developed, the next step is to incorporate them into a general purpose computer program. In addition, this technique should be able to handle three-dimensional space frame systems and integrated frame and sheet-metal structures. A new computer program, "NONDRIS" (NONlinear Dynamic Response of Integrated Structures) [10], has been developed to do this. The "NONDRIS" program contains beam, plate, spring (or truss), and rigid-body elements. Each element type is coded in a modular form so that any one element or a combination of several elements can be used effectively as an independent program.

The present paper explores the use of this general purpose computer program to compute vehicle response to side impact. As a first step toward full vehicle analysis, the vehicle is represented as a simplified space frame structure which can be modeled by beam elements, nonlinear stiffness elements, and concentrated masses. The model is used to compute deflections, local section buckling of the beams, strain rates, and fracture for the following load cases: 1) side crush due to quasi-static loading and 2) side impact by a rigid barrier at impact speeds of 24 and 34 km/h. To verify the analytical study, experimental space frame structures were fabricated and subjected to the aforementioned load conditions. Comparisons between measured and computed results indicate that total side crush, resisting forces, and deformed profiles can be numerically predicted.

In the following sections, we will first present a brief description of the "NONDRIS" program. This will be followed by descriptions of the static side crush of the first space frame (designated as Space Frame I) which was subjected to point loadings and the rigid barrier side crush of the second space frame (designated as Space Frame II) which was subjected to static as well as dynamic loadings.

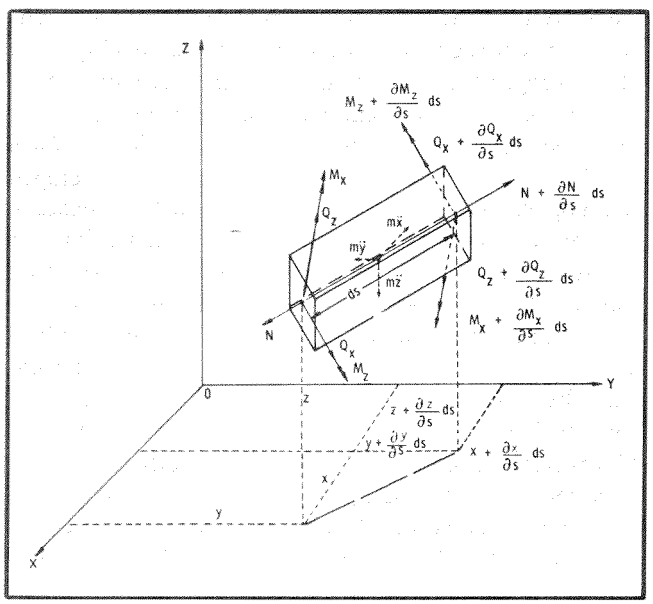


Figure 1. Nomenclature for a three-dimensional structural element.

THEORY

Beam Member

(1) *Kinematics.* A Lagrangian coordinate system—(x,y,z,)—is used to describe the motion of the structural element as shown in Figure 1. The direction cosines of a typical structural element are

$$\cos\alpha = \frac{\partial x}{\partial s}, \cos\beta = \frac{\partial y}{\partial s}, \cos\gamma = \frac{\partial z}{\partial s} \qquad (1)$$

where $\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$, $ds = [(dx)^2 + (dy)^2 + (dz)^2]^{1/2}$ and where ds is the length of the infinitesimal element. The slopes of the projections of this three-dimensional element on the y-z and x-y plane are

$$\theta_z = \cos^{-1}\frac{1}{\sin\alpha}\frac{\partial y}{\partial s} \qquad (2)$$

and

$$\theta_x = \cos^{-1}\frac{1}{\sin\gamma}\frac{\partial y}{\partial s}. \qquad (3)$$

(2) *Equations of Motion.* Figure 1 also illustrates the internal and external forces acting upon a deformed element of a three-dimensional structure. These internal forces consist of bending moments, M_x and M_z; axial force, N; shear forces, Q_x and Q_z; and twist, T. The external forces consist of inertia forces, $m\ddot{x}$, $m\ddot{y}$, and $m\ddot{z}$; and constraint forces, F_x, F_y, and F_z.

The differential equations of dynamic equilibrium for this element in the x, y, and z directions, respectively, are

$$\frac{\partial(N\sin\gamma\sin\theta_x)}{\partial s} + \frac{\partial(Q_x\cos\theta_x)}{\partial s} = m\ddot{x}$$

$$\frac{\partial(N \sin \gamma \cos \theta_z)}{\partial s} - \frac{\partial(Q_x \sin \theta_x + Q_z \sin \theta_z)}{\partial s} = m\ddot{y} \quad (4)$$

$$\frac{\partial(N \sin \gamma \sin \theta_z)}{\partial s} + \frac{\partial(Q_z \cos \theta_z)}{\partial s} = m\ddot{z}$$

where

$$Q_z = \frac{\partial M_z}{\partial s} \qquad Q_x = \frac{\partial M_x}{\partial s} \quad (5)$$

In developing Eqs. (4) and (5), it is assumed that the twist, T, is negligible.

(3) *Idealized Thickness Model.* An idealized thickness model, illustrated in Figure 2 and consisting of a number of discrete segments for the cross section of the beam column, is used to keep track of the material deformations of the structure. Each segment is characterized by the area, A_{ij}, and its distances, ξ_{ij} and η_{ij}, to the c.g. of the *ith* section. These discrete segments are considered to be separated by material that cannot carry normal stress but that has infinite shear rigidity. With this simplified model of the cross section, the strain and stress in the structure can be defined by the strain and stress in these individual segments. It is assumed that plane sections remain plane throughout the deformation process.

(4) *Strain-Displacement Relationship.* The strain at the *jth* segment, located at distances, ξ_{ij} and η_{ij}, from the two centroidal axes of the *ith* section, may be expressed approximately as

$$\epsilon_{ij} = \frac{\Delta s_i - \Delta s_i^o}{\Delta s_i^o} - \xi_{ij} \frac{(\Delta\theta_z)_i - (\Delta\theta_z)_i^o}{(\Delta s_{i+1}^o \sin \alpha_{i+1}^o + \Delta s_i^o \sin \alpha_i^o)/2} - \eta_{ij} \frac{(\Delta\theta_x)_i - (\Delta\theta_x)_i^o}{(\Delta s_{i+1}^o \sin \gamma_{i+1}^o + \Delta s_i^o \sin \gamma_i^o)/2} \quad (6)$$

where Δs_i is the length of the deformed link i, and $(\Delta\theta_z)_i$, $(\Delta\theta_x)_i$, are the angles between the deformed links i and i+1 in the z and x directions, respectively. The index o refers to the undeformed position at time zero.

(5) *Stress-Strain Relationship.* In this engineering approach, it is assumed that the axial stress depends directly on the axial strain. The relationship can be characterized by means of the nominal stress vs. the nominal strain curve obtained from a uniaxial tensile test. Generally, most ductile materials can have their nominal stress-strain relationship reasonably idealized by an elastic, linear strain-hardening representation, including the Bauschinger effect.

A common approximation to account for possible strain-rate sensitivity is

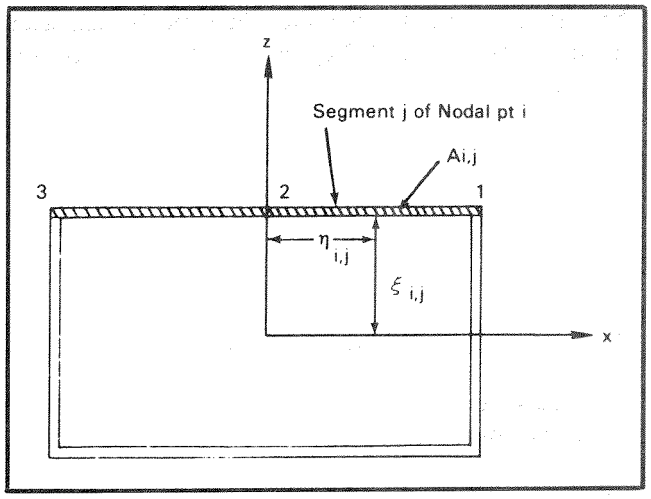


Figure 2. Idealized discrete segments for cross section.

$$\sigma_y = \sigma_o \left[1 + \left(\frac{\dot{\epsilon}}{D}\right)^{1/p}\right]. \quad (7)$$

In this approximation, the effect of the strain-rate is to raise the yield stress σ_y of the material above its quasi-static value σ_o, such that the associated strain-hardening portion of the curve is kept parallel to the static strain-hardening curve as illustrated in Figure 3. The quantities D and p in Eq. (7) are treated as material constants. For mild steel, test results show D and p to be 40.4 s^{-1} and 5, respectively.

(6) *Calculation of the Element Forces.* Having calculated the stress, σ_{ij}, in the segment pattern of the cross section by substituting the corresponding strain, ϵ_{ij}, into

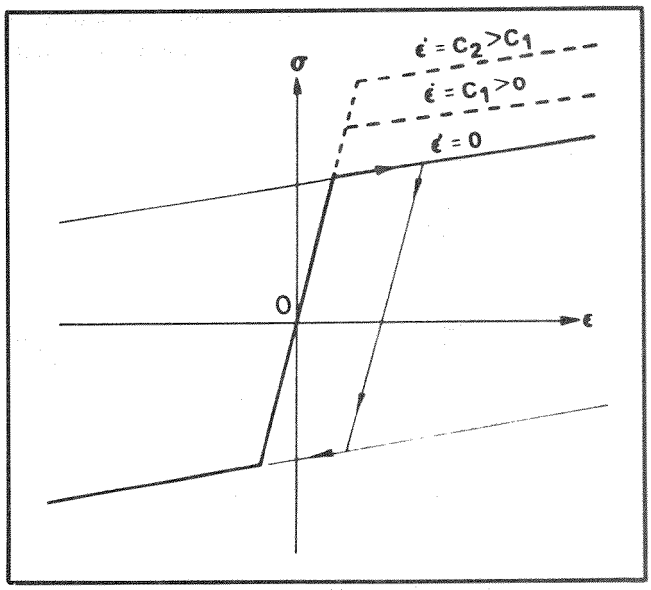


Figure 3. Stress vs. strain.

the stress-strain relationship, the axial force, N_i, and bending moments, $(M_x)_i$ and $(M_z)_i$, at the *ith* nodal point can be approximated as

$$N_i = \sum_{j=1}^{J} \sum_{k=1}^{K} \sigma_{ij} A_{ij}$$

$$(M_x)_i = \sum_{j=1}^{J} \sum_{k=1}^{K} \sigma_{ij} \xi_{ij} A_{ij} \qquad (8)$$

$$(M_z)_i = \sum_{j=1}^{J} \sum_{k=1}^{K} \sigma_{ij} \eta_{ij} A_{ij}.$$

(7) *Large Local Deformation of Sections.* It is almost always justifiable in engineering analysis to neglect the cross-sectional change of a beam column undergoing large deformation. However, for beam columns with thin-walled sections, the cross sections undergo significant distortions during bending as shown in Figure 4. For a solid section without a significant sectional change, the two distances, ξ_{ij} and η_{ij}, in Figure 2 remain constant during global deformation process, while in the case of a thin-walled section with significant sectional distortions, these two distances change during global deformation of the structure. In the present approach, the adjustments of ξ_{ij} and η_{ij} associated with the bending of the cross section are treated by means of empirical relationships between the distances and the bending angles. The relations between depth changes and bending angles of some typical box sections are shown in Figure 5.

Rigid-Body Element

One of the important concepts employed in developing this general purpose technique is that the joints of the structural members described above are considered as rigid bodies experiencing six degrees of freedom. Figure 6 illustrates the motion of joints with the forces and moments acting on them from the surrounding structural members or attachments. Then the equations of motion of joints may be written as

$$\sum_{i=1}^{p} (\bar{F}_x)^i_{n_\ell} i = \bar{m}_\ell \ddot{x}_\ell$$

$$\sum_{i=1}^{p} (\bar{F}_y)^i_{n_\ell} i = \bar{m}_\ell \ddot{y}_\ell$$

$$\sum_{i=1}^{p} (\bar{F}_z)^i_{n_\ell} i = \bar{m}_\ell \ddot{z}_\ell \qquad (9)$$

$$\sum_{i=1}^{p} (\bar{M}_x)^i_{n_\ell} i = (\bar{I}_x)_\ell (\ddot{\theta}_x)_\ell$$

$$\sum_{i=1}^{p} (\bar{M}_y)^i_{n_\ell} i = (\bar{I}_y)_\ell (\ddot{\theta}_y)_\ell$$

$$\sum_{i=1}^{p} (\bar{M}_z)^i_{n_\ell} i = (\bar{I}_z)_\ell (\ddot{\theta}_z)_\ell.$$

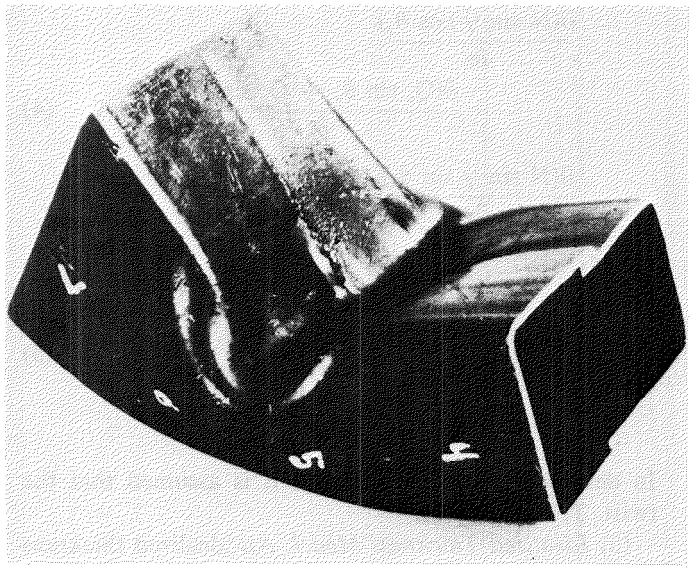


Figure 4. Typical detail of plastic hinge in frame member.

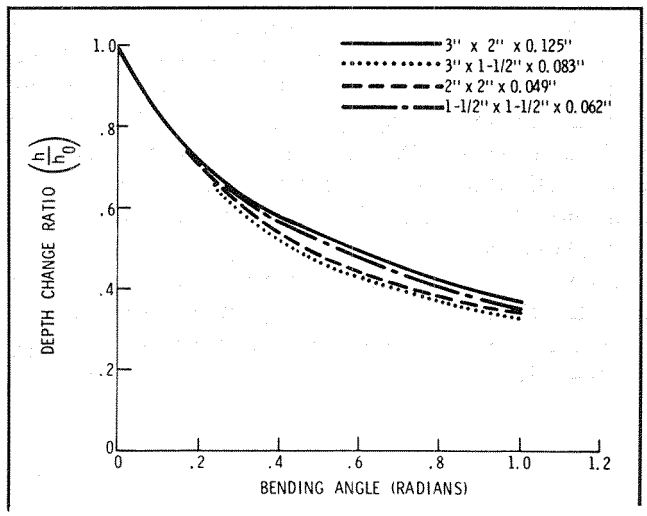


Figure 5. Cross-sectional depth changes vs. bending angles.

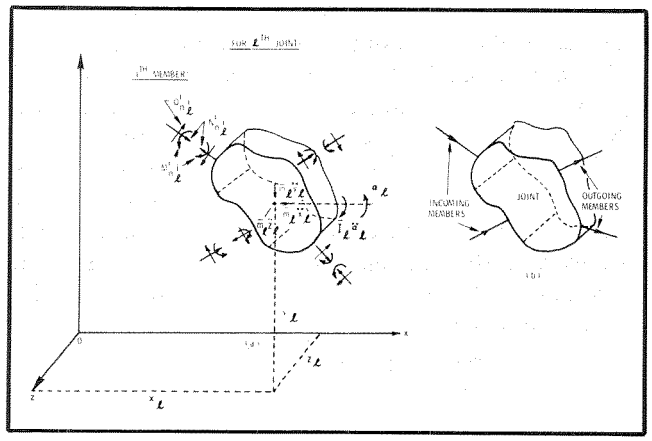


Figure 6. Schematic diagram showing the equilibrium state of the ℓ th joint.

Time-Integration Scheme

In order to solve the equations of motion of the dynamic system, an explicit integration scheme derived from the central finite difference is used:

$$(x)_{t+\Delta t} = (\ddot{x})_t (\Delta t)^2 + 2(x)_t - (x)_{t-\Delta t}. \qquad (10)$$

It has been recognized that this integration scheme in conjunction with the lumped mass model is considered as one of the most efficient numerical schemes in nonlinear transient problems. It should be noted, however, that the integration step size, Δt, has to be carefully chosen such that the stability criterion involved in the wave motion be met. The stability criterion, in general, requires that the amount of time taken by a wave to travel over an element length be greater than the chosen time step, Δt. This may be expressed as

$$\Delta t < \Delta s\sqrt{\rho/E} \qquad (11)$$

where Δs is the element length, ρ is the density of the material, and E is the Young's modulus.

STATIC SIDE CRUSH OF SPACE FRAME I

Structural Model

The space frame shown in Figure 7 is designated as Space Frame I. It should be noted that each of the beam members has uniform rectangular thin-walled sections along its length. The space frame is clamped at both its front end and rear end and then subjected to side crush loadings at two points, A and B. The deflections at A and B are equal and assumed to be in the lateral direction only.

The structural model of this space frame consists of 26 box-beam members, 11 rigid masses for member joints and 2 for the boundary fixtures at either end. Each beam member is then further discretized at a number of nodal points, ranging from 8 to 11, along its length. At each nodal point, the thin-walled box section is represented by 8 discrete segments as demonstrated in Reference 10. The beam elements in NONDRIS used to model the beam members of the space frame are capable of dealing with large rigid-body motion and structural deformation accompanied by local sectional buckling.

The member joints are assumed to be rigid points having no geometric dimensions. As shown in Figure 8a, when the joint is modeled as a rigid joint, the assumption of a rigid joint would impose that the joint angle, θ, remains unchanged during deformation. However, joints of thin-walled frame structures usually experience some degree of flexibility due to deformation of the attached structures. The modeling technique for rigid joints must be modified to account for the joint flexibilities. One modification can be made simply by assigning one additional nodal point beyond the joint as shown in Figure 8b. These additional nodal points (or fictitious nodal points) and the joint maintain their rigidities while the structure attached to the joint would experience deformation depending on its sectional and material properties. This modeling technique provides one of the easiest ways to deal with the complex, multi-axial deformation characteristics associated with flexible joints. Certainly, it should be noted that, when the inelastic joint data in multi-axial loading conditions can be determined experimentally for each joint, the joints of the structural model can then be represented by a point with a three-dimensional rotational "spring" available in NONDRIS. However, due to the path-dependent nature associated with large inelastic joint deformations in multi-axial loading conditions, it is generally quite cumbersome, if not impossible, to establish the "spring" characteristics (or loading surface) for each joint.

An explicitly integrated dynamic approach is used to solve this quasi-static problem. This approach to solving static problems is usually referred to as the "dynamic relaxation method" and is based on the fact that a damped system excited by a constant force ultimately comes to rest at the static equilibrium of the system.

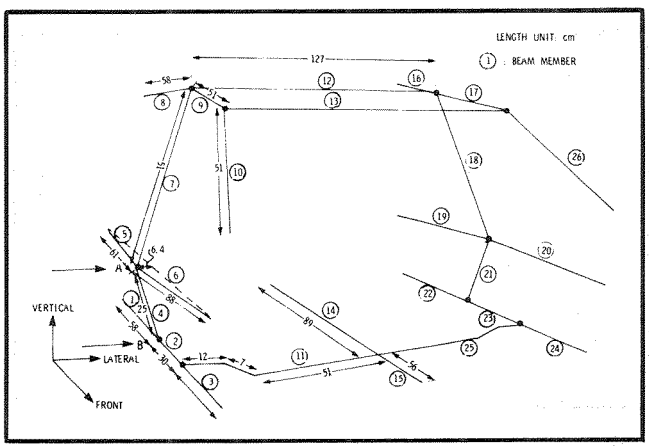


Figure 7. Sketch and dimensions of Space Frame I.

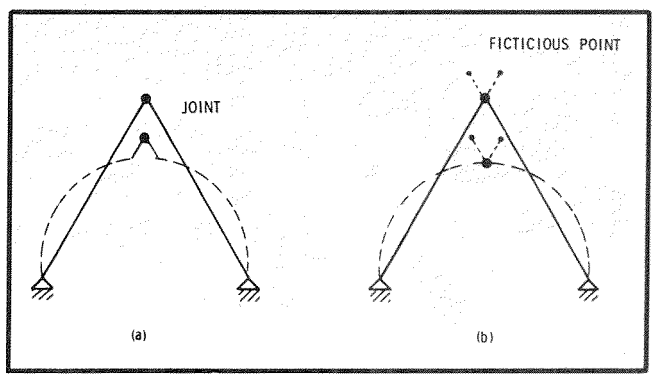


Figure 8. Rigid joints modeled as point masse with extended ficticious member nodal points.

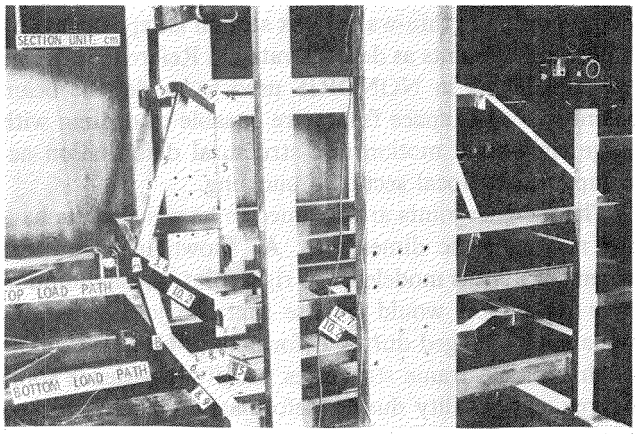


Figure 9. Test setup for static crush of Space Frame I.

The two rigid masses which represent the front and rear boundaries, respectively, are assumed to be so large that they remain stationary as the loading is being applied to the space frame. The material used in this space frame is SAE 1010, which has a Young's modulus of 2.07×10^5 MPa, a yield stress of 172 MPa, and a tensile strength of 235 MPa at a strain equal to 0.25.

Experimental Testing

As shown in Figure 9, this space frame is clamped to the fixtures at both the front and rear ends and is then side crushed statically at two points, A and B, by two rigid pusher tubes connected to the ram face of the crusher. Load cells are used to record the forces exerted by the space frame at its top and bottom load paths. In addition to the force measurements, the displacements of some key locations are also recorded. Figure 10 shows the deformed space frame after being crushed. As one can see, extremely large structural deformation and fracture of material are experienced.

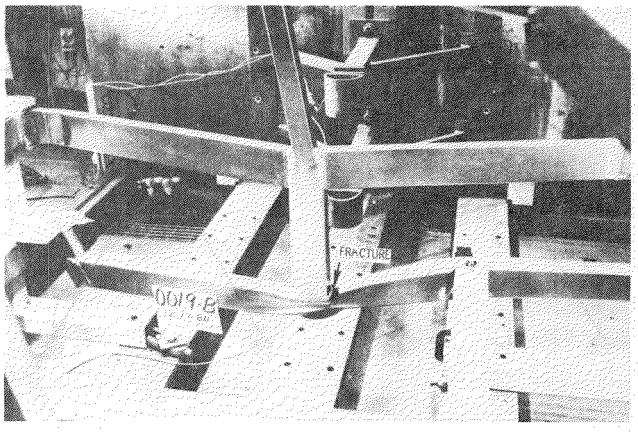


Figure 10. Deformed members of Space Frame I after side crush.

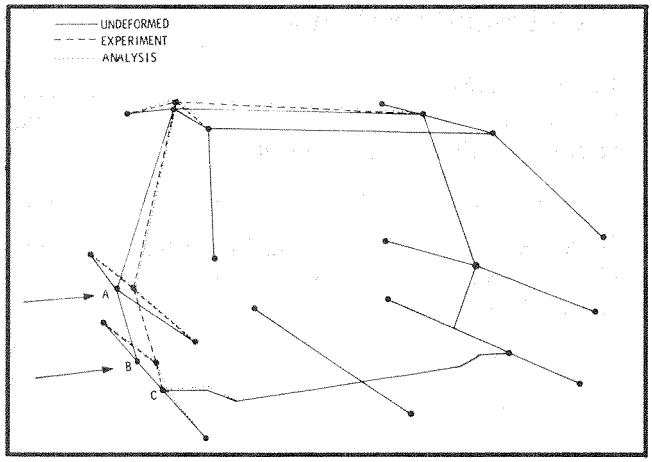


Figure 11. Comparison of measured and calculated deformed profiles of Space Frame I.

Correlations of Structural Model and Experiment

In essence, the NONDRIS program can compute the detailed deformation and forces associated with every point in the structural model of the space frame. For comparison purposes, Figure 11 illustrates only the deformed profiles of the space frame, measured experimentally and computed from the model for side crush of 12.7 cm at points A and B. It can be seen that the agreement between model and experiment is indeed very good. Both the calculated results and the experimental measurements indicate that, as point A is being pushed, beam members 5 and 6 (Figure 7) were snapped inward, with one end of member 7 traveling with point A and the other end pushing up its joint at the top. Also, as a result of large deflection at point B, there are significant structural deformations occurring in tension on members 1, 2, and 3. On the other hand, the structures on the far side of the space frame experienced very small deformations.

In addition to the deformation profiles, the force-deflection curves of the space frame are usually used to characterize its structural resistance. Figures 12 and 13

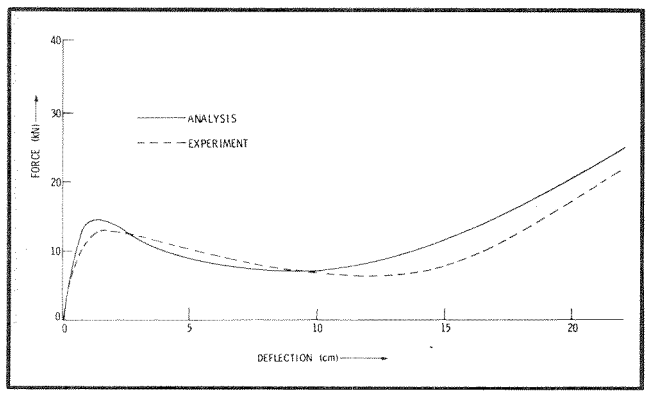


Figure 12. Force-deflection curve comparison between analysis and experiment at top load path.

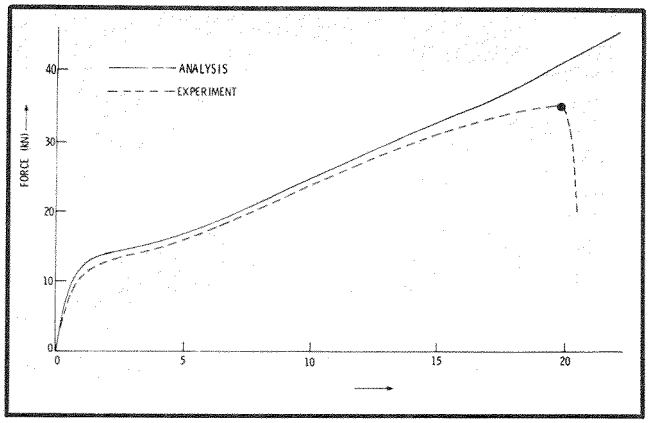


Figure 13. Force-deflection curve comparison between analysis and experiment at bottom load path.

present the force-deflection curves of the space frame at its top load path and bottom load path, respectively. As discussed previously, members 5 and 6 experience the "snap through" phenomenon as point A is being pushed and, as a result, the force level drops after the critical point until these two members reverse from compression modes to tension modes and gradually accumulate their tensile resistances. In Figure 12, the computed results follow the test data reasonably well in spite of some discrepancies in magnitude. Similarly, the force-deflection curve at the bottom load path has been computed and compared with the experimental measurements. Figure 13 indicates that both the computed and the measured forces increase monotonically with deflections mainly because members 1, 2, and 3 are subjected to tension throughout the whole deformation process. As one can see, the computed force-deflection curve is in good agreement with test data, except in the region after the fracture point. In this particular case, fracture was not considered in the model.

STATIC AND DYNAMIC RIGID BARRIER SIDE CRUSH OF SPACE FRAME II

Structural Model (Static Loading)

Figure 14 shows the sketch of the second space frame, designated as Space Frame II. Space Frame II differs from Space Frame I by: 1) attaching the relatively rigid front and rear ends and 2) aligning members 5 and 6 (Figure 7) to eliminate the "kink". The structural model, as depicted in Figure 15, consists of 25 beam members and 11 masses for their joints. It should be pointed out that the modeling technique for beam members and their joints is the same as discussed in the previous section. Since the main interest in this study lies in modeling the side impact response of the middle portion of this space frame, which is intended to simulate the vehicle passenger compartment, the front and rear ends are modeled as two

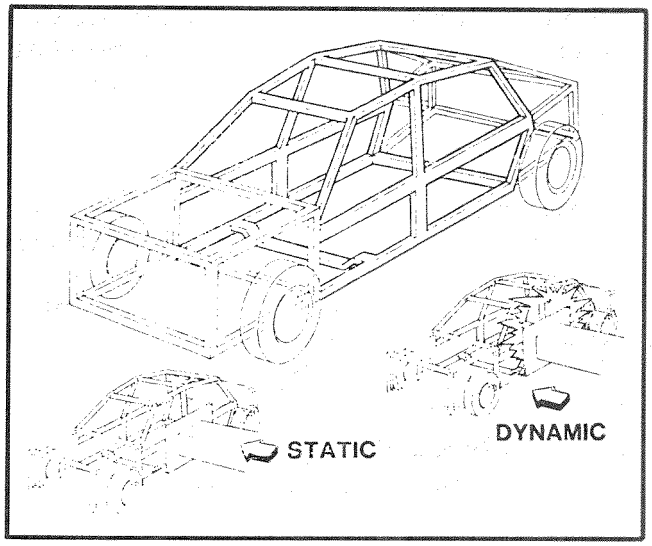


Figure 14. Sketch of Space Frame II.

rigid masses undergoing no structural deformation. Another aspect of this model which differs from the previous one is that this space frame is subjected to side crush loadings by a rigid steel rectangular plate (101 cm × 38 cm × 2.5 cm) as shown by the shaded area in Figure 15. In order to simplify the complex nature of the contact area between the impacted structures and the rigid barrier, an assumption is made that the rigid barrier and the impacted structures are in constant contact. In other words, after the initial contact they remain in contact, acting like a single rigid mass. This assumption is justifiable in view of the large inelastic deformation which occurred on the impacted structures of the space frame.

There are two loading conditions, static and dynamic, applied to this space frame. First, in the case of static loading, the front and rear ends are constrained from moving laterally and vertically when the shaded area of the model in Figure 15 is subjected to lateral forces. The analytical solution technique as described in the previous

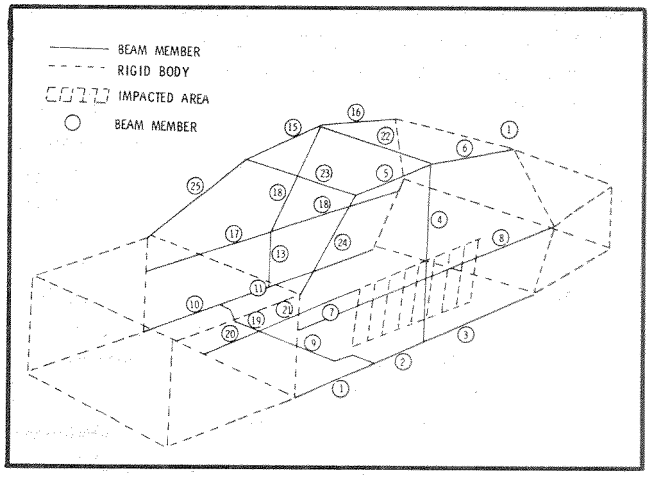


Figure 15. The structural model of Space Frame II.

section is also applied to this case. A bilinear representation for approximating the stress-strain curve of SAE 1010 steel, used in Space Frame I, is also adopted for this case of loading conditions. However, due to the fact that local fracture can significantly weaken the crush strength of structures, a simplified fracture model based on the maximum strain theory has been incorporated in the structural model. The maximum strain of each beam member at each step of the calculation is obtained, and then the material tensile fracture strain is used as a critical strain beyond which the beam member is assumed to fail and offers no structural resistance.

Structural Model (Dynamic Loading)

The structural model shown in Figure 15 and discussed in the preceding section is also applicable to dynamic loading conditions. In this case, the space frame is initially stationary and subjected to dynamic impacts normal to the side by a rigid moving barrier at 24 and 34 km/h. With the same assumption of constant contact between the moving barrier and the impacted structures of the space frame, the rigid mass representing the shaded area in Figure 15, which includes the moving barrier mass and the mass of the impacted structures, has an initial lateral velocity equivalent to the impact speed. The front and rear ends are allowed to move in the three translational dimensions and to yaw about their vertical axes.

Finally, one of the important characteristics associated with the dynamic response of structures is the "strain-rate sensitivity effect" associated with such structural materials as steel. This is accounted for as described in section (5) of the theoretical description. The material constants for the strain-rate effect of steel, D and p [Eq. (7)], are 40.4/sec and 5, respectively.

Experimental Testing (Static and Dynamic)

Figure 16 illustrates the static test setup of Space Frame II. Both its front and rear ends are suspended in such a way that they are only allowed to move freely in the longitudinal direction and yaw about their vertical axes. Grease is applied on the contact surfaces between the space frame and suspending fixtures to minimize friction. A heavy steel plate (101 cm $\times$ 38 cm $\times$ 2.5 cm) extending out from the ram face of the crusher serves as a rigid barrier. Then the space frame is statically side crushed by the rigid barrier as shown in Figure 16. The reaction forces on the ram face of the crusher are recorded. Note that this crush testing is displacement controlled. The deformed profiles of those main beam members after crush are shown in Figure 17. Large plastic deformations (or plastic hinges) are quite obvious, and separation of member 7 (Figure 15) from the front end at its joint has been observed as a result of tearing of the end plate.

Two dynamic side impacts of a Space Frame II con-

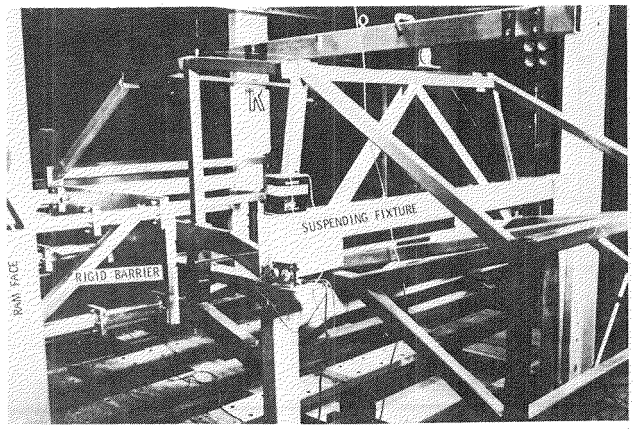


Figure 16. Test setup for static barrier side crush of Space Frame II.

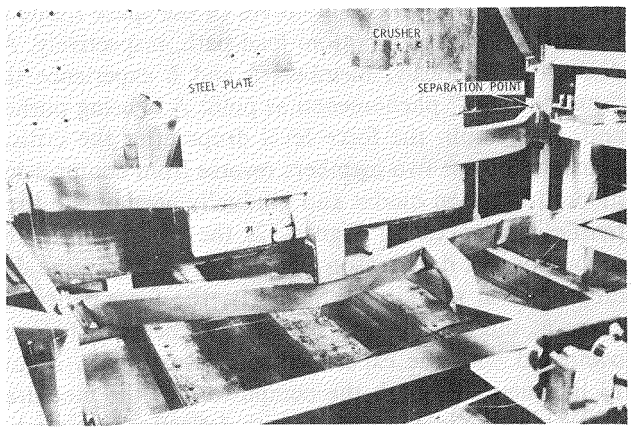


Figure 17. Deformed members of Space Frame II after side crush.

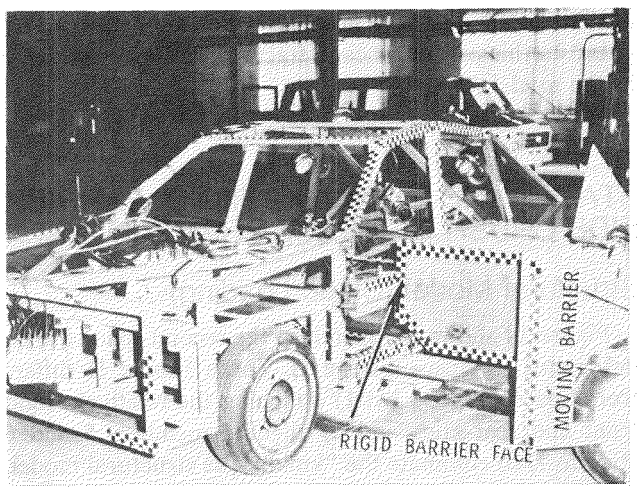


Figure 18. Proving ground test setup for rigid barrier side impact of Space Frame II.

figuration have been conducted at impact speeds of 24 and 34 km/h, respectively. Figure 18 illustrates the dynamic side impact test arrangements in which the space frame is stationary before impact and a rigid plate with

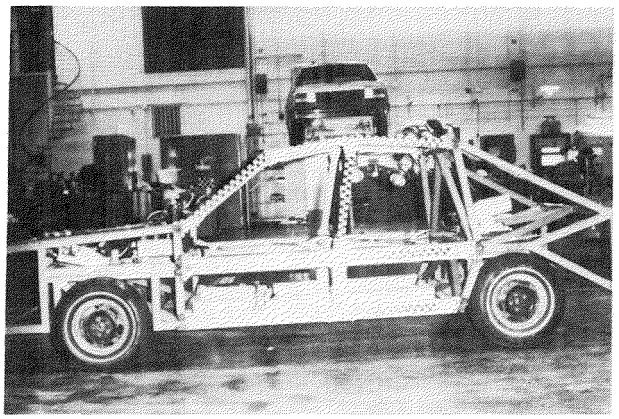


Figure 19. Picture of Space Frame II before test.

plywood on top (the same steel plate used in the static test) is attached to a moving barrier. The moving barrier impacts the space frame in the same area as in the static test. A large number of recordings are used to measure accelerations and displacements of the space frame and the moving barrier during impact. Figures 19 and 20 show the space frame before and after the side impact at a speed of 34 km/h. The deformation patterns of the space frame resulting from side impacts are, in fact, quite similar to those in the static case. Separation of member 7 at its joint with the front end resulting from material fracture is also observed in the case of the 34 km/h side impact. However, no obvious fracture occurred in the case of the 24 km/h impact.

Correlations of Structural Models and Experiments

Static Case. Based on the structural model described previously, the NONDRIS program has computed the force-deflection curve of Space Frame II subjected to a static rigid barrier side crush. As presented in Figure 21,

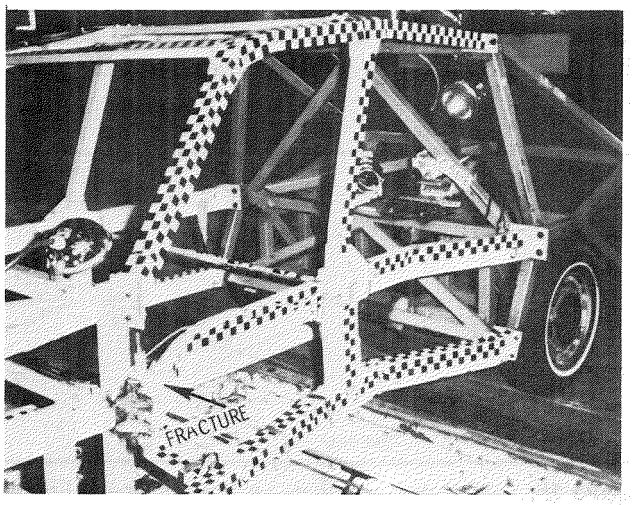


Figure 20. Picture of Space Frame II after test at 34 km/h.

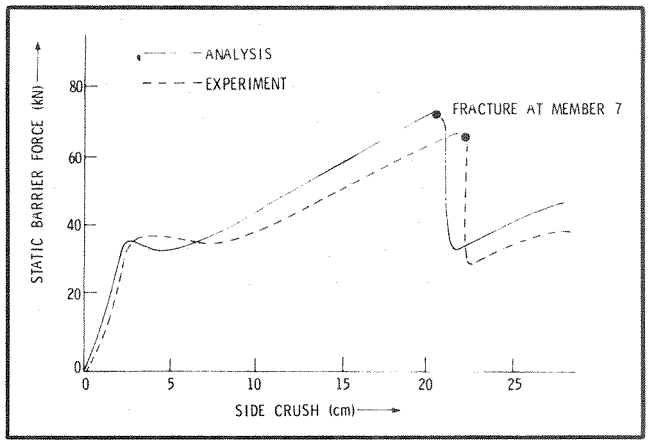


Figure 21. Comparison of force-deflection curves obtained analytically and experimentally for Space Frame II subject to static side crush.

the computed force-deflection curve agrees reasonably well with the measured experimental data. Both the computed and the measured results indicate that, as the rigid barrier crushes the space frame, those major beam members such as 7, 8, 1, 2, and 3 (Figure 15) experience mostly tensile deformation and, as a result, the force levels rise as deflection increases. The computed results and experimental observations all indicate that a separation occurred at the joint between member 7 and the front end as a result of excessive stretching. The material fracture strain used in the model to calculate the fracturing point is 25%. Furthermore, it should be noted that the force level in Figure 21 drops significantly after the fracture point, indicating the great loss of structural resistance due to the fracture at member 7.

Dynamic Case. The dynamic responses of the space frame subjected to side impacts at speeds of 24 and 34 km/h, respectively, have been computed with the NONDRIS program. In these computations, the masses for the front end, the rear end, and the moving barrier are 308, 285, and 1350 kg, respectively. The moment of inertia

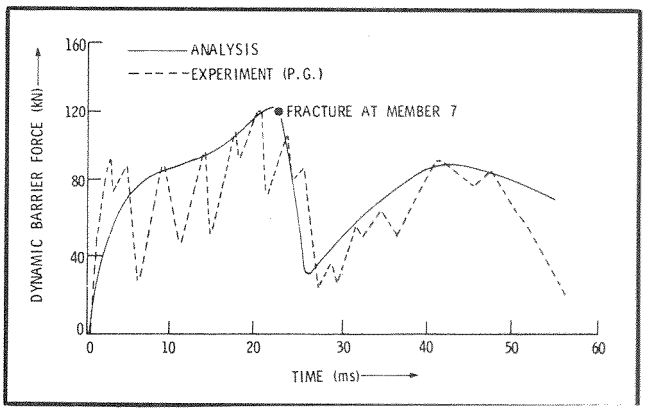


Figure 22. Comparison of dynamic force-time curves between analysis and experiment for Space Frame II subjected to side impact at 34 km/h.

for the front end is 3200 kg·cm² and 3070 kg·cm² for the rear end.

Figure 22 shows the computed dynamic barrier force time history as compared with that measured at the General Motors Proving Ground. It can be seen that they agree with each other reasonably well, considering the extreme complexities involved in this kind of contact problem. The spurious oscillations associated with the experimental measurements in force are caused mainly by vibrations occurring on the contact surface between the space frame and the moving barrier. Both the computed and measured force levels experienced drastic drops as a result of fracture at member 7 near the front end of the space frame when subjected to a side impact of 34 km/h.

Figure 23 illustrates the comparison of calculated and measured lateral velocities of the moving barrier and the space frame at its far side from the impacted area in the case of the 34 km/h impact. As one can see, in the first 15 ms after impact, the calculated velocities seem to be in good agreement with experimental measurements, while somewhat large discrepancies between them are present at the later time after impact, mainly because of the assumption of perfect contact (no separation allowed) used in the model. However, when the lateral displacements, integrated from the velocities, are compared with

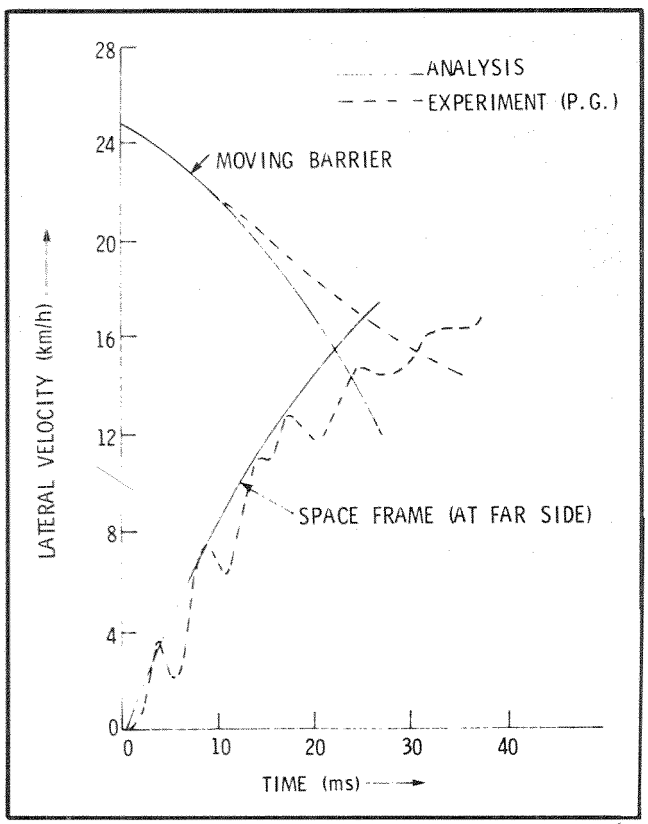


Figure 23. Lateral velocities of the rigid moving barrier and Space Frame II after 34 km/h since impact.

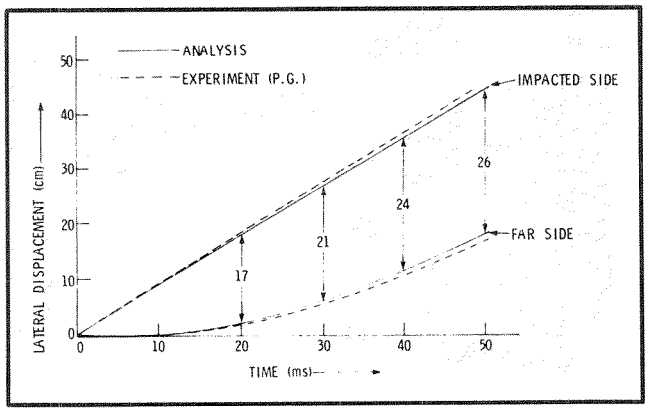


Figure 24. Lateral displacements vs. time and the total side crushes of Space Frame II at 34/h impact.

those computed and measured experimentally, the agreements are found to be much better as shown in Figure 24. It can be seen here that most of the intrusion occurs before the far side starts moving in rigid body motion. The difference in lateral displacement between the impact side and far side is called side crush. In the case of the 34 km/h side impact, the maximum side crush was about 26 cm. Similar computations have been done for Space Frame II subjected to a 90° side impact by a moving barrier at an impact speed of 24 km/h. Figure 25 shows the comparison of lateral displacements between those computed and measured at the impact side and far side. The maximum side crush is about 14 cm. It should be noted that the overall deformation modes of the space frames have been found to be quite similar for both 24 and 34 km/h rigid barrier side impact velocities.

Comparison of Static and Dynamic Force-Deflection Curves. One of the most convenient, commonly used measures to characterize the crush strength of a structure has been the force-deflection curve. Therefore, the force-deflection curves of Space Frame II are presented in Figure 26 to summarize its structural responses to the three loading conditions considered here: 1) static, 2) 24 km/h impact, and 3) 34 km/h impact. It can be seen that there is a great increase in force levels from the static

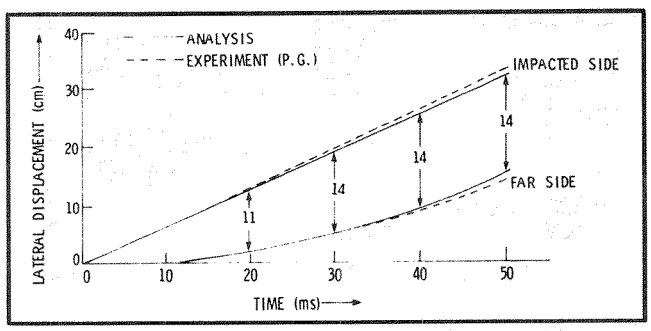


Figure 25. Lateral displacements vs. time of Space Frame II at 24 km/h.

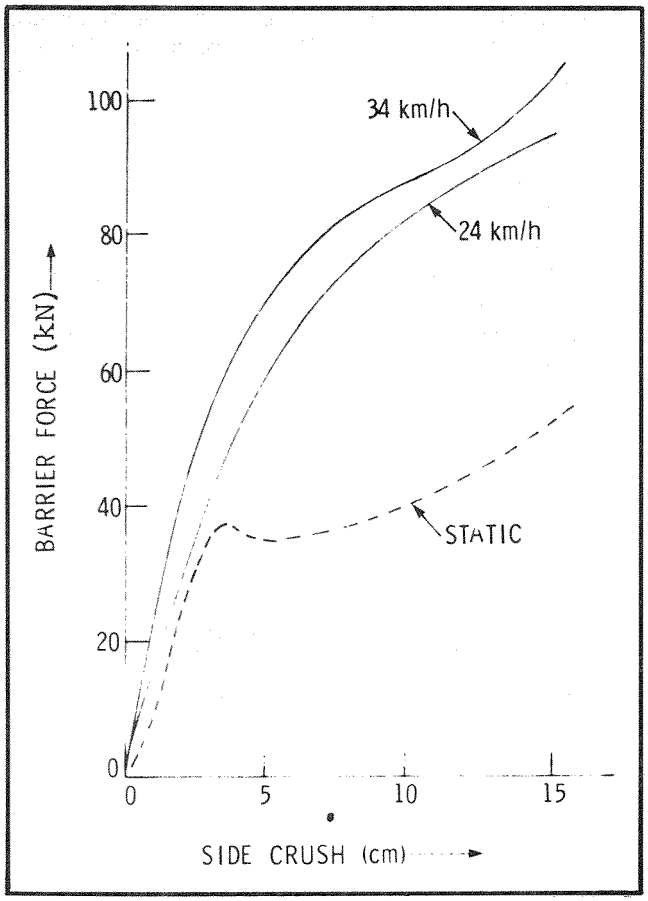


Figure 26. Summary of the force-deflection curves of Space Frame II for the loading conditions: 1) static, 2) 24 km/h, and 3) 34 km/h.

loading to the 24 km/h impact, while only a slight increase in force levels is observed from the 24 km/h impact to the 34 km/h impact. Evidently, the relationship between static and dynamic force-deflection curves is not linearly related to the impact speeds. In general, it depends on the structural geometry, the properties of the structural materials, and the loading speed. As demonstrated in this study, the present computerized analytical technique can be used to characterize the force-deflection curves of various structures subjected to different loading speeds. Furthermore, with this technique one can also study the effect of strain-rate sensitivity of material on the force-deflection curve. Figure 27 illustrates the force-deflection curves of Space Frame II subjected to the 34 km/h side impact obtained from the structural models with and without the strain-rate sensitivity effect of steel. It has become quite obvious that significant increases in structural resistance in dynamic loading conditions are attributed to the strain-rate effect of steel.

CONCLUDING REMARKS

From the above correlations between computed and measured results, one can conclude that the present computerized analytical technique can be used with reasonable accuracy to compute the structural response of space frames when subjected to static or dynamic side loadings. With this technique, the significant effect of the strain-rate sensitivity of steel on the dynamic force-deflection curves of the space frames has been quantitatively determined.

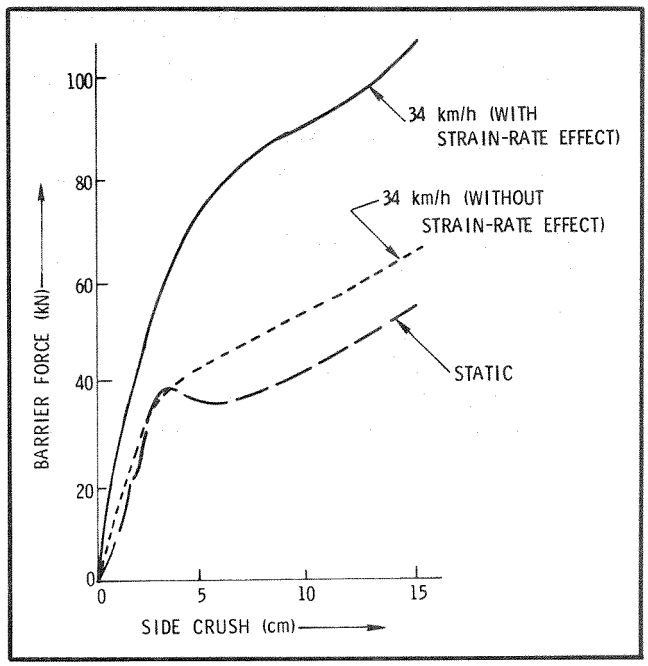


Figure 27. Comparison of dynamic force-deflection curves of Space Frame II at 34 km/h side impact obtained with and without strain-rate effect.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Messrs. C. J. Griswold and T. Juechter of Fisher Body Engineering for their cooperation and effort in experimental testing.

REFERENCES

1. M. Monk, A. Burgett, and L. DeLarm, "Computerized Side Impact Injury Analysis," Proceedings of the Twenty-first Stapp Car Crash Conference, October 1977.
2. D. Cesari, M. Ramet, and D. Herry-Martin, "Injury Mechanisms in Side Impact," Proceedings of the Twenty-second Stapp Car Crash Conference, October 1978.
3. M. M. Kamal, "Analysis and Simulation of Vehicle-to-Barrier Impact," *SAE Transactions*, 79 SAE Paper No. 700414, 1970.
4. K. H. Lin, "A Rear-End Barrier Impact Simulation

Model for Unibody Passenger Cars," *SAE Transactions*, 82, SAE Paper No. 730156, 1973.
5. C. M. Ni and D. S. Fine, "Predicting Crash Response of Automotive Structural Components," *SAE Transactions*, 87, SAE Paper No. 780671, 1978.
6. C. M. Ni, "A Numerical Method for Nonlinear Impact Analysis of Planar Frames," Proceedings of the First International Conference on Computational Methods in Nonlinear Mechanics, Austin, Texas, 1974.
7. G. H. Tidbury and D. Kecman, "Investigation into the Behavior of Hinges Produced by Bending Collapse of Vehicle Structural Components," Proceedings of the 17th International Congress of FISITA, pp. 849-864, Budapest, 1978.
8. W. Abramowicz and T. Wierzbicki, "A Kinematic Approach to Crushing of Shell Structures," Proceedings of the 3rd International Conference on Vehicle Structural Mechanics, p. 83, Troy, Michigan, 1979.
9. C. M. Ni, "A Quadrilateral Finite Difference Plate Element for Nonlinear Transient Analysis of Panels," *Computers & Structures*, Vol. 15, No. 1, pp. 1-10, 1982.
10. C. M. Ni, "A General Purpose Analytical Technique for Nonlinear Dynamic Response of Integrated Structures," Proceedings of the Fourth International Conference on Vehicle Structural Mechanics, November 1981.

Application Of The Fiat Methodology For Characterizing Vehicle Structural Responses In Side Impacts

L. M. "MORRIE" SHAW
Arndt & Associates

CARL RAGLAND
National Highway Traffic Safety Administration

ABSTRACT

Over the past several years, Dynamic Science, Inc., under funding from Fiat Auto S.p.A., developed a methodology for evaluating vehicle crash compatibility. The ultimate goal was to provide compatibility characterization technology in the frontal, side, and rear impact environments. The result of this research has been extremely encouraging, providing accurate analysis and predictive capabilities, as well as justification of the methodology approach.

Because of the increasing concern for vehicle crash compatibility, the U.S. National Highway Traffic Safety Administration (NHTSA) acquired the Fiat Methodology in 1980. The NHTSA then increased the funding of an ongoing program to apply the Fiat Methodology to a side impact research program. Frontal and side structural characterizations were used in the side impact analysis.

This paper summarizes the results from the above NHTSA research program emphasizing the applicability of the Fiat Methodology to the characterization of vehicle structural responses in side impacts. Validation of the side structure characterization is discussed and presented along with comparisons between predictive analysis and crash test results.

INTRODUCTION

For more than a decade automotive safety researchers have recognized the significance of vehicle crash compatibility in evaluating vehicle crashworthiness within the overall accident environment. This problem is most evident in the side impact environment where frontal structures engage side structures. The traditional methods for evaluating a vehicle's crashworthiness in side collisions have included static loading tests such as prescribed in FMVSS 214 and moving barrier tests prescribed in FMVSS 208 and SAE J972a. However these approaches do not specifically address structural incompatibility between front and side structures nor do they adequately define the intruding mechanisms for evaluating occupant loading and injury. These limitations have prompted researchers to.study and recommend other testing and evaluative approaches which more closely represent the crash dynamics and structural interactions associated with traffic mix side impact encounters. To effectively manage such a complex interactive evaluation, it is necessary to concentrate on vehicle test and analysis techniques which consider all significant aspects of the crash environment.

In 1973, Fiat Auto S.p.A. and Dynamic Science, Inc. began formulation of test and analysis techniques for evaluation of vehicle crash compatibility. Since this initial formulation, Dynamic Science, Inc., under funding from Fiat Auto S.p.A. developed a methodology for evaluating vehicle crash compatibility. The ultimate goal was to provide compatibility characterization technology in frontal, side and rear impact environments. The results of this research have been extremely encouraging—accurate

analysis and predictive capabilities have been developed, as well as justification of the methodology approach.

Because of the increasing concern for vehicle crash compatibility, the U.S. National Highway Traffic Safety Administration (NHTSA) acquired the Fiat Methodology in 1980. With the recent emphasis on the vehicle side impact environment, it became imperative that subsequent development of the Fiat Methodology be concerned with the front-to-side environment. The NHTSA then increased the funding of an ongoing program (Reference 1) to initialize the application of the Fiat Methodology to side impact analysis. Both frontal and side structural characterizations were used in this study.

This paper summarizes the results from the above NHTSA research program, emphasizing the applicability of the Fiat Methodology to the characterization of vehicle structural responses in side impacts. A companion paper, Reference 2, summarizes the applicability of the Fiat Methodology for characterizing frontal impacts. The frontal characterization obtained in Reference 2 is used in the vehicle front-to-vehicle side prediction presented herein.

FIAT METHODOLOGY APPROACH

Franchini (References 3 and 4) discussed and highlighted the Fiat Methodology in prior Experimental Safety Vehicles (ESV) conferences. However, it seems appropriate to summarize the Fiat Methodology approach prior to presenting the results used for the NHTSA study.

The Fiat Methodology has resulted in new test and analysis approaches and techniques for evaluating vehicle-to-vehicle crash interactions. The research accomplished to date has resulted in the design and development of test hardware, test techniques, data analysis software and crash simulation software, along with validation of the basic methodology. Figure 1 flow charts the basic engineering approach and illustrates the coupling of experimental test data and analytical technology to define and characterize a vehicle's response to crash environments.

It was recognized from the beginning of the Fiat Methodology development effort that the results and analyses must be based on experimental data. As illustrated in Figure 1, the first step is a structural characterization test of the vehicle under the appropriate impact conditions. For our research, this was accomplished through the use of a test device developed to enhance structural data acquisition. The test device has been discussed and presented by Franchini in References 3 and 4 and consists of a 36-module load-measuring moving barrier fitted with energy-absorbing honeycomb blocks attached to each module. The purposes of the test device include:

1. Simulation of the structural interface interactions involved in vehicle-to-vehicle encounters,
2. Measurement of crash interface loads and deflections between the test device and vehicle being characterized, and
3. Simulation, as closely as possible, of inertia reactions associated with vehicle-to-vehicle impacts.

Of equal importance in the characterization test is the instrumentation of the vehicle being characterized. It must adequately define the structural dynamics and inertial reactions (including occupants, restraints, engine, suspensions, etc.) that characterize the vehicle's response to the crash environment. The vehicle instrumentation is dependent upon the impact mode (front, side, rear) and upon the vehicle's design configuration.

The second step of the Fiat Methodology was to develop analysis techniques which would permit characterization of a vehicle's structural response to a crash test environment. This was accomplished by developing a data processing software package referred to as Computer Program A. As illustrated in Figure 1, Program A accepts as input the kinematic and dynamic behavior obtained from the vehicle characterization test data, the vehicle parametric data, and analytical model configuration. The program then processes these data to define the necessary structural properties of the general lumped-parameter vehicle model which are required to reproduce the given kinematic input. The end product is an analytical model of the vehicle being characterized, using full-scale crash data.

The third step of the Fiat Methodology was to develop techniques which simulate crash encounters between characterized vehicles. This was accomplished through the development of a software package referred to as Computer Program B. As illustrated in Figure 1, Program B accepts as input lumped-mass nonlinear spring model representations such as defined by Program A output (or other desired impact conditions) and computes the crash response of the vehicles. Program B can also be used to check Program A output by simulating the vehicle characterization test, thus providing model validation and a means for model improvement.

Once a vehicle's model characterization has been validated, it can be used to study structural crash interaction with other characterized vehicle structures or barriers. A sufficient number of characterized vehicles representing the traffic mix environment could then provide a data base for evaluating an individual vehicle's structural crashworthiness compatibility with a traffic mix population environment.

SIDE STRUCTURAL CHARACTERIZATION

In the Fiat S.p.A.-sponsored Fiat Methodology development efforts, the Fiat 132 sedan was the primary evaluation vehicle. As a result, a considerable test data base had been generated for that vehicle in both the frontal and side impact configurations. The Fiat 132 was con-

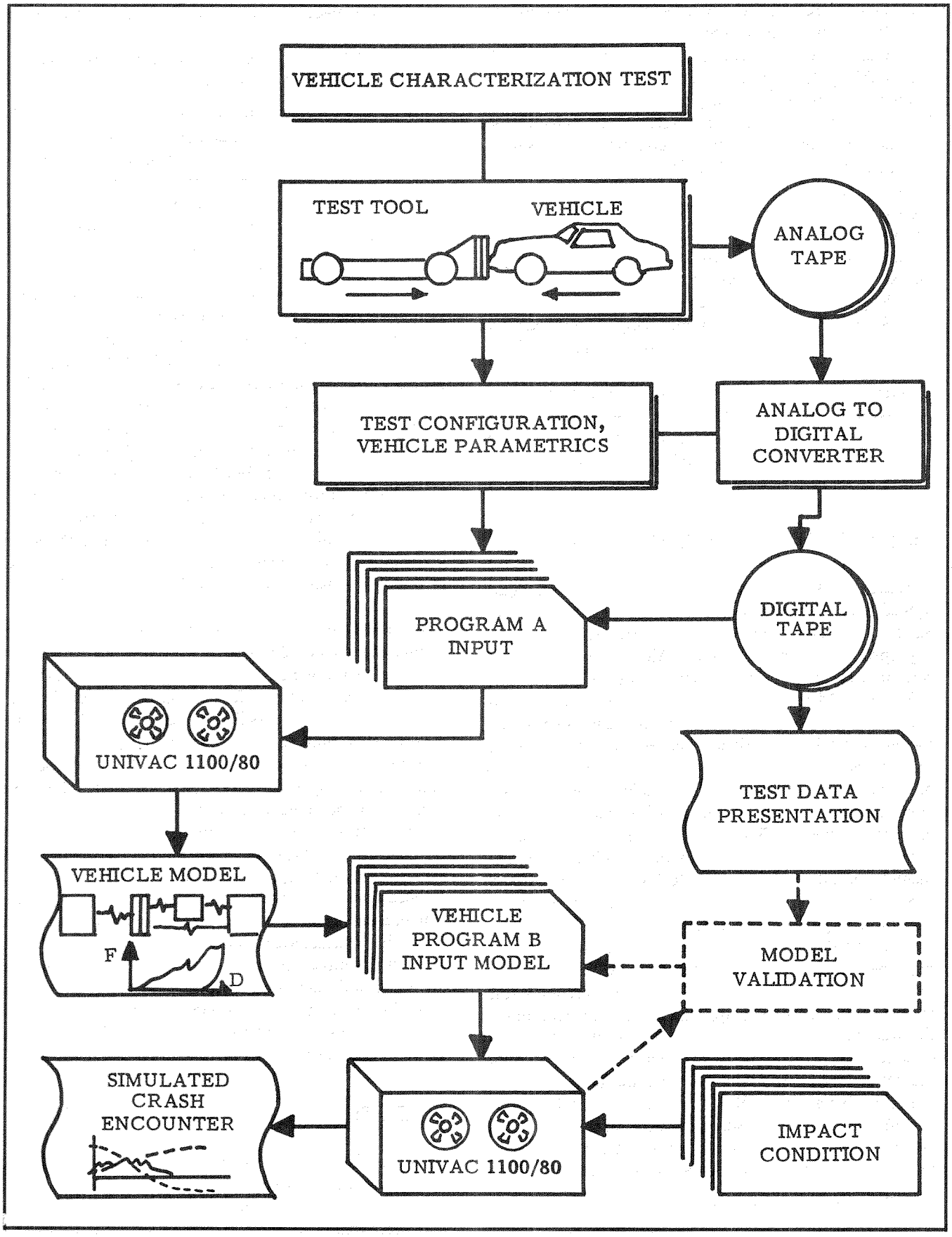


Figure 1. Fiat methodology approach.

sequently selected as the study vehicle for the NHTSA demonstration program (Reference 1). The Fiat 132 four-door sedan is a conventional front engine, rear wheel drive vehicle with a curb weight of approximately 2,380 pounds (1,080 kg).

The Fiat 132 side structures characterization effort is illustrated in Figure 2. It included full-scale characterization testing, computer data processing, model development, and model validation. The objective of this effort was to:

1. Obtain crash test results from a test between the Fiat test tool and a Fiat 132 sedan in a 90-degree side impact,
2. Exercise Program A, with the test data as input, to define the analytical side characterization model for the Fiat 132, and
3. Provide, by exercising Computer Program B, with the Fiat 132 side model as input, a validation of the side model.

Structural Characterization Test

The Fiat test tool to Fiat 132 side characterization test involved a 90-degree side impact between the Fiat test tool bullet vehicle and a Fiat 132 sedan target vehicle. The test configuration was identical to that illustrated by Franchini in Reference 4. Table 1 summarizes the test conditions for this characterization test.

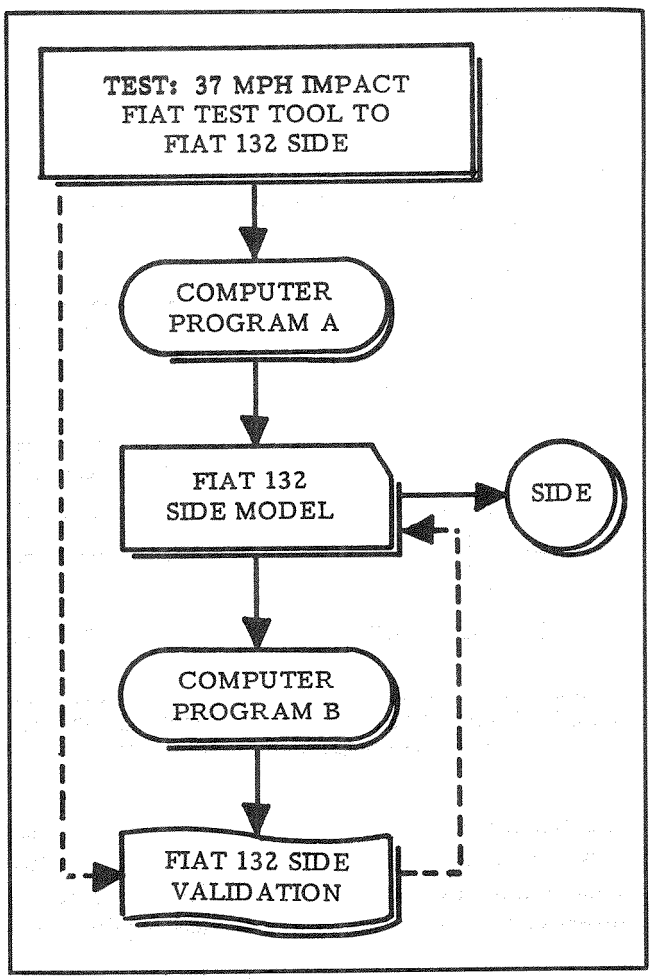


Figure 2. Flow chart of side structural characterization.

Table 1. Fiat test tool-to-Fiat 132 side characterization test.

Fiat 132 test weight	2933 lb (1330 kg mass)
Fiat test tool weight	3995 lb (1812 kg mass)
Test tool impact velocity	37.49 mph (60.33 km/h)
Fiat 132 velocity	0
Impact orientation	90 degrees
Impact alignment	Centerline of test tool aligned with Fiat 132 front seat "H" point

The Fiat 132 included fully instrumented driver and left rear passenger Part 572 dummies and extensive accelerometer instrumentation. Interior door intrusion mechanics were measured with deflection tubes mounted across the occupant compartment. The deflection tubes were instrumented with accelerometers at the end of the deflection tube, adjacent to the impact point, and deflection potentiometers to measure the intrusion. This instrumentation scheme provided a means to check the measured door acceleration, through double integration, with the measured deflection tube displacement and occupant compartment motion. The Fiat test tool carried 36 load cells along with string potentiometers for measuring test tool honeycomb deflections and frame accelerometers.

Structural Model Development and Validation

The data from the Fiat test tool-to-Fiat 132 side characterization test were processed through a Class 60 digital filter and input, along with the Fiat 132 parametric data and representative model configuration, into Computer Program A. Because this work was the initial step in the application of the Fiat Methodology to side impacts, the above step was accomplished after much initial effort in defining the optimum model configuration and approach. The output of Program A defined the interconnecting spring load deflection characteristics between the analytical model masses. For the Fiat 132 characterization test, the analytical model configuration, with respect to vehicle mass representations, is illustrated in Figure 3. This model incorporates both the Fiat 132 and Fiat test tool inertial representations.

The Fiat 132 model, along with the interconnecting spring characteristics and the analytical model of the Fiat test tool were input into Computer Program B and exercised under the impact conditions of the characterization test. This procedure validated the Fiat 132 analytical model by direct comparison of predicted and test results and provided an opportunity to fine tune the spring characteristics. It has been our experience that fine tuning, following the initial Program B validation run, is normally

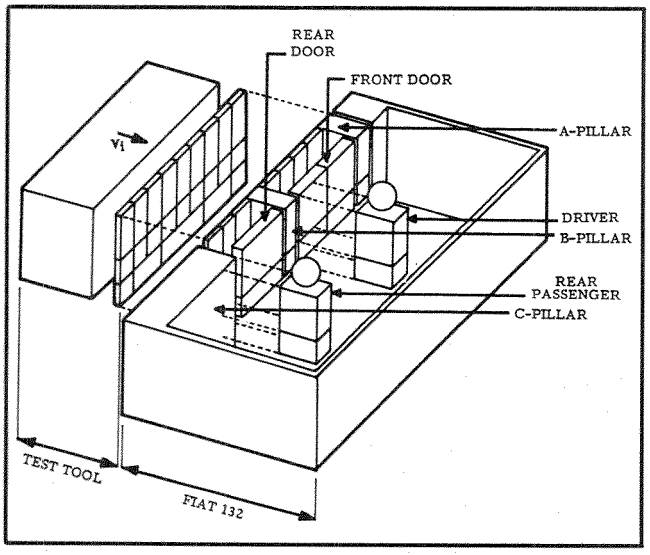


Figure 3. Model configuration for Fiat 132 side.

confined to improvements in the definition of the analytical spring unloading characteristics. This definition is extremely sensitive to data inaccuracies near the end of the crash pulse. Other fine tuning should not be necessary if test data retrieval is accurate.

The results of the Fiat 132 side model validation are summarized in Table 2. Figure 4 compares the predicted lateral compartment acceleration of the Fiat 132 to the actual test data. Figure 5 presents the corresponding predicted Fiat test tool acceleration response. Figure 6 compares the Fiat 132 compartment and Fiat test tool predicted velocity profiles to the test results.

The difficulty of measuring interior door response during side impacts has been established in several side impact programs, including the recent NHTSA program discussed in Reference 5. This is particularly true with 90-degree impacts. Present accelerometers and data acquisition systems have been found to provide incorrect

Table 2. Fiat 132 side model validation results summary.

Parameter	Simulation	Test data
Bullet vehicle (test tool) weight (lb)	3995	3995
Target vehicle (Fiat 132) weight (lb)	2911	2933
Bullet vehicle velocity (mph)	37.5	37.5
Target vehicle velocity (mph)	0	0
Maximum dynamic mutual crush (integrated acceleration) (in.)	18.8	19.8
Test tool velocity change at 100 msec (mph)	17.8	17.5
Target vehicle velocity change at 100 msec (mph)	23.8	22.4

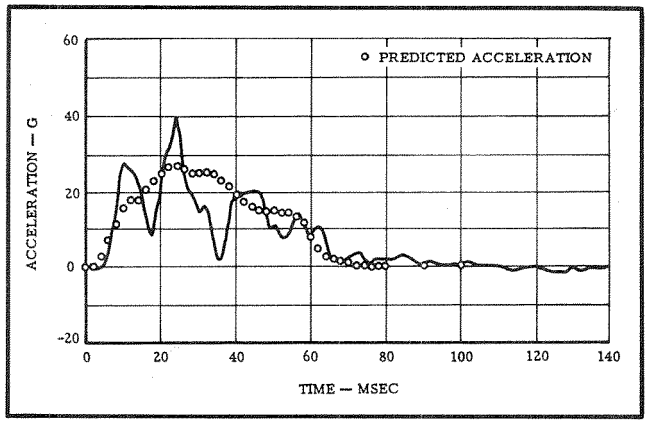


Figure 4. Comparison between predicted and test results for the Fiat 132 compartment.

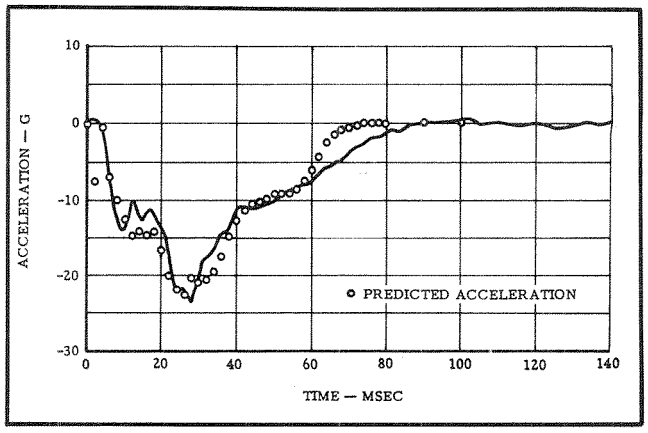


Figure 5. Comparison between predicted and test results for the test tool.

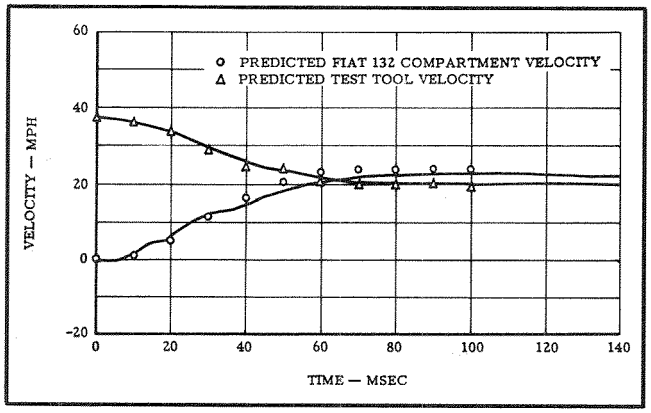


Figure 6. Comparison between predicted and test results for the Fiat 132 compartment and test tool.

acceleration measurements without the aid of deflection tubes. Even with the use of deflection tubes, door response measurements are not always successful. Therefore, the current generation of side impact models required some data correction. The procedure for correcting deteriorated door acceleration data was developed and defined as de-

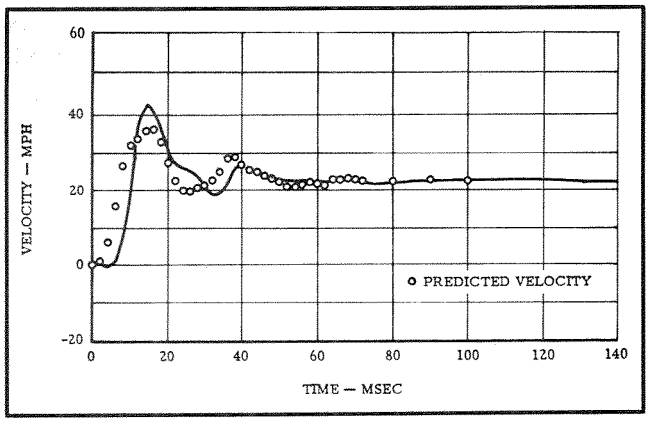


Figure 7. Comparison between predicted and test results for the Fiat 132 upper rear door velocity.

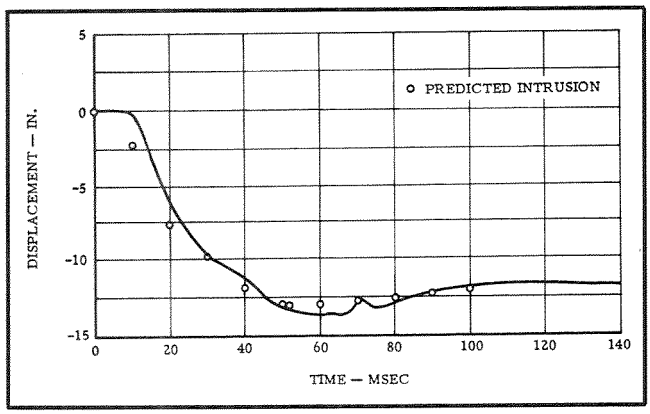


Figure 8. Comparison between predicted and test results for the Fiat 132 upper rear door intrusion.

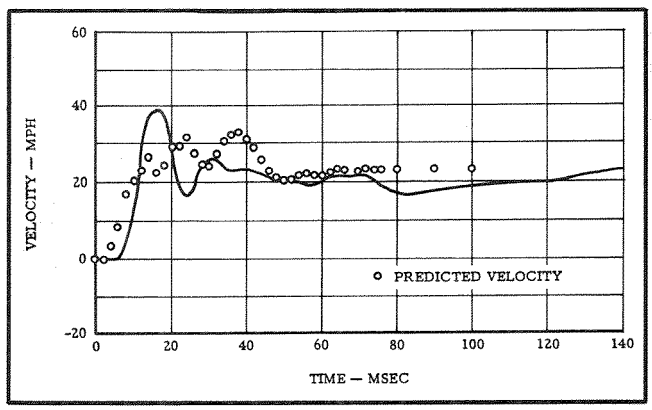


Figure 9. Comparison between predicted and test results for the Fiat 132 upper front door velocity.

scribed in Reference 6. This analysis indicated that the severity of this acceleration response often causes saturation of the instrumentation and, in effect clipped a portion of the acceleration pulse, resulting in a shift in the integrated velocity profile by a constant delta velocity. Correction requires a shift in the velocity profile to correlate with the vehicle's compartment velocity when the maximum mutual crush point is reached. As a result, direct comparison between predicted and actual data must be viewed with this problem in mind, and with common sense with regard to door dynamics. Figure 7 compares the predicted velocity profile for the Fiat 132 upper rear door interior panel to the velocity measured in the characterization test, near the center of the panel. Figure 8 shows the predicted intrusion history for the same location compared to the corresponding deflection tube data. The predicted velocity profile for the upper front door, adjacent to the driver thorax is shown in Figure 9, along with the test data just forward of the driver chest. Figure 10 compares the corresponding predicted intrusion history for this upper front door panel to deflection tube data.

The predicted velocity and intrusion profiles for the lower rear door of the Fiat 132 are shown in Figures 11 and 12, respectively, compared to their corresponding test data. Similarly, Figures 13 and 14 compare the predicted lower front door velocity and intrusion histories, adjacent to the driver pelvis, to test data.

The predicted maximum dynamic exterior crush profile of the Fiat 132 during simulation of the test tool-to-Fiat

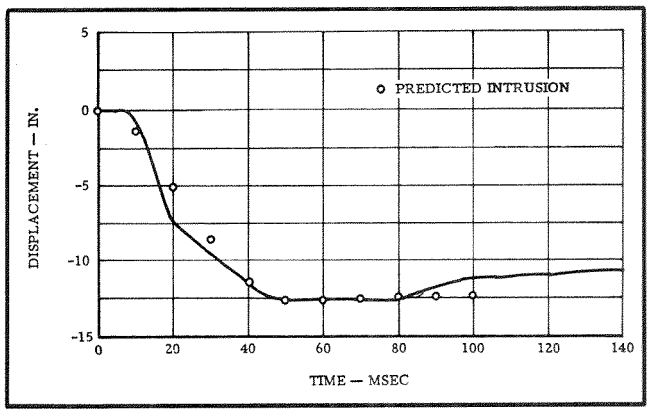


Figure 10. Comparison between predicted and test results for the Fiat 132 upper front door intrusion.

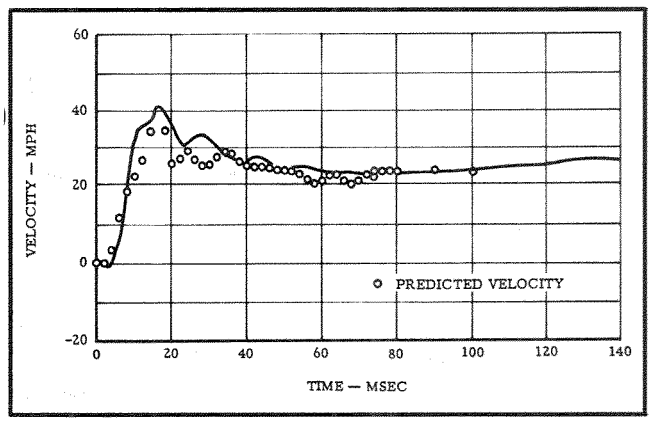


Figure 11. Comparison between predicted and test results for the Fiat 132 lower rear door velocity.

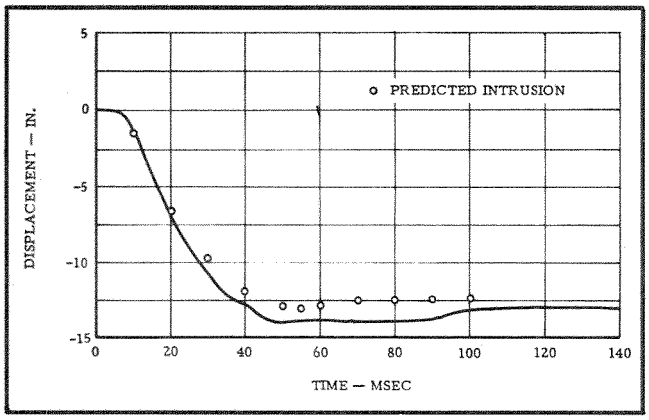


Figure 12. Comparison between predicted and test results for the Fiat 132 lower rear door intrusion.

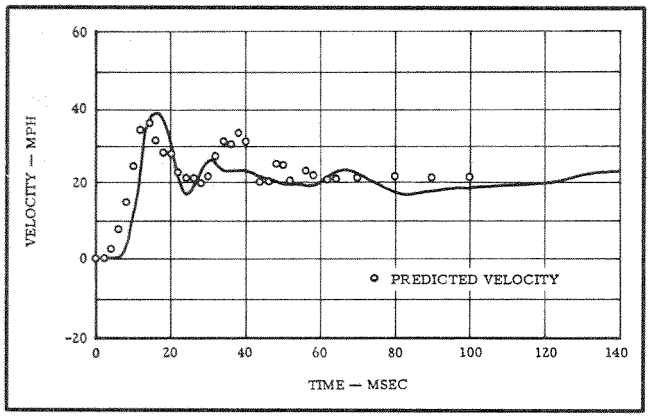


Figure 13. Comparison between predicted and test results for the Fiat 132 lower front door velocity.

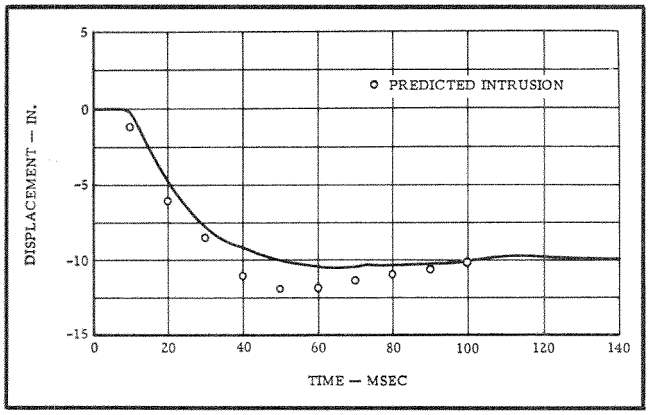


Figure 14. Comparison between predicted and test results for the Fiat 132 lower front door intrusion.

132 side characterization test is shown at two different vertical stations in Figures 15 and 16. The actual post-test measured crush at locations near each of the predicted locations are shown in each of these figures for comparison.

The analytical model to obtain these results from Program B consisted of 58 degrees of freedom, including the Fiat 132 side and the Fiat test-tool models. The results shown indicate quite respectable simulation accuracy, particularly when considering the need to improve data quality for the door interior during full-scale tests.

VEHICLE FRONT-TO-VEHICLE SIDE PREDICTIVE CAPABILITY

The validated Fiat 132 side model and the validated Fiat 132 frontal model presented in Reference 2 were input into Computer Program B along with the initial conditions associated with a Fiat 132 front-to-Fiat 132 side crash test (Reference 7) conducted under the conditions presented in Table 3. This effort is illustrated in Figure 17. The resulting simulation provided 57 degrees of freedom including both vehicle representations. Table 4 presents a summary of the predicted results compared to the actual test data.

Figure 18 compares the predicted target Fiat 132 (side model) lateral compartment response to the actual test data. Figure 19 compares the bullet Fiat 132 (frontal model) longitudinal compartment response to the actual test data. The predicted upper rear door interior velocity response is shown in Figure 20 compared to the test data near the same location. The prediction for the upper front door corresponding to that area adjacent to the driver

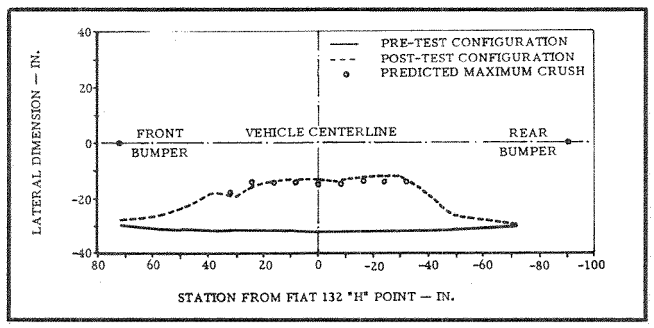


Figure 15. Comparison between predicted maximum dynamic exterior crush 28.0 inches above ground and post-test measurements for the Fiat 132.

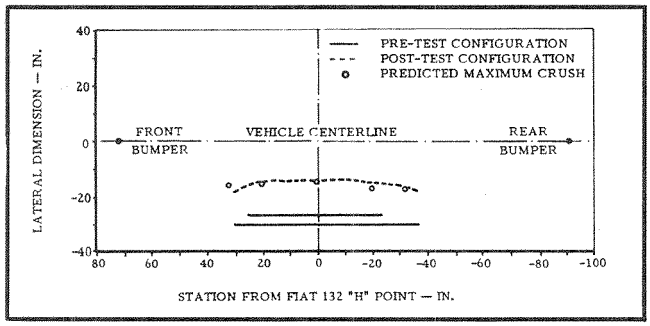


Figure 16. Comparison between predicted maximum dynamic exterior crush 10.5 inches above ground and post-test measurements for the Fiat 132.

Table 3. Fiat 132 front-to-Fiat 132 side impact test.

Fiat 132 bullet vehicle (frontal) weight (lb)	2823
Fiat 132 target vehicle (side) weight (lb)	2920
Bullet Fiat 132 impact velocity (mph)	30.1
Target Fiat 132 impact velocity (mph)	0
Impact orientation (deg)	90
Impact Alignment	Centerline of bullet vehicle aligned 6 inches forward of Fiat 132 front seat "H" point
Occupants	Both vehicles
Driver	Target vehicle
Left rear passenger	Bullet vehicle
Right front passenger	

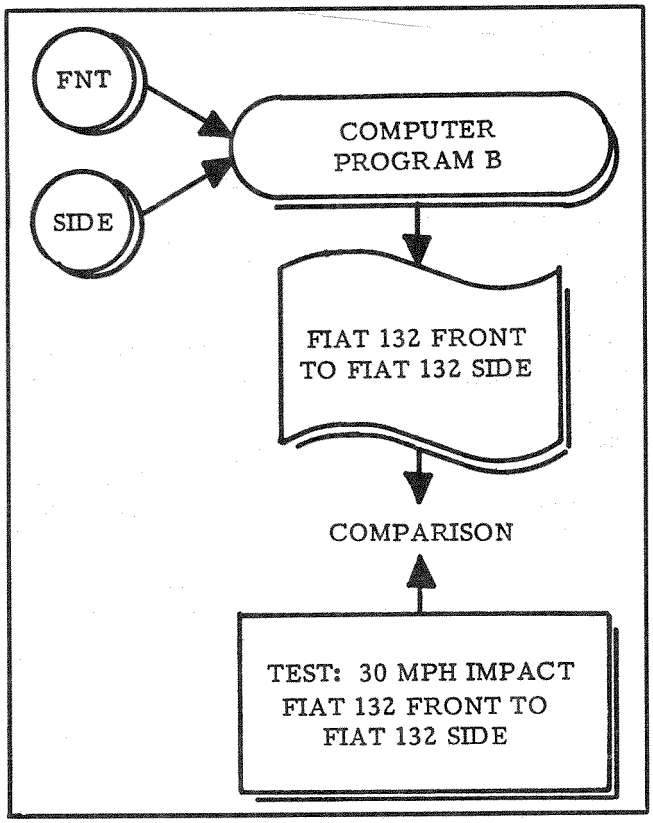


Figure 17. Flow chart for vehicle front to vehicle side prediction.

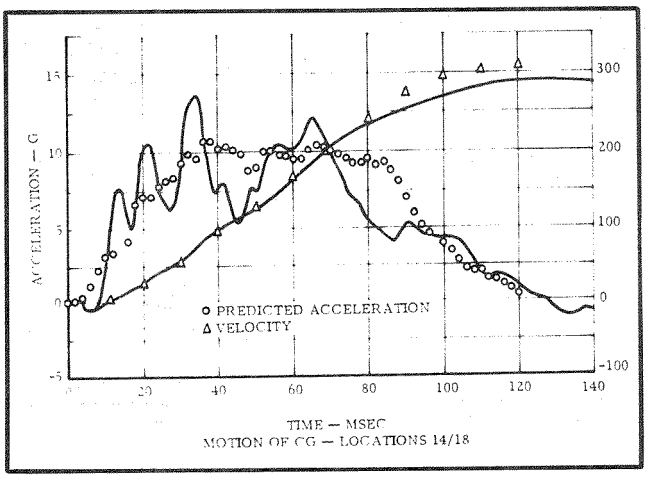


Figure 18. Comparison between predicted and test results for the Fiat 132 target compartment.

Table 4. Fiat 132 front-to-Fiat 132 side predicted crash results summary.

Parameter	Simulation	Test data
Bullet vehicle weight (lb), Fiat 132 front	2798	2823
Target vehicle weight (lb), Fiat 132 side	2912	2920
Bullet vehicle velocity (mph)	30.1	30.1
Target vehicle velocity (mph)	0	0
Maximum dynamic mutual crush (integrated acceleration) (in.)	24.3	25.3
Velocity change at 120 msec (from accelerometer data)		
Bullet vehicle (mph)	18.1	17.9
Target vehicle (mph)	17.5	16.5

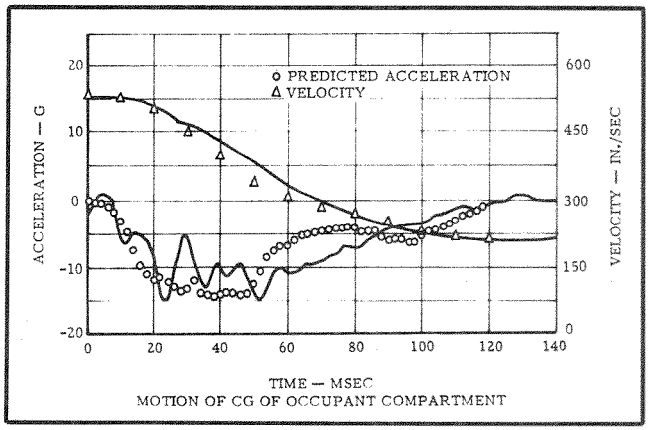


Figure 19. Comparison between predicted and test results for the Fiat 132 bullet compartment.

thorax is shown in Figure 21 along with the corresponding measured data just forward of the drivers chest.

Figures 22 and 23 compare the predicted maximum dynamic exterior side crush profiles for two different vertical locations on the Fiat 132 target vehicle to the post-test measured deformation profiles. Figure 24 presents the predicted Fiat 132 bullet vehicle maximum dynamic

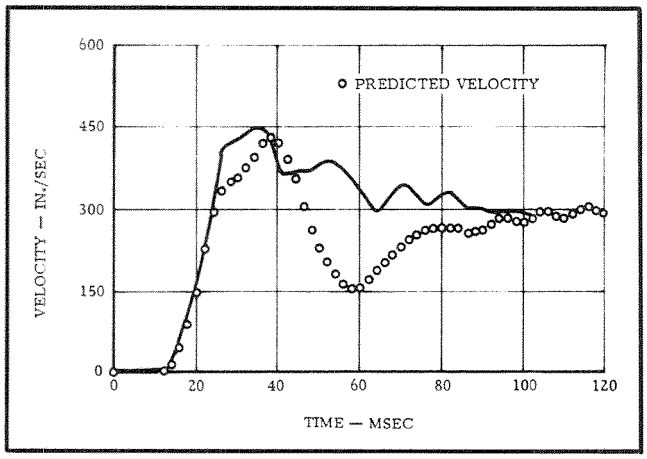


Figure 20. Comparison between predicted and test results for the target Fiat 132 upper rear door velocity.

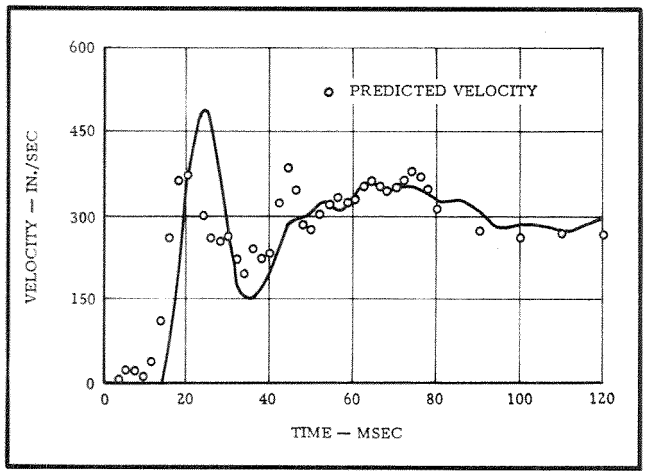


Figure 21. Comparison between predicted and test results for the target Fiat 132 upper front door velocity.

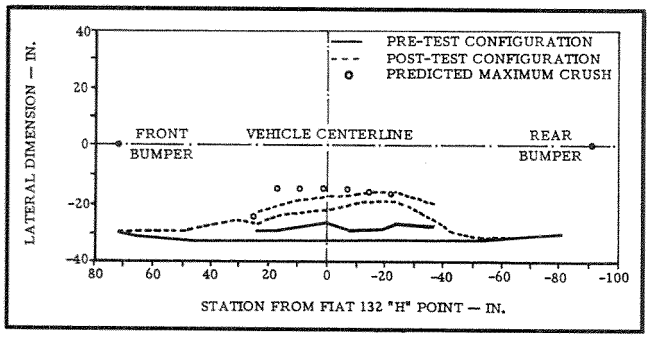


Figure 22. Comparison between predicted maximum dynamic exterior crush 28.0 inches above ground and post-test measurements for the target Fiat 132.

exterior crush at 28 inches above the ground level compared to post-crash measurements.

In presenting and comparing the predicted results with the front-to-side impact test results, test measurement locations and simulation panel locations did not perfectly coincide. Thus, comparisons are based on data for locations nearest to the simulated locations. The generation of the model from test data and the comparison of predicted results to test data highly depend on our ability to obtain and accurately measure interior door responses.

CONCLUSIONS

Previous Fiat Methodology research had concentrated on the characterization and predictive capabilities associated with front-to-front collisions. The success of this prior work was demonstrated in the results presented in a companion paper (Reference 2). The predictions for both the test tool-to-Fiat 132 front validation simulation and the Fiat 132 front-to-front simulation presented in Reference 2, were well within the accuracies obtainable within state-of-the-art in test data acquisition and manufacturing tolerances.

The work reported herein initiated an investigation into the side impact problem utilizing the Fiat Methodology, test tool, and computer analysis procedures. Although the side impact problems, from a structural point of view, are much more difficult to define than the frontal impact problem, the results obtained from the Fiat Methodology for side impact simulation were quite impressive. This was particularly true when considering the relatively short period devoted to its development as compared to the time devoted to the frontal problem. The most difficult problem faced in the development of the side structures model concerned the utilization and application of the

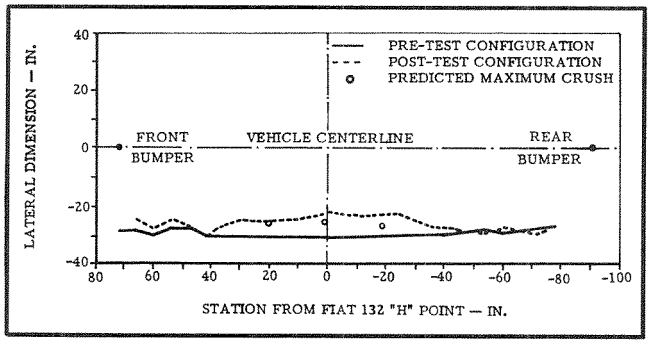


Figure 23. Comparison between predicted maximum dynamic exterior crush 28.0 inches above ground and Post-test measurements for the target Fiat 23.

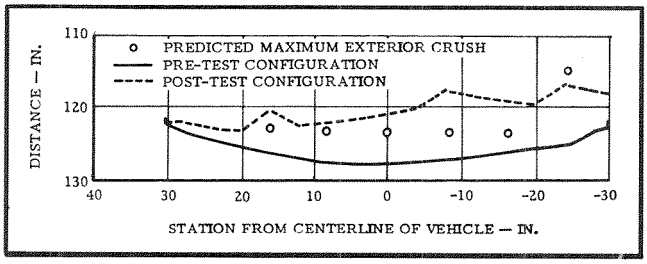


Figure 24. Comparison between predicted exterior front crush profile for a height of 28.0 inches above ground level and post-test measurements on bullet Fiat 132 vehicle.

full-scale side impact test data. Due to the present difficulties in instrumentation and acquisition of interior door data (on the impacted side), the accuracy and reliability of these data is compromised. This often required correction of door data to correlate with the laws of structural mechanics and physics. Such corrections can be somewhat subjective. Since these data are the basis by which the vehicle structure is characterized, the accuracy of the side model presented herein is somewhat impaired by these problems.

During prior Fiat compatibility research, it was found that the development of the Fiat Methodology's predictive technology was evolutionary in nature—the achievement of a certain level of model sophistication resulted in improved modeling and characterization techniques. The side impact characterization results presented in this paper represent the initial application of the Fiat Methodology to the side impact crash response problem. Continued work should provide improved data acquisition techniques and structural model representations.

The present state-of-the-art in accurate side impact characterization is primarily limited by the quality of the data. It was observed that, for those areas of characterization where the test data were representative of actual responses, the simulated responses compared well with actual responses. This does not imply that the analytical representation of the side impact model cannot or should not be improved. However, improvement could be achieved more readily with improved test data.

It is recommended, for future efforts, that a high priority be given initially to improving the instruments, data acquisition, and instrumentation procedures for obtaining the interior door response of side impacted vehicles. Many approaches have been explored in the past, including installation of accelerometers on mechanical filters and utilization of various types and brands of accelerometers. The most successful approach has been to install the accelerometer on a deflection tube which is also instrumented for measuring deflection. This provides a measurement of door response in the lateral direction only, and results in a realistic interior door acceleration profile while providing a deflection measurement which can be used to validate and/or correct the acceleration data.

The objective of the Fiat Methodology is to provide a means by which vehicle response interactions can be determined with minimal testing requirements. The ability of the Fiat Methodology to accomplish this goal in the future for the side impact environment was clearly demonstrated. The problems identified in this analysis are felt to be solvable and within state-of-the-art in electronic measurement technology.

REFERENCES

1. Shaw, L. M., Knight, R. E. and Trudgen, A. C. "Application of the Fiat Methodology to Vehicle Side Impact", Report Number to be Assigned by the National Highway Traffic Safety Administration, Contract Number DOT-HS-8-01933, Modification Number 4, Dated September 1981.
2. Shaw, L. M., Ragland, C., "Application of the Fiat Methodology to the Characterization of Vehicle Structural Responses in Frontal Impact", Ninth International Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, November 1 through 4, 1982.
3. Franchini, E., "Fiat Technical Presentation", Sixth International Technical Conference on Experimental Safety Vehicles, Washington, D.C., U.S.A., Pages 129 through 157, October 12 through 15, 1976.
4. Franchini, E., "Side Collision", Seventh International Technical Conference on Experimental Safety Vehicles, Paris, France, Pages 456 through 476, June 5 through 8, 1979.
5. "Countermeasures for Side Impact", Contract No. DOT-HS-9-02177, National Highway Traffic Safety Administration.
6. "Countermeasures for Side Impact", Monthly Progress Reports of Contract No. DOT-HS-9-02177, National Highway Traffic Safety Administration.
7. Shaw, L. M., Knight, R. E., and Rodack, M., "Report of Test 8333-1; Fiat 132 Front-to-Fiat 132 Side Impact," Contract No. DOT-HS-8-01933, Modification No. 4, Dynamic Science, Inc. Report No. 833-80-073, March 1980.

Technical Session No. 4

Accident Data Collection and Analysis

Prof. Dr. Bernd Friedel, Chairman, Federal Republic of Germany

Review of MOT Vehicle Accident Investigation in Past Seven Years

KOSHIRO ONO
Japan Automobile Research Institute, Inc.
TAKASHI SATO
Traffic Safety and Nuisance Research Institute, Ministry of Transport

ABSTRACT

In order to upgrade present motor vehicle safety standards, the Ministry of Transport initiated its motor vehicle accident "on the scene investigation" since 1973, with the purpose of collecting factual data.

This investigation is being carried out by the accident investigation teams of the Traffic Safety and Nuisance Research Institute of the Ministry of Transport and Japan Automobile Research Institute in cooperation with the National Police Agency and Medical Association of Japan. Regions of Ishikawa, Saitama, Ibaraki and Okayama Prefectures were selected as investigation areas.

Particular accidents were subject to investigation according to the following: a) aspects of accident reflected on the current safety standards were inadequate; and b) occupant injuries were presumably caused by motor vehicle interior parts. Every year approximately 50 cases were investigated, and vehicle accidents covered by this investigation up to 1979 consisted of vehicle to vehicle head-on collisions (39 cases), side collisions (92 cases), rear-end collisions (76 cases), single vehicle collisions (42 cases) and vehicle to motorcycle, bicycle or pedestrian accidents (147 cases).

Methodology and results of this investigation will be presented together with the summary of 249 cases of vehicle to vehicle and single vehicle to object accidents. For passenger cars and light vans, the relationship among impact speed, vehicle interior parts/components and occupant injuries by the principal direction of force are derived. Studies have been also made on effects of injury reduction measures according to the relationship between the EBS (Equivalent Barrier Speed) and occupant injuries, by means of vehicle model year classification.

INTRODUCTION

In September, 1972, the Council for Transport Technics submitted its first recommendation entitled "Technical Measures for Safety of Motor Vehicles—First Program Plan for Future Motor Vehicle Safety Standards" [1] to the MOT (the Ministry of Transport). Based on this recommendation, the MOT initiated its investigation and analysis in 1973 regarding actual conditions of motor vehicle accidents, and has been striving for the improvement of motor vehicle safety through detailed analyses for the clarification of relationship between vehicle construction/interior parts and components and injuries of human body, and the reinforcement and evaluation of future safety standards.

Situations surrounding motor vehicles, however, changed drastically since the first recommendation due to the popularization of motor vehicles and expansion of highway systems, etc. In this regard, the Council for Transport Technics submitted its second recommendation in October, 1980, in which the Council pointed out that the ongoing system employed and contents of the investigation and analysis done so far should be improved and strengthened [2].

This investigation and analysis have been continued by the MOT as one of the measures taken in series in order to attain objectives and targets in the first and second recommendations [3]. Accidents covered by this investigation for a period of seven years from 1973 to 1979 totaled to 396 accidents consisting of 207 vehicle to vehicle (four-wheeler to four-wheeler) head-on, side and rear-end collisions, 42 single vehicle (four-wheeler) accidents and 147 four-wheeler to motorcycle, moped, bicycle or pedestrian accidents.

In this paper, the present status of the investigation and analysis carried out since 1973 will be given, and the outline of findings of the investigation on 249 accidents involving 486 vehicles, out of the total accidents covered by the investigation, will be described. In addition to the above, investigations were made for passenger cars and light vans regarding the distribution of striking speeds, the tendency of occupant injuries against the equivalent barrier speeds (the speeds converted into corresponding values for barrier impact tests), relationship between vehicle interior parts/components and occupant injuries, and the relationship between vehicle interior deformations and occupant injuries, based on the principal direction of force by general area of damage, the striking speeds and/or the equivalent barrier speeds. Studies have been also made on effects of injury reduction measures according to the relationship between the equivalent barrier speeds and occupant injuries, by means of vehicle model year classification.

PRESENT STATUS OF THE INVESTIGATION AND ANALYSIS

This investigation is being carried out by joint efforts of the accident analysis team of the Traffic Safety & Public Nuisance Research Institute of the MOT and the accident investigation team of Japan Automobile Research Institute (JARI) under the joint cooperation of National Police Agency, the Ministry of Construction, Japan Medical Association, Japan Automobile Manufacturers Association (JAMA), etc.

(1) Objectives of Investigation: To grasp actual conditions of traffic accidents accurately, and to make detailed analyses on the correlation between damageable objects attributable to the vehicle construction and injured physical regions of occupants, severity of injuries, etc. in order to contribute to the reinforcement of motor vehicle safety standards through findings of the investigation and analysis. Further, re-evaluating each item of the safety standards already put into effect, and verifying the effects of such standards in order to feed back the results of such studies to the safety standards.

(2) Areas and Durations of Investigations: In investigating accidents, it is necessary to carry out investigations at actual scenes of accidents in order to gather necessary information of actual accident conditions and check on contents and severity of injuries, etc. in addition to the detailed investigation on vehicle damage conditions. Due to the above, areas and duration of such investigations were set on a premise that thorough cooperation would be given by local police, medical associations, etc. Areas covered between 1973 and 1979 were Ishikawa, Saitama, Ibaraki and Okayama Prefectures. The duration of investigation was set as one month between August and September of each year, which was repeated for consecutive two years for each area.

(3) Types of Accidents Subject to Investigation and Number of Investigations: Casualties and vehicle damages of passenger cars and trucks were subject to investigation. Emphasis was placed on the investigation on accidents in which the relationship between the vehicle construction/interior parts and components and injuries appeared to be significant, and accidents that seemed to be useful for the verification of effects of motor vehicle safety standards and regulations. The number of investigations per year was set as 50 to 60.

(4) Investigation System: An investigation team consisting of 5 to 6 persons stayed at the designated police station in each area throughout the investigation period, from 8 o'clock in the morning to 6 o'clock in the evening. No investigation was made at night. Such investigation was, therefore, in the form of "scene" investigation at the site of accident that occurred during daytime, or "trace" investigation for accident that had occurred during the previous night. In case of a scene investigation, the local police informs the investigation team that an accident has occurred, then the team goes to the accident scene to check on the accident conditions so as to decide whether the accident should be included as an object of the investigation. At the accident scene, traffic and road conditions as well as accident vehicles will be investigated, and people involved in the accident will be interviewed, etc. If any casualty has occurred, the team goes to the hospital and checks on the contents, severity, etc. of injuries. In case of a trace investigation, the local police informs the team that an accident occurred the previous night, and the team considers whether the accident should be included in the investigation. Then the team goes to the accident scene, traffic and road environments are checked, and accident vehicles are investigated at the repair shop, etc. to which the vehicles were moved. Interviews are then made at the hospital with injured occupants and doctors in charge, in order to check contents, severity, etc. of injuries. The outline of accident investigation system on the scene is shown in Figure 1.

(5) Investigation Items and Data Collection Form: In order to obtain effective data for the safety of motor vehicles and injury reduction measures in particular, it is necessary to check on behaviors of vehicles before and after the accident as well as damages of vehicle construction/parts and components, in order to make a detailed analysis on the relationship between the injuries of occupants, etc. and the parts or components which injured the occupants upon collision. In this regard, investigation items shown in Figure 2 are required. The data collection forms are made available in seven kinds so that such forms may allow not only the investigation of conditions of vehicle construction/parts and equipment, determination of the correlationship between the parts and components which injured the occupants and the physical regions of occupants that are injured, but also traffic environments upon accident. The outline of the seven kinds of data collection forms is as follows.

OUTLINE OF ALL VEHICLES SUBJECT TO THE INVESTIGATION

Number of Accidents Subject to the Investigation Classified by Fiscal Years and Areas

The number of accidents classified by fiscal years and areas is shown on Table 1. As for the number of accidents, some differences are observed from year to year, ranging from 51 accidents in 1974 to 65 accidents in 1976, which are attributed to different numbers of accidents in different areas. Numbers of accidents classified by types of

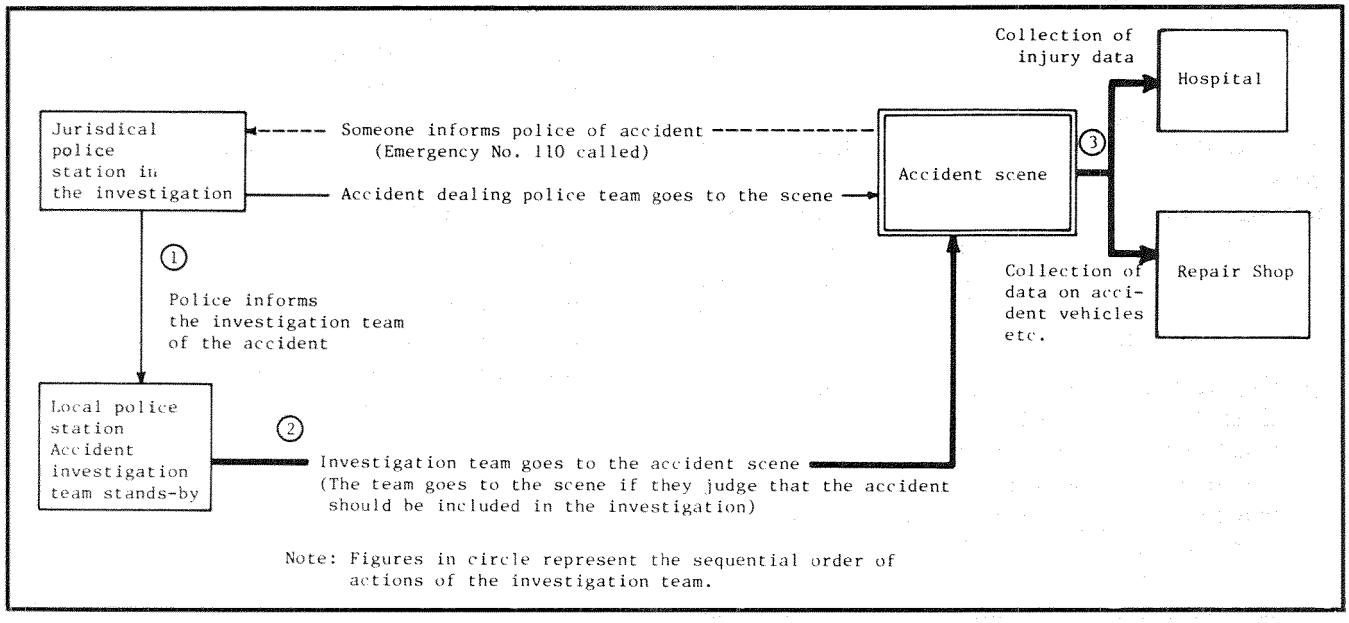


Figure 1. Outline of accident investigation system on the scene.

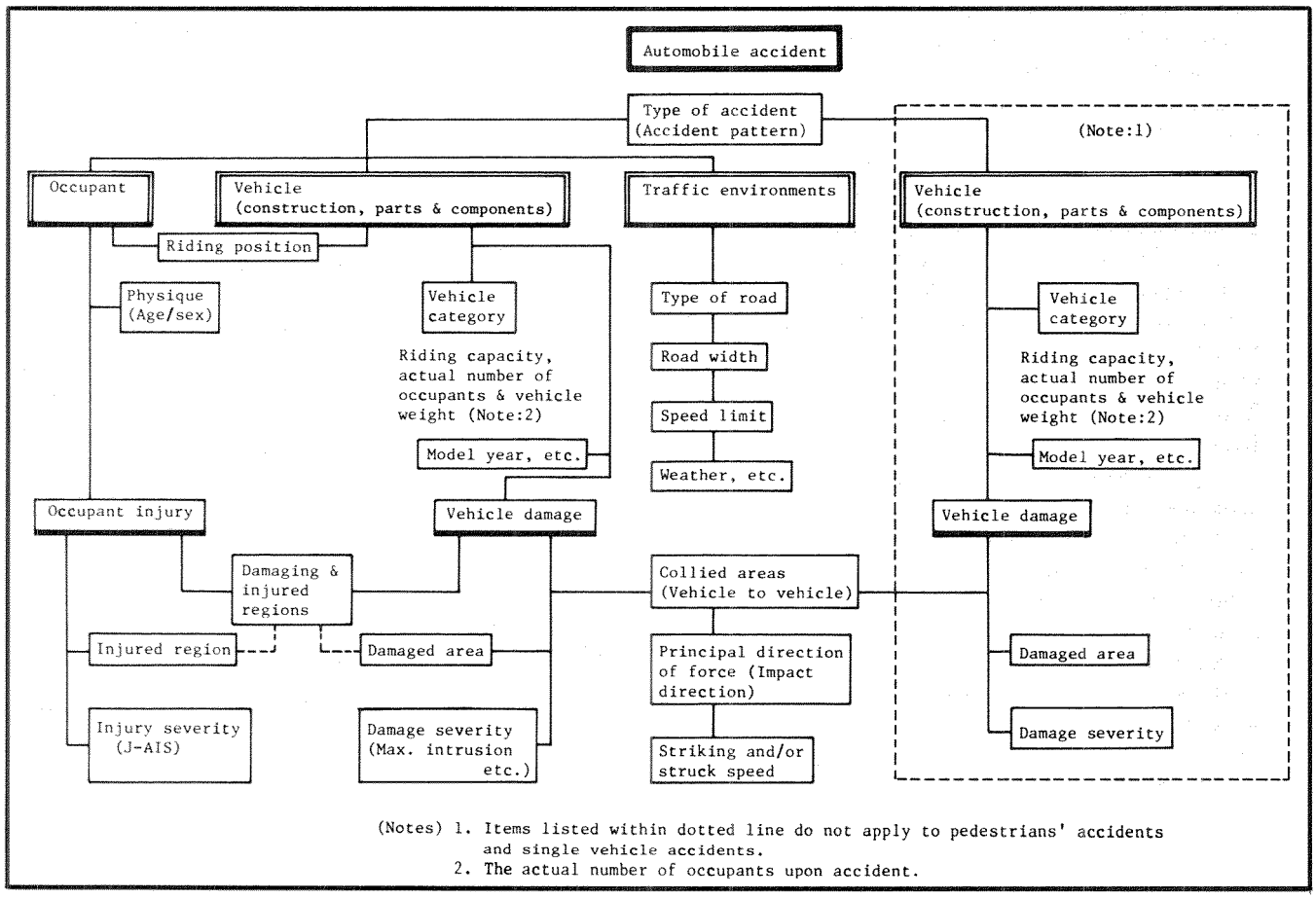


Figure 2. Elements of motor vehicle accident analysis mainly for injury reduction.

Table 1. Outline of all accidents investigated in past seven years.

Items \ Year			'73	'74	'75	'76	'77	'78	'79	Total
Investigation area			Kanazawa City Ishikawa Pref.		Ageo City Saitama Pref.		Tsuchiura City Ibaragi Pref.		Okayama City Okayama Pref.	
No. of accidents investigated	Vehicle to Vehicle (Four-wheeler to four-wheeler)	Head-on collision	6 (10.3%)	3 (5.9%)	2 (3.6%)	4 (6.2%)	9 (15.0%)	14 (25.9%)	1 (1.9%)	39(9.8%)
		Side collision	9 (15.5%)	14 (27.5%)	10 (18.2%)	17 (2.6%)	16 (26.6%)	16 (29.6%)	10 (18.9%)	92(23.2%)
		Rear-end collision	27 (46.6%)	5 (9.8%)	12 (21.8%)	7 (10.8%)	9 (15.0%)	9 (16.7%)	7 (13.2%)	76(19.2%)
	Single vehicle accident		2 (3.5%)	7 (13.7%)	3 (5.5%)	4 (6.2%)	6 (10.0%)	11 (20.4%)	9 (17.0%)	42(10.6%)
	Four-wheeler to motorcycle, moped or bicycle		4 (6.9%)	8 (15.6%)	24 (43.6%)	22 (33.8%)	13 (21.7%)	3 (5.6%)	20 (37.7%)	94(23.7%)
	Vehicle to pedestrian		10 (17.2%)	14 (27.5%)	4 (7.3%)	11 (16.9%)	7 (11.7%)	1 (1.8%)	6 (11.3%)	53(13.5%)
	Total		58 (100%)	51 (100%)	55 (100%)	65 (100%)	60 (100%)	54 (100%)	53 (100%)	396(100%)
Vehicle, etc. involved accidents (units)	Passenger cars		70	55	51	62	59	65	42	404
	Light vans		19	10	10	10	14	2	7	72
	Trucks		15	10	23	26	28	32	23	157
	Motorcycles & mopeds		2	7	10	11	9	2	14	55
	Bicycles		2	1	14	11	4	1	6	39
	Others		2(Bus & fire truck)	-	-	1 (Bus)	-	1 (Bus)	-	4
	Total		110	83	108	121	114	103	92	731
Those involved in accidents(persons)	Drivers & other occupants		173	127	151	182	163	181	92	1069
	Pedestrians (including motorcycle/moped riders & cyclists)		17	25	31	35	21	4	27	160
	Total		190	152	182	217	184	185	119	1229
Casualties (Persons)	No. of persons killed (fatalities)		1 (0.5%)	1 (0.6%)	8 (4.4%)	12 (5.5%)	5 (2.7%)	6 (3.3%)	6 (5.0%)	39(3.2%)
	No. of persons injured		81 (42.7%)	86 (56.6%)	98 (53.8%)	89 (41.0%)	97 (52.7%)	126 (68.1%)	71 (59.7%)	648(52.7%)
	No. of intact occupants		108 (56.8%)	65 (42.8%)	76 (41.8)	116 (53.5%)	82 (44.6%)	53 (28.6%)	42 (35.3%)	542(44.1%)
	Total		190 (100%)	152 (100%)	182 (100%)	217 (100%)	184 (100%)	185 (100%)	119 (100%)	1229(100%)

accidents are as follows; vehicle to vehicle (four-wheeler to four-wheeler) head-on collisions 92, rear-end collisions 76, vehicle single accidents 42, four-wheeler to motorcycle, moped or bicycle 94, and vehicle to pedestrian accidents 53, which totalled to 396 accidents. Number of vehicles involved in accidents is 731, while the number of persons involved in accidents is 1,229. Data classified by years and types of accident show that rear-end collisions in Ishikawa Prefecture in 1973 are greater in number than any other prefecture and year. This is explained by the fact that Ishikawa Prefecture is located in the Hokuriku District (northern part of Japan facing the Sea of Japan) and the investigation was made in January when roads were snowy and vehicles were apt to slip, easily causing rear-end collisions. Taking account of the situation mentioned above, investigations in 1974 and subsequent years were done during summer from August to September.

Number of Vehicles Classified by Principal Direction of Impact Force and General Area of Damage

While accidents investigated in the past seven years including accidents of motorcycle, mopeds, bicycles and pedestrians that amounted to 396, accidents of two-wheelers and pedestrians are excluded where as only four-wheeler to four-wheeler accidents and single four-wheeler accidents are included in the analysis of this section and that of the following section in order to analyze the relationship between vehicle structures and occupant injuries.

Numbers of vehicles and component ratios classified by principal direction of impact force and general area of damage are shown in Figure 3. Frontal collisions (11, 12 and 01 o'clocks in terms of principal force of direction and general area of damage) amounted to 276 vehicles (56.9%), rear-end collisions (05, 06 and 07 o'clocks) amounted to 87 vehicles (17.9%), right side collisions (02, 03 and 04 o'clocks) amounted to 50 vehicles (10.2%), left side collisions (08, 09 and 10 o'clocks) amounted to 44 vehicles and others including roll-overs amounted to 29 vehicles (5.9%). The comparison by the principal direction of force and general area of damage shows that frontal and rear-end collisions account for about 75% of the total. For the classification of principal direction of force and general area of damage, "Collision Deformation Classification (CDC)" by SAE J224 was employed [6]. In the CDC classification, the primary collision and the secondary collision are distinguished for both striking vehicle and struck vehicle, but the classifications are all made by the primary collision in Figure 3.

Occupant Injuries Classified by Principal Direction of Force and General Area of Damage

The number of occupants on the 486 vehicles concerned amounts to 844. Numbers of occupants and component

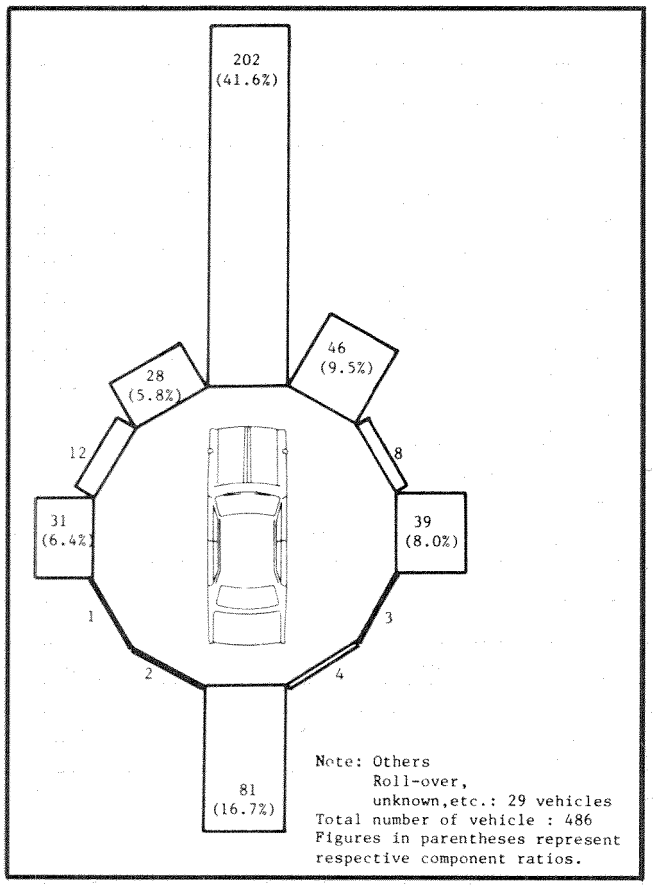


Figure 3. Number of vehicle and component ratios classified by principal direction of force & general area of damage.

ratios of injury severity scores classified by principal direction of force and general area of damage are shown in Figure 4. Numbers of occupants injured and rates of injuries according to the above classification are as follows; in the case of frontal collisions, those injured amounted to 284 persons against the total number of 472 occupants, accounting for 60% or so; for rear-end collisions, those injured were 88 persons out of 132 occupants, accounting for about 67%; for right side collisions, 69 persons out of 90 occupants, accounting for about 77%; in the case of left side collisions, 48 persons out of 81 occupants, accounting for 59% or so; and for others including roll-over accidents, 35 persons out of total occupants of 68 persons, accounting for about 52%. Comparisons of injury rates show that rates of occupants injured by right side and rear-end collisions are greater by 5 to 15% than those injured by frontal collisions. Severities of occupant injuries in terms of the injury rates of severe injuries exceeding ISS 21 are also compared as follows: frontal collisions, 12% or so; rear-end collisions, approximately 1%; right side collisions, about 17%; and left side collisions, 7% or so, indicating that the incidence rate of occupant severe injuries is the smallest for rear-end collisions.

On the other hand, the comparison of numbers of injured occupants shows that occupants injured by frontal and rear-end collisions amount to 372 against the total 524 occupants injured, accounting for 71% or so, while right and left side collisions account for 22% of the total 117 injured occupants.

ANALYSIS OF ACCIDENTS IN WHICH PASSENGER CARS AND LIGHT VANS WERE INVOLVED

In this section the relationship between motor vehicle construction/interior parts and components and occupant injuries will be analyzed based on the principal direction of force by general area of damage, striking vehicle speeds and equivalent barrier speeds. Small passenger cars, light vans and ordinary passenger cars with relatively high vehicle and occupant component ratios (68% of all vehicles, and 73% of occupants) without substantial differences in vehicle weight and construction are focussed for this analysis.

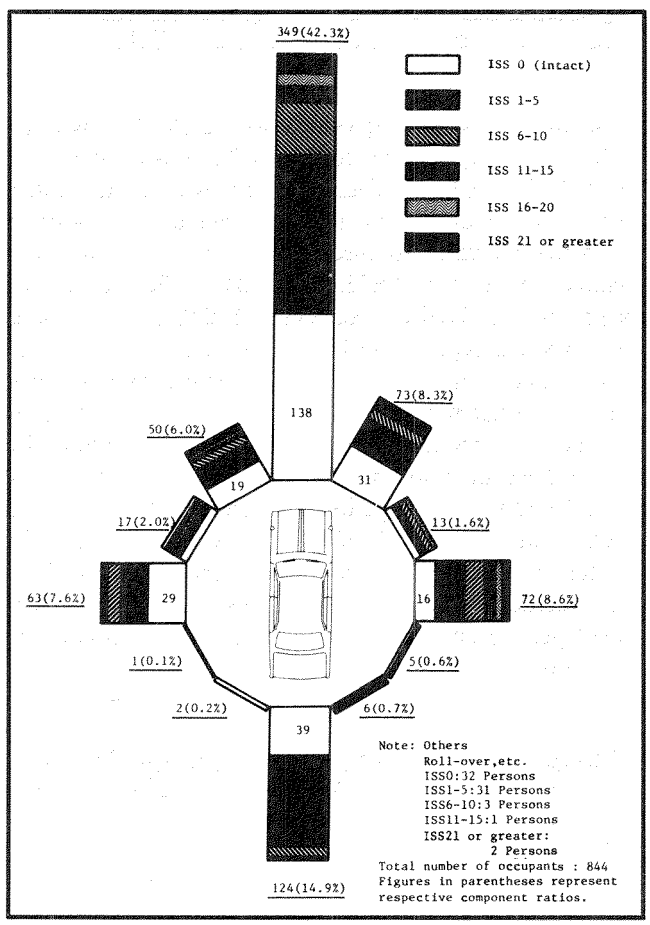


Figure 4. Number of occupants and component ratios of injury severity scores classified by principal direction of force and general area of damage.

Distribution of the Striking Vehicle Speeds

Cumulative incidence rates of striking speeds for small passenger cars involved in frontal collisions (11, 12 and 01 o'clocks) according to the classification by kinds of vehicles are shown in Figure 5. The speeds shown in the figure represent speeds immediately before collisions, and the figure is an analysis based on the lengths of vehicle slip traces before and after the collision, angle of collision, amounts of vehicle damages, etc. The table in the figure indicates numbers of incidences classified by striking vehicle speeds. All vehicles involved in frontal collisions are either small passenger car/light van or ordinary passenger car (including single vehicle frontal collisions). For side and rear-end collisions, the principal direction of force of vehicle is either 11, 12 or 01 o'clock. In case of multiple collisions, the primary collision is subject to the analysis. Data of 168 vehicles involved in frontal collisions classified by types of accidents are arranged and the cumulative incidence rates of striking speeds are shown by the dotted line. The speed around 50% line of overall cumulative incidence rate of impact speeds is approximately 30 km/h, while the tendency of the distribution of striking vehicle speeds classified by types of accidents is as stated below.

TOA	ID	SVS(km/h) 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90	Total
HC	FE	8 2 2 3 4 9 5 9 2 9 3 2 3 2	63
SC	FE	2 7 5 9 4 11 4 4 4 6 3 6 1 1 1	68
RC	FE	2 10 2 5 2 5 4 2 1 3 1	37

SVS : Striking Vehicle Speed
ID : Impact Direction FE : Front end
TOA : Types of Accidents
HC : Head-on collisions (including single vehicle accidents)
Vehicles with their front ends collided against other vehicles
SC : Side collisions
Vehicles with their front ends collided against sides of other vehicles
RC : Rear-end collisions
Vehicles with their front ends collided against rear ends of other vehicles

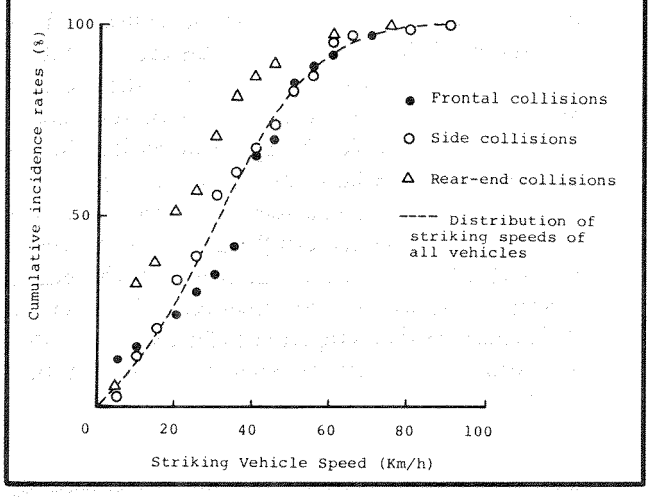


Figure 5. Cumulative incidence rates of striking speeds of frontal collision vehicles (11, 12 and 01 o'clocks) consisting of small passenger cars and light vans and ordinary passenger cars classified by types of accidents.

1) Frontal collisions (including single vehicle accidents) amount to 63 vehicles, and the striking vehicle speed on the 50% line of the cumulative incidence rate is 40 km/h or so.
2) Of all side collisions, vehicles with their front ends collided against sides of other vehicles amount to 68. At the cumulative incidence rate of 50% line, the striking vehicle speed is about 30 km/h which approximates with the distribution tendency of the overall striking speed.
3) Of all rear-end collisions, vehicles with their front ends collided against rear-ends of other vehicles amount to 37, and the striking speed on the 50% line of the cumulative incidence rate is 20 km/h or so.

Severities of Occupant Injuries and Equivalent Barrier Speeds

It is not appropriate to compare severities of occupant injuries based on the quantity of impact on the vehicle caused by collision and the injury of the occupant, using the striking speed alone, since the quantity of impact on each vehicle differs according to the direction of impact, weight of the other vehicle, rigidity of the struck member, etc. even if the striking speed is the same. In this section, the relationship between the quantity of impact on the vehicle and the injury severity will be studied, for which equivalent barrier speeds converted for barrier impact tests that represent actual effective values of striking speeds are used as an indication for the quantity of impact on the vehicle. Equivalent barrier speeds are calculated by using relationship among momentum conservation law, kinematic energy conservation law, vehicle deformation and the quantity of energies absorbed.

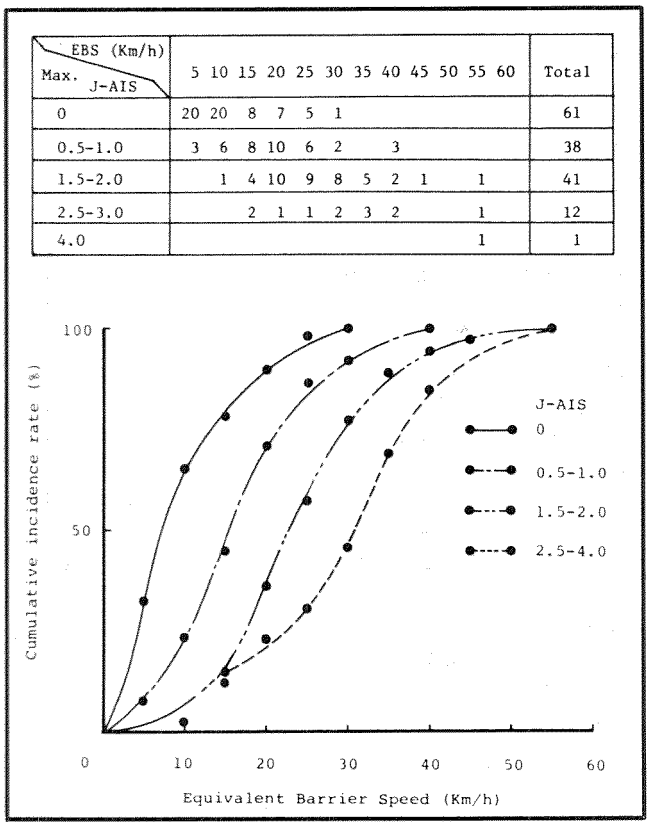
Figure 6 shows the relationship between the severity of the maximum injury of the occupants of small passenger cars, ordinary passenger cars and light vans, and the cumulative rate of equivalent barrier speeds. These are 153 vehicles (occupants concerned are 153 drivers), out of all vehicles shown in Figure 5, for which equivalent barrier speeds are calculated. The table in the figure indicates the number of incidences of the maximum injury (J-AIS). From this figure, it is found that the occupant injury tendency against the equivalent barrier speeds is as follows.

1) In a collision where the driver is not injured, the speed at which the cumulative rate reaches 50% is 7 km/h or so. Likewise, the speed is 15 km/h for minor injuries (J-Ais 0.5 to 1.0 or AIS 1), 23 km/h or so for moderate injuries (J-AIS 1.5 to 2.0 or AIS 2), and about 30 km/h for severe or more serious injuries (J-AIS 2.5 to 4.0 or AIS 3 to 4).

2) Although severely injured occupants are found when the equivalent barrier speed reaches approximately 15 km/h, a clear tendency is not determined as the number of severely injured occupants are as few as 13.

Vehicle Interior Parts/Constructions and Severity of Occupant Injuries

The relationships between vehicle interior parts/constructions and severity of occupant injuries were analyzed for small passenger cars only. For injuries of 534 occupants of 285 small passenger cars, the severity of injuries and incidence rate classified by parts/construction of different portions in vehicle compartments are shown in Figure 7. Occupants injured upon accidents amount to 363, while the total number of injuries amounts to 884, with the average number of injuries per person being 2.4. Of parts and components which injured occupants in vehicle compartments, the front portions have the highest rate. Figure 8 shows results of the investigation on injury incidence rate for each part of the front portion. From this figure, it is found that instrument panels, steering assemblies, etc. account for the majority.



EBS (Km/h) / Max. J-AIS	5	10	15	20	25	30	35	40	45	50	55	60	Total
0	20	20	8	7	5	1							61
0.5-1.0	3	6	8	10	6	2		3					38
1.5-2.0		1	4	10	9	8	5	2	1		1		41
2.5-3.0			2	1	1	2	3	2			1		12
4.0											1		1

Figure 6. Maximum J-AIS of drivers of small passenger cars, light vans and ordinary passenger cars and cumulative incidence rates of equivalent barrier speed for frontal collision (11, 12 and 01 o'clocks) vehicles.

Secondly, the relationship between the equivalent barrier speed and the severity of injury is studied for instrument panel, steering assembly (wheel and spoke) and windshield, respectively. Vehicles subject to this analysis include ordinary passenger cars and light vans, in addition to small passenger cars. Vehicles of such frontal collisions amount to 75, with 117 front seat occupants without seat belts.

1) Injuries caused by instrument panels
The relationship between the injuries caused by instrument panels and equivalent barrier speeds is shown in Figure 9. The number of occupants injured by instrument panels amount to 26 drivers and 24 occupants sitting by drivers' side in 38 vehicles. Injuries started occurring at the equivalent barrier speed of 10 km/h, some severe injuries (J-AIS 2.5 or AIS 3) are found where the speed exceeded 25 km/h. In this figure, a comparison is made between drivers and those sitting beside the driver had some severe injuries than the drivers.

2) Injuries caused by steering assemblies
The relationship between the injuries caused by steering assemblies and equivalent barrier speeds is shown in Figure 10. The number of occupants injured by steering assemblies amounts to 48 drivers out of total 61 drivers in 61 vehicles. In this figure, a comparison is made between vehicles with steering energy absorption devices and vehicles without such devices, in order to clarify the effects of such devices. Injuries started occurring at the equivalent barrier speed of 5 km/h, and one severe injury case (3.0 for both J-AIS and AIS) is found at the speed of 15 km/h. The latter case was the fracture of a knee bone which collided against the steering column from a lateral direction. The activation of steering energy absorption is observed at the equivalent barrier speed of 20 km/h. Some cases are also found in which occupants were left intact at the speed of 40 km/h owing to the activation of the energy absorption device. At the speed of 55 km/h, occupants' injuries where the energy absorption devices activated remained relatively minor as J-AIS 0.5 and 2.0, while occupant's injury was as severe as J-AIS 3.0 due to the non-activation of the energy absorption device. In some other cases, however, no differences are found regardless of activation or non-activation of such devices, where the equivalent barrier speeds were 20 to 35 km/h.

3) Injuries caused by windshields
The relationship between the injuries caused by windshields and equivalent barrier speeds is shown in Figure 11. Those injured by windshields amount to 20 drivers and 19 occupants sitting beside drivers in 31 vehicles. Injuries started occurring at the equivalent barrier speed of 15 km/h, and two severe

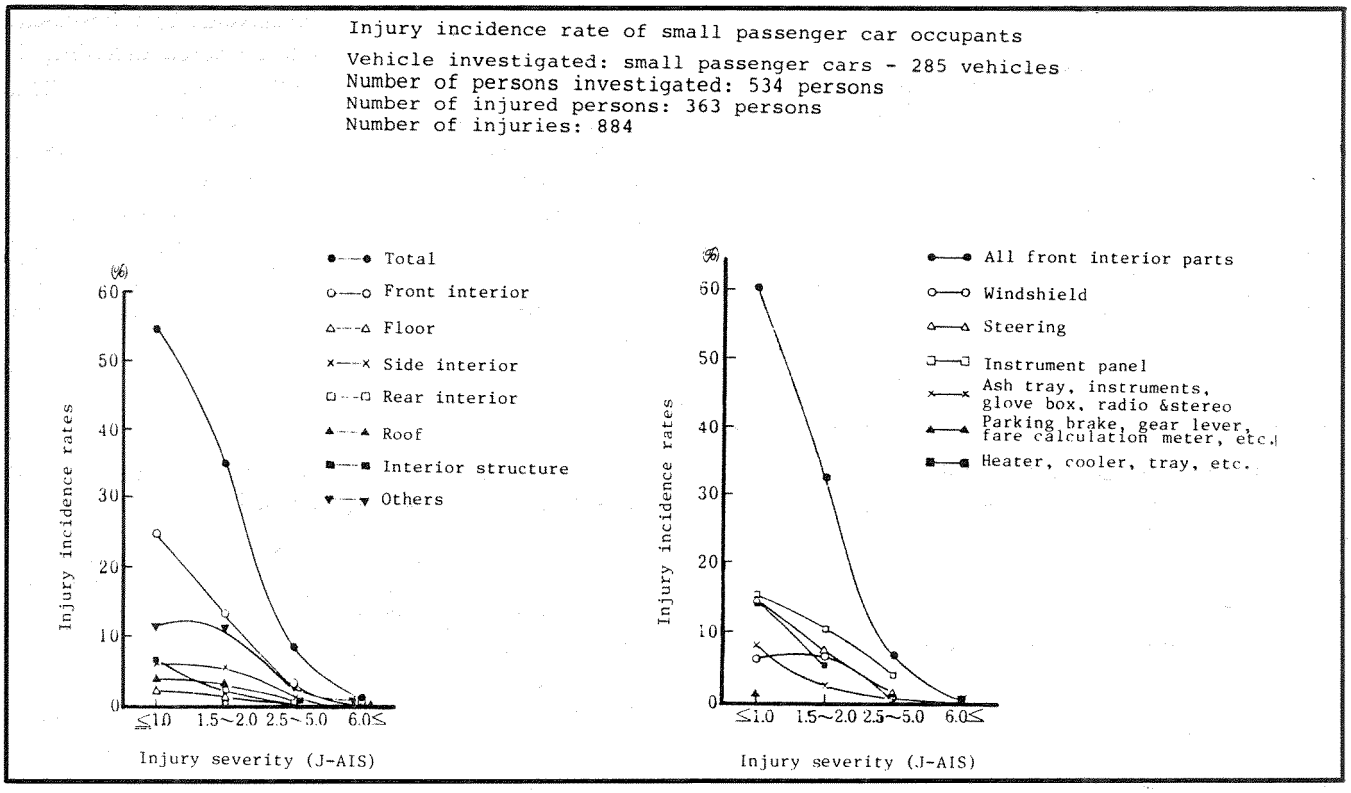


Figure 7. Injury severity and injury incidence rates classified by interior parts or components of small passenger cars.

Figure 8. Injury severity and injury incidence rates classified by vehicle interior front parts or components of small passenger cars.

injury cases (J-AIS 2.5) are found at the speed exceeded 27 km/h. In this figure, a comparison of injuries between drivers and occupants sitting beside drivers, and another comparison between different kinds of windshields (zone tempered windshield, ordinary PVB laminated and HPR laminated windshields) are shown. In case of the former comparison, no significant difference is found, whereas the latter comparison is hardly valid since the number of data is inadequate for HPR laminated windshield (2 incidences and 2 occupants) and ordinary PVB laminated windshield (3 incidences and 5 occupants) as the majority of windshield were made of zone tempered windshield.

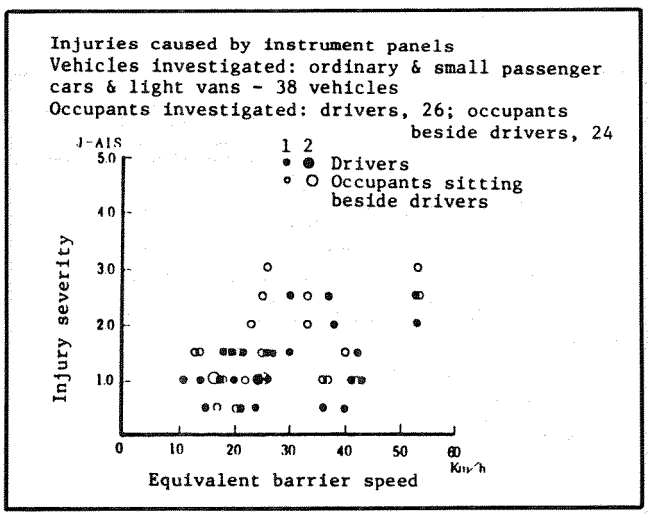


Figure 9. Injury severity of front seat occupants injured by instrument panels of frontal collision (11, 12 & 01 o'clocks) vehicles.

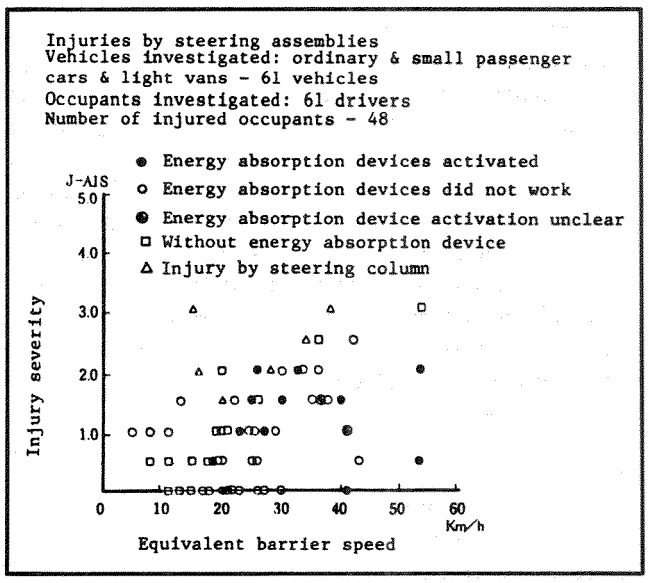


Figure 10. Injury severity of drivers injured by steering assemblies of frontal collision (11, 12 & 01 o'clocks).

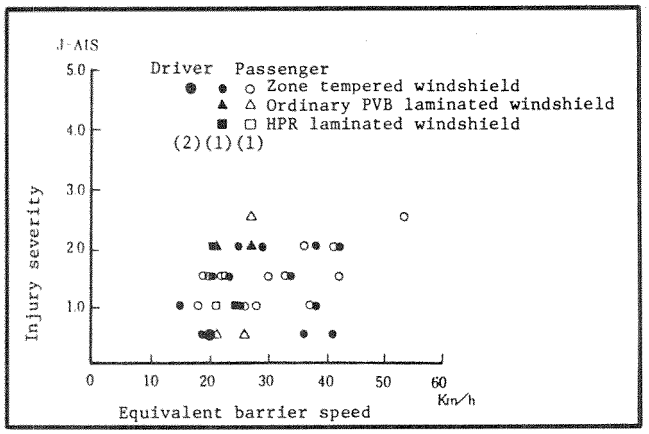


Figure 11. Injury severity of front seat occupants injured by windshields of frontal collision (11, 12 and 01 o'clocks) vehicles.

Vehicle Interior Deformations and Occupant Injuries

Upon investigation of the safety of a vehicle at the time of collision, it is often judged by the relationship between the occupant injury incidence rate and actual effective value of the collision speed. In order to confirm the effect of vehicle interior deformations on the injury severity of occupants in addition to the above, the maximum intrusion rate in the vehicle compartment is used as an indication and the relationship between the occupant injury severity and the equivalent barrier speed is analyzed here. Vehicles subject to this analysis are 97 small passenger cars and light vans (97 drivers) which collided against front ends of other vehicles with the principal direction of force of 12 o'clock, for which deformations occurred at the portion in front of the driver. Injury Severity Score is also used as another indication for occupant injuries, and the classification of severity scores is as follows: intact and minor injuries, ISS 0 to 5; moderate injuries, ISS 6 to 15; severe or serious, ISS 16 or greater.

The relationship between the maximum intrusion/equivalent barrier speeds and the occupant injury severities of frontal collision vehicles is shown in Figure 12. In case of vehicles without interior deformations, a proportional relationship tends to exist between the speed and the injury severity. In cases where the equivalent barrier speeds exceed 35 km/h, interior deformations are found in most vehicles, and the tendency of occupant injury severities is apt to change according to the degree of vehicle compartment deformations. A comparison between injury severities of vehicles with or without interior deformations is as follows: a) For vehicles without interior deformations around the equivalent barrier speed of 35 km/h, majority of the severities of occupant injuries are in the range of ISS 0 to 5 (minor injuries), while injury severities of ISS 6 or greater are found only for 11 occupants out of the total 89 occupants. b) For vehicles with interior deformations and the speed exceeding 35 km/h, on the other hand, moderate and severe injuries of ISS 6 or greater tend to increase, which amount to 5 occupants out of the total 6 occupants. As for interior deformations, one case of such deformations is found at the speed of 20 km/h or so, and slightly injured occupants with ISS of 0 to 5 are found at the speed of 40 km/h with the maximum intrusion of 10 cm. The equivalent barrier speed range for the occurrence of severe injuries of ISS 16 or greater is approximately 35 km/h or greater.

Injury Severities and Equivalent Barrier Speed Classified by Vehicle Model Years

From 1973 or so, vehicles produced in Japan began to reflect safety concepts and technology developed for Experimental Safety Vehicles (ESV), and such technology has been contributing greatly to the reduction of occupant injuries as safety measures for motor vehicles. An attempt is made here to analyze the relationship between injury severities and equivalent barrier speeds according to the classification by model years, aimed at the verification of effects of such measures.

Vehicles subject to this analysis are 153 small passenger cars and light vans including ordinary passenger cars, all of which involved in frontal collisions (drivers, 153). The vehicle model years are classified into two categories; i.e., vehicles with model years up to 1973, and vehicles with 1974 and subsequent model years. ISS is applied here as the indication for occupant injury severities, which are classified into 4 categories; i.e., intact: ISS 0, minor: ISS 1 to 5, moderate I: ISS 6 to 10 and moderate II: ISS 11 or greater.

The relationship between the equivalent barrier speeds

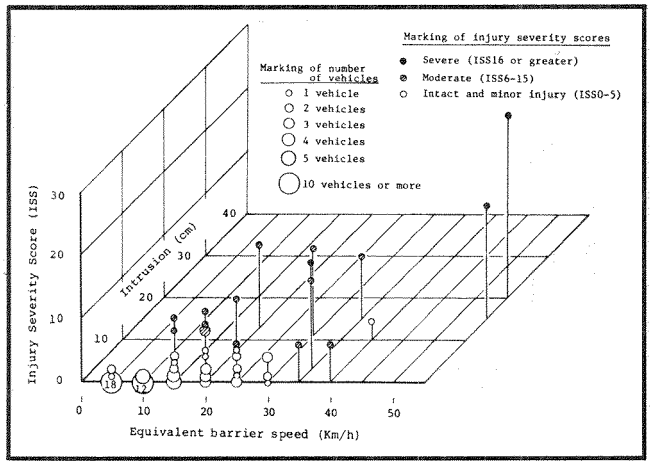
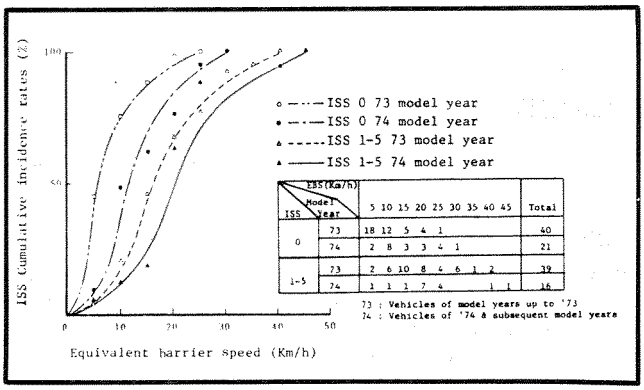


Figure 12. Occupant injury severity scores, equivalent barrier speeds and intrusions of frontal collision small passenger cars and light vans (12 o'clock).

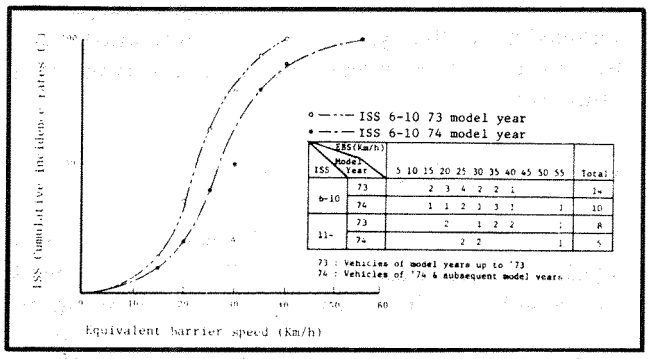
and injury severity cumulative incidence rates for frontal collision vehicles according to vehicle model years is shown in Figures 13 and 14. On the table included in Figure 14, numbers of occupants with moderate injuries of ISS 11 or greater are listed, but such numbers are not plotted in the figure due to the absence of adequate data. From this figure, it may be said as follows, regarding the tendency of injuries for each model year category against the equivalent barrier speeds for occupants of frontal collision vehicles.

1) The comparison of cumulative incidence rates of ISS 0, 1 to 5 and 6 to 10, according to the model year classification reveals that the vehicles of 1974 and subsequent model years show higher equivalent barrier speeds than vehicles of model years up to 1973, on the whole, by 5 to 10 km/h.
2) The comparison of the same data by means of 50% line cumulative incidence rate of equivalent barrier speeds classified by the injury severity scores indicates that vehicles of 1974 and subsequent model years have higher equivalent barrier speeds than the other category of vehicles, by 5 km/h or so.
3) From the foregoing, it is obvious that vehicles of 1974 and subsequent model years have higher equivalent barrier speeds than the other vehicles. It is thus assumed that occupant injury reduction measures are taking effect.



ISS	Model Year	5	10	15	20	25	30	35	40	45	Total
0	73	18	12	5	4	1					40
	74	2	8	3	3	4	1				21
1-5	73	2	6	10	8	4	6	1	2		39
	74	1	1	1	7	4		1	1		16

Figure 13. Equivalent barrier speeds and ISS cumulative incidence rates of frontal collision (11, 12 and 01 o'clocks) small and ordinary passenger cars and light vans' drivers, classified by model years.



ISS	Model Year	5	10	15	20	25	30	35	40	45	50	55	Total
6-10	73				2	3	4	2	2	1			14
	74			1	1	2	2	3	1		1		10
11-	73				2		1	2	2				8
	74					2	2			1			5

Figure 14. Equivalent barrier speeds and ISS cumulative incidence rates of frontal collision (11, 12 and 01 o'clocks) small and ordinary passenger cars and light vans' drivers, classified by model years.

CONCLUSIONS

In this paper, the present status of the investigation on actual conditions of motor vehicle accidents has been described, and analyses have been made mainly on the relationship between the vehicle construction/interior parts and components and the severities of occupant injuries for 486 vehicles involved in vehicle to vehicle or single vehicle accidents, out of the total 396 accidents covered by this investigation up to 1979, excluding motorcycles, mopeds, bicycles and pedestrians. A particular emphasis has been placed on passenger cars and light vans involved in frontal collisions regarding the relationship among the vehicle striking speeds and/or equivalent barrier speeds and severities of occupant injuries.

Since the number of investigations made per year was as few as 50 to 60, data obtained through such investigations are limited, making it difficult to identify areas of problems as statistical data. Following points, however, have been implied through the current analysis results.

(1) The striking speed of frontal collision vehicles is about 30 km/h by the 50% line of cumulative incidence rates.
(2) The investigation on the tendency of the equivalent barrier speed and the occupant injury severity reveals that the speed is approximately 7 km/h on the 50% line for intact occupants, 15 km/h for minor injuries, 23 km/h for moderate injuries and 30 km/h for severe injuries.
(3) The part and component which injured occupants of frontal collision vehicles is the front portion of the vehicle compartment, which accounts for 50% of the total. Interior parts and components are the instrument panel, steering assembly, windshield, etc. in that order. The activation of the energy absorption devices started around the equivalent barrier speed of 20 km/h.
(4) Most of frontal collision vehicles with interior deformations due to the maximum intrusion of 10 cm or greater are those with equivalent barrier speeds of 35 km/h or greater, and the occupant injuries around that speed range from moderate to severe.
(5) In the comparison between the equivalent barrier speeds and the severity of injuries, it was found that vehicles of 1974 and subsequent model years

had less severe occupant injuries than vehicles of model years up to 1973, resulting in about 5 km/h difference in terms of equivalent barrier speeds.

CONCLUDING REMARKS

This report is a summary of the seven years investigation and analysis on actual conditions of motor vehicle accidents made by the Ministry of Transport (MOT). It may not be necessarily said, however, that the relationship between the vehicle construction/interior parts and components and the severity of injuries can be analyzed accurately, due to the limited number of investigations (50 to 60 per year) made so far.

In this regard, it will be necessary to carry out steady investigations and analyses in coming years from a more extensive viewpoint, and to make further efforts to accumulate more data so that results and findings of the above may be reflected on the reinforcement and assessment of future safety standards.

REFERENCES

1. The Councils for Transport Technics, "Technical Measures for Safety of Motor Vehicles—First Program Plan for Future Motor Vehicle Safety Standards", September, 1972 (Japanese).
2. The Councils for Transport Technics, "Technical Measures for Safety of Motor Vehicles—Second Program Plan for Future Motor Vehicle Safety Standards", October, 1980 (Japanese).
3. Motor Vehicle Department of the Ministry of Transport, "Motor Vehicle Accident Investigation and Analysis Reports", 1973 to 1981 (Japanese).
4. Susan P. Baker and Brian O'Neill, "The Injury Severity Score—An Update", The Journal of Trauma, Vol. 16, No. 11, 1976.
5. Susan P. Baker et al., "The Injury Severity Score—A Method for Describing Patients with Multiple Injuries and Evaluating Emergency Care", The Journal of Trauma, Vol. 14, No. 3, 1974.
6. SAE Recommended Practice J224a, "Collision Deformation Classification".

Hospital-Based Traffic Accident Registration and Analysis in Göteborg

O. BUNKETORP and B. ROMANUS
Department of Orthopaedic Surgery II, University of Göteborg, Sweden
B. ALDMAN
Department of Traffic Safety, Chalmers University of Technology Göteborg, Sweden

ABSTRACT

Traffic accidents have been analysed systematically in Göteborg since 1966. For this a computer-based information system has been used since 1971. This system processes accident and environment data from police reports and traffic measurements and facilitates continuous traffic regulations and road improvements. The number of traffic accidents per year in Göteborg decreased from 6,000 to 3,900 during 1971-1980, mainly as a result of successful traffic safety investments.

A complementary registration of traffic accident casualties was started at the emergency hospitals in 1979. The purpose was improved injury classification and decreased number of not-reported accidents. This hospital-based primary registration was expanded to include the medical and social consequences for patients injured in traffic accidents during three months in 1979. The time in hospital, the hospital costs, the time on sick-leave and compensations from the health insurance indicated the accident outcome. The time in hospital and the hospital costs were found to be the most useful accident outcome variables. Pedestrian accidents were by far the most important category according to this analysis.

Improved traffic safety depends among other things on reliable traffic and accident data. A continued decrease of the accident number should be a goal for the road traffic authorities. A more differentiated injury classification should improve the accident analysis and justify a continued use of this system. Medical information can be used in a more precise way to achieve this as indicated in this study.

INTRODUCTION

Swedish official statistics on traffic accidents are based on police reports. These include traffic, road and vehicle data as well as injury classifications according to the definitions in Table 1. The total costs for different injury severities have been calculated from expenses for medical care, estimated loss of future production caused by the permanent disability, costs for administration and material damage (1).

Investments for improved traffic safety should be proportional to the total costs for traffic accidents. Measures for accident prevention and injury mitigation should be evaluated in cost-benefit analysis by national and local road traffic authorities. Public accident data are not qualified for that purpose. There is a large number of accidents not reported, varying according to the injury severity, the type of accident, and the accident place (2, 3). The injury severity is also incorrectly reported in a number of cases, which is not neglectable. Costs for human injuries are to some extent imaginary. The absolute costs indicated in Table 1 are estimated mean values for a large number of accident types and outcomes not related to the age of the injured or to any other accident variable. The measure of the accident outcome should be more differentiated corresponding to this variation. A relative measure for accident outcomes could be a basis for this differentiation.

A computerized information system for traffic accident analysis (NPKTRAFO) has been used in Göteborg since 1971. This system was intended to store and process accident data for a defined region to describe the accident development, analyse the cause of the accidents, especially traffic environment factors, and to facilitate priority judgments for traffic safety investments on the road network.

A registration of traffic accident casualties at the hospitals in Göteborg was introduced in 1979. The primary intention was to complete the official accident outcome data and decrease the number of not-reported accidents. A further intention was to classify the accident outcomes for different categories of road users and ages.

In an earlier study the time in hospital, the hospital costs, the time on sick-leave and the compensations from the health insurance have been evaluated as indicators of the accident outcome. The time in hospital was suggested to be the most useful accident outcome estimate (4).

SCOPE

The aim of this presentation is

I. To illustrate the method for traffic accident analysis and the accident development in Göteborg.
II. To calculate the medical costs for different categories of road users in traffic accidents.

METHODS AND MATERIAL

The method of the traffic accident analysis has been described by the Town Planning Council of Göteborg (5). The analysis is based on official police reports and local road traffic data. It includes the type and time of accident, the place of accident defined in a regional and local geographic reference system, and the characteristics of the local road traffic environment. The disturbance of the normal traffic flow preceding the accident indicates the possible accident cause. The injury severity reported by the police indicates the accident outcome.

Table 1. Injury severity and costs of traffic accidents according to Swedish official statistics in 1979.

Injury severity	Definition	Costs (Sw.Cr. $\times 10^6$)
Fatality	Dead within 30 days as a result of the accident	0.9
Serious injury	Fracture, crush injury, severe cut or laceration, cerebral concussion, internal lesion or any other lesion which causes detention at hospital	0.1
Slight injury	Any other injury	0.02
Material damage	No injury	0.005

The road network is divided into a main network which includes national, primary, and secondary roads, a local network including feeder roads and local streets and other places including parking places, etc. The greater part of the accidents occur on the main road network. The accidents can be well located on the main network. On the local network and other places the accidents can be located to districts only.

I. Action Effect Analysis. The effect of rebuildings and of traffic regulations carried out during 1974-1976 was studied in some places of the road network by the Traffic Planning Department of the Town Planning Council (6). The number of accidents before and after the changes was subtracted and the corresponding injury cost difference was compared to the investments. Corrections were made for the average traffic development in the region and for the number of accidents not known by the police. The real number of road-users killed and injured was estimated using correction factors recommended by the Swedish National Road Administration: 1.06 for killed, 2.13 for seriously injured, 5.9 for slightly injured. The correction factor for accidents without human injuries was 8.0.

II. Accident Outcome Analysis. The individual accident outcome can be indicated by one or several of the accident outcome variables:

v_1 = time in hospital
v_2 = time on sick-leave
v_3 = hospital costs
v_4 = health insurance compensations.

The median or the mean value of v_1, v_2, v_3, and v_4 for all categories of road users i are the accident outcome parameters $P_{i,1}$, $P_{i,2}$, $P_{i,3}$, and $P_{i,4}$, respectively.

In the earlier study (4) the median values were used to compare the accident outcome for the different road

user categories. A standardized accident outcome factor was defined taking into account all the four accident outcome variables mentioned above. Only 50% of the injured were entitled to compensations from the public health insurance. Thus, we concluded the time in hospital or the hospital costs to be the most useful accident outcome variables. The mean and the median values of these variables are used as accident outcome parameters in this study. Extra personal resources during March, October, and November 1979 made a follow-up study possible of the accident outcome for road users injured during these months.

Accident Development. Data from 50,000 accidents were stored and processed in the computer during 1971-1980. The traffic intensity increased by 22% but the total number of accidents per year decreased from 6,000 to 3,900 (35%) during this period (Fig. 1). Human injuries occurred at about 20% of the accidents. A fuel rationing occurred in 1974. This decreased the traffic intensity and reduced the total number of accidents during this year but not the number of accidents with human injuries (6).

The number of injured decreased by 28%, equally for seriously and slightly injured. The number of fatalities decreased slightly but the difference was not significant (Fig. 2).

The number of persons killed and injured exceeded the number of accidents with human injuries by 20%.

The number of children (< 17 years) killed and injured during this period was reduced by 33%. The number of elders (> 64 years) killed and injured was reduced by 15%. Approximately 50% of all road users killed in traffic accidents were pedestrians. Pedestrians more often were seriously injured or killed than slightly injured in traffic accidents (Fig. 3). The number of pedestrian accidents decreased less during the later part of the period.

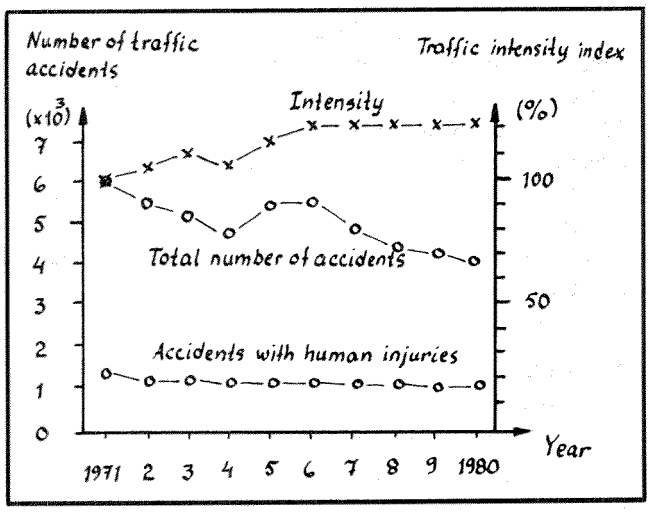


Figure 1. Number of traffic accidents and traffic intensity index in Göteborg during 1971-1980 according to official statistics.

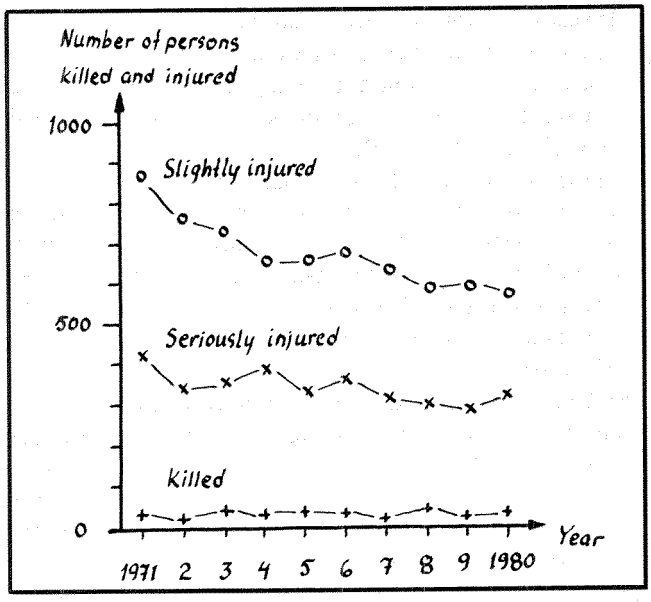


Figure 2. Number of persons killed and injured in traffic accidents in Göteborg during 1971-1980 according to official statistics.

Effect of Rebuildings and Traffic Regulations. Approximately 80% of the accidents occurred on the main network, 15% on the local network and 5% in the other places. The effect of road rebuildings and traffic regulations was studied in 9 and 166 places, respectively (6). The number of traffic accidents before and after the changes was reduced by 44% (Table 2).

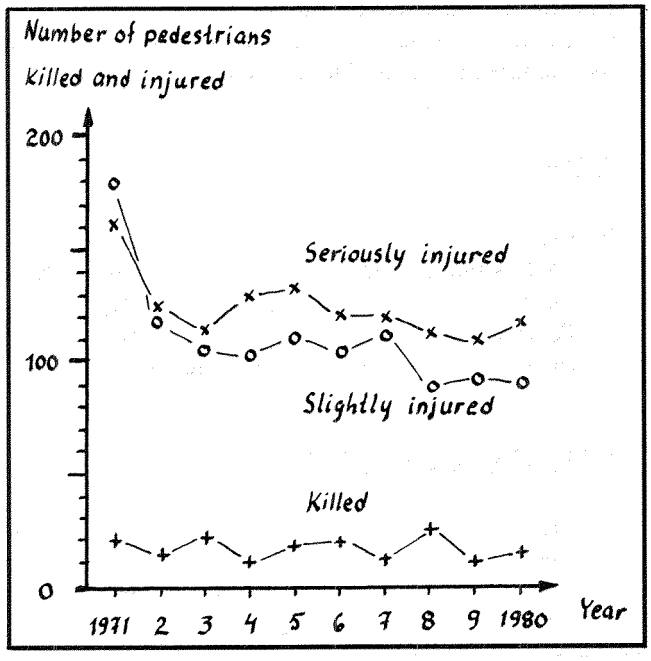


Figure 3. Number of pedestrians killed and injured in traffic accidents in Göteborg during 1971-1980 according to official statistics.

Table 2. Number of accidents before and after rebuildings and traffic regulations in Göteborg during 1974-1976 according to official statistics.

Measure	Number of accidents per year Before	After	Reduction	%
Rebuildings	572	319	253	44
Regulations	468	267	201	43
Total	1,040	586	454	44

The average reduction in other parts of the road network was 7%.

The annual accident cost reduction was 24×10^6 Sw.Cr. on eight of the rebuilt places corresponding to 14% of the investments. On the ninth place both traffic intensity and number of accidents increased. The calculated profitability for all the investigated traffic safety investments was 18%.

RESULTS

Accident Outcome

Relative Admission Frequency. During March, October, and November 1979, 354 patients injured in traffic accidents were admitted to hospital. Two of these died because of the injuries. Table 3 shows the number of in- and out-patients and the road user categories they represent. Pedestrians and car drivers were most frequently admitted, each corresponding to 27% of the total number. Thirty-five percent of all injured were treated as in-patients. This figure ranged from 20% for car passengers to 54% for pedestrians.

Median and Mean Time in Hospital and Hospital Costs. Table 4 shows the median and the mean time in hospital and the hospital costs for 123 in-patients injured in traffic accidents during March, October, and November 1979. Car drivers show the least serious accident outcome, motor-cycles the most serious. Pedestrians account for 80% of the total costs for injured road users.

Hospital Out-Patients. Sixty-five percent (231) of all injured left the hospital on the day of admission. Fifteen were children and 23 elders not registered at the health insurance office. The mean cost for examination and treatment was 188 Sw.Cr. Ninety-one patients received payments from the health insurance office. The sum of these payments was 139,000 Sw.Cr. in total. This is 4% of the hospital costs for the 123 hospital in-patients. The mean costs for medical care and public health insurance compensations for the out-patients was 788 Sw.Cr. which is 2.5% of the corresponding costs for in-patients.

DISCUSSION

According to official statistics the annual number of persons killed and injured in traffic accidents in Sweden decreased during 1971-1980 by 30% and 12%, respectively. Seat belts, helmets, speed limits, mandatory daytime running lights, traffic regulations, and safer roads and traffic environments are all factors being credited for this favourable development. The isolated effect of any accident-preventing or injury-mitigating factor could not be confirmed so easily.

The total number of traffic accidents in Göteborg decreased by 35% during 1971-1980 (Fig. 1). There was a 28 percent reduction of injured persons but only a slight reduction of fatalities in traffic accidents (Fig. 2).

From data collected by the National Social Welfare Board of Sweden Nilsson and Thulin reported on hospital in-patients injured in traffic accidents in 17 of 24 counties in Sweden during 1977 (8). The number of casualties, the number of hospital periods, and the time in hospital were related to population and travel data. There was no connection to the accident data given in police reports. Their report illustrates how existing data can be used for general traffic accident studies. The data indicate the average

Table 3. Patients injured in traffic accidents admitted to hospital during March, October, and November 1979. Type of medical care.

Road user category	Type of medical care: Out-patients Total	Out-patients Percent	In-patients Total	In-patients Percent	Total number admitted Total	Total number admitted Percent
Pedestrians	45	46	52	54	97	27
Bicyclists	19	59	13	41	32	9
Moped drivers	18	67	9	33	27	8
Motor-cyclists	7	78	2	22	9	3
Car drivers	66	69	29	31	95	27
Car passengers	63	80	16	20	79	22
Others	13	87	2	13	15	4
Total	231	65	123	35	354	100

Table 4. Hospital in-patients injured in traffic accidents admitted during March, October, and November 1979. Median and mean values of time in hospital (days) and hospital costs (Sw. Cr. $\times 10^3$).

Road user category	Number of cases	Hospital median		Hospital mean		Total hospital	
		Time (Days)	Costs ($\times 10^3$)	Time (Days)	Costs ($\times 10^3$)	Costs ($\times 10^3$)	(Percent)
Pedestrians	52	7	11	39	51.4	2.672	80
Bicyclists	13	5	4	9	13.2	0.172	5
Moped drivers	9	7	8	5	7.5	0.068	2
Motor-cyclists	2	20	25	18	23.4	0.047	2
Car drivers	29	1	1	4	8.1	0.234	7
Car passengers	16	2	2	8	9.1	0.145	4
Others	2	2	2	2	2.7	0.005	0
Total	123	4	5	20	27.2	3.343	100

accident outcome for urban and rural districts. The type of accidents differs in these areas. Another accident outcome is to be expected in urban traffic.

The real hospital costs is the most significant accident outcome variable. In this study the mean daily cost of the different care units were used as an approximate of the real costs. The real daily costs are highest for old patients with multiple injuries as has been shown in a study of the real costs for hospital in-patients in Sweden 1979 (7).

The time in hospital is a useful accident outcome variable for practical purposes. This accident outcome variable and the real hospital costs are good estimates of the accident outcomes for injured road users who survive. Fatalities, however, do not sufficiently influence the accident outcome parameters if the real time and costs in hospital are used.

A fatality could be given an outcome corresponding to hospital care during the rest of the expected lifetime. In that case the accident outcome would be continuous for severely hurt patients who survive and equally hurt patients who do not survive. In this study the actual time in hospital was used.

The time on sick-leave, and the corresponding payments from the health insurance are complementary but less useful information. In this study 50% of the injured were not compensated by the health insurance office. In some cases the injured were registered for illness not related to the accidents. The number of visits to medical care as out-patient also give additional information about the accident outcome.

In this study car drivers and pedestrians were most frequently admitted to hospital; each in 27%. The average accident outcome differed significantly. About 70% of the car drivers could leave the hospital on the same day. Half of the other car drivers could leave the hospital the next day. Only 15% of all the car drivers had to stay in hospital for two days or more. More than 50% of the pedestrians were treated as in-patients. Half of them had to stay for one week or more in hospital.

The small number of accidents in this analysis does not permit subdivisions in age classes. Children and elders are important risk groups. They are usually unprotected and not adopted to the demands of modern traffic. Elders more often sustain life-threatening injuries and permanent impairment is more frequently seen as a result of traffic accidents in this age group compared to children (9). This analysis also indicates that pedestrians by far belong to the most expensive category of injured road users in Göteborg. Eighty per cent of the costs for hospital in-patients injured in traffic accidents were due to pedestrians. More than half of these were injured by cars. According to these results a considerable part of the budget for traffic regulation measures should be directed to improve pedestrian safety as far as human injuries are concerned. These investments should be concentrated to areas where elderly people stay.

CONCLUSIONS

This study of traffic accidents in Göteborg 1971-1980 indicates:

—A markedly decreased annual number of accidents as a result of road rebuildings and traffic regulations.
—A more favourable development of casualties than in the rest of Sweden.
—A slightly reduced number of fatalities, less favourable than in the rest of Sweden.
—That pedestrians account for eighty per cent of the hospital costs for injured road users.
—The importance of hospital-based injury classification to improve the cost benefit analysis for traffic safety investments.

REFERENCES

1. Johnsson, E. (1974). Samhällskostnader för trafikolyckor, yrkesskador och sjukdomar orsakade av tobaksrökning. EFI, Ekonomiska forskningsinstitutet vid Handelshögskolan i Stockholm (Liber).

2. Hansson, P. (1974). Road Traffic Casualties in a Surgical Department. Acta Chirurgica Scandinavia, Supplementum 442.
3. Tolagen, A. (1977). Trafikskadade i Östergötland. Thesis, University of Linköping No 46, 1977.
4. Bunketorp, O., Romanus, B., Nilsson, W. (1982). Traffic accident registration and analysis in Göteborg. Proceedings of the VIIth IRCOBI Conference, Köln, September 8-10, 1982.
5. "Trafikolyckor i Göteborg 1973—Slutredovisning." Rapport 1975:10, Stadsbyggnadskontoret, Göteborg 1973.
6. Trafiksäkerhetsåtgärder på 1970-talet, en effektanalys. Trafikdata 4/82, Stadsbyggnadskontoret, Göteborg 1982.
7. Stålhammar, D., Aldman, B., Brismar, B., Bunketorp, O., Holmgren, E., Lindström, L., Nygren, Å., Romanus, B. (1982). Injuries caused by biomechanical impacts—continuous evaluation of hospital data. Proceedings of the VIIth IRCOBI Conference. Köln, September 8-10, 1982.
8. Nilsson, G., Thulin, H. (1982). Beskrivning av trafiksäkerhetsläget med hjälp av Socialstyrelsens patientstatistik. National Road and Traffic Research Institute, Report No 237, 1982.
9. Bunketorp, O., Romanus, B. (1981). Clinical Studies on Leg Injuries in Car-Pedestrian Accidents. Proceedings of the VIth IRCOBI Conference, Salon de Provence, September 8-10, 1981.

ACKNOWLEDGEMENTS

This study was supported by grants from:

National Association for Victims of Traffic and Poliomyelitis.
The Swedish Medical Society
The Swedish Road Safety Office

Feasibility of Relating Laboratory Injury Measures in Simulated Accidents to Real-World Occurrences in Side Impacts

WILLIAM A. BOEHLY and J. N. KANIANTHRA
National Highway Traffic Safety Administration

ABSTRACT

A major tool utilized by safety researchers is full-scale laboratory crash testing. The results of these tests on baseline vehicles, and vehicles equipped with safety countermeasures, are often utilized to predict the real-world safety performance of the baseline vehicles, as well as the expected performance of modified vehicles equipped with the countermeasures.

This paper analyzes one particular crash configuration, left side impacts, to determine if a relationship exists between laboratory crash test results and real-world accident injuries. This configuration is chosen because 1) the necessary tools exist—a test barrier which represents a motor vehicle in terms of weight and stiffness; and a dummy which responds in a human-like manner and whose responses can be related to injury, and 2) accident data exist which are consistent with the laboratory crash environment in terms of crash direction and velocity change (delta-V). The NHTSA National Crash Severity Study (NCSS) and the National Accident Sampling System (NASS) provided the accident data for this study. The laboratory crash test data were obtained from the NHTSA Office of Vehicle Research.

On the basis of this analysis, it is concluded that in specific crash environments, the relationship between dummy predicted chest injury and real-world driver chest injury is good. In the case of head injury, the relationship between laboratory tests and real-world accidents was not satisfactory.

Full-scale laboratory crash tests should be continued to assess the crashworthiness of motor vehicles. The results of one crash test or one accident, however, should not be the basis for specifying a vehicle's crashworthiness. Additional research is required in biomechanics, accident analysis techniques and laboratory crash simulation to enhance the ability of predicting real-world performance based upon laboratory tests.

INTRODUCTION

One of the techniques utilized to evaluate vehicle crashworthiness—the protection of its occupants in a crash—is full-scale crash testing. Here, crashworthiness is based upon measures obtained from the responses of instrumented test dummies in controlled laboratory crashes. Two basic types of vehicles are utilized in these full-scale tests—baseline and modified. Baseline or production vehicles are tested, and the results analyzed to indicate the need for crashworthiness improvement. Additionally, the results serve to direct the approach utilized in countermeasure development. Modified vehicles incorporating these countermeasures are crash tested to determine the

level of improvement in crashworthiness obtained by incorporating the countermeasures. Of fundamental importance is the relationship of baseline and modified vehicle crash test results to human injuries in real-world crashes. Regardless of the approach utilized to transfer safety technology to the marketplace—regulation, evolution of safety countermeasures in production, or rating information—relating dummy measures in laboratory crashes to real-world injuries is a vital component of motor vehicle safety research. Admittedly, limitations on the knowledge of biomechanics, the complexity of the dynamics in vehicle crash occurrence and the many problems associated with obtaining reliable and repeatable laboratory and field measures, immensely increase the difficulty in relating laboratory crash results with real-world occurrences.

Nevertheless, the need for analysis and correlation of injury measures obtained from vehicle crashes in the laboratory to those experienced in the real-world far outweigh the limitations. Such effort is extremely valuable in many respects. First, it will serve to assess the state-of-the-art procedures and methodologies used to describe real-world accident occurrences, their levels of crash severity and their injury consequences. Secondly, relationships of laboratory/real-world data will yield improved laboratory test conditions which would better simulate those variables identified as relevant in causing occupant injury. Finally, analysis of the real-world and laboratory data can result in improved relationships between injury levels predicted by test dummies and probabilities of injury, at various levels of severity, in actual crash victims. Eventually, such analyses will provide safety researchers the ability to predict injuries based upon laboratory tests in vehicles if they were exposed to real-world crashes. As such, they can also determine benefits of safety countermeasure development, assist in vehicle research and serve as a means to rank real-world vehicle performance.

In order to relate real-world injuries to dummy measures in laboratory crash tests, it is necessary that certain information be available. First, real-world accident data which include descriptors of crash severity and occupant injury must exist. Crash severity is a parameter which is extremely difficult to quantify. Many safety researchers utilize the crash mode or direction, along with the velocity change, delta-V, of the vehicle to quantify the severity of the crash. These parameters are utilized in this paper. A second required source of information relate to laboratory crash tests which simulate a crash direction and level of severity in the real-world. Finally, the tools utilized in laboratory tests must be representative of the component they are simulating. In laboratory crash testing, the test barrier is used to simulate another motor vehicle and the test dummy to simulate a human. The only set of crashes in which sufficient data exist to satisfy all these conditions is in side impact. This paper is an attempt to determine the feasibility of relating available data in NHTSA National Center for Statistics and Analysis (NCSA) accident data files for side impacts and laboratory crash data in the Office of Vehicle Safety Research (OVSR). This effort is limited to left side impacts and driver injury data existing in the data files of the National Crash Severity Study (NCSS) (1) and the National Accident Sampling System (NASS) (2) files for 1979 and 1980. The laboratory test data pertain to side impact test data available in the OVSR dynamic crash test catalog. The approach presented in this paper develops relationships between driver injury severity in real-world left side-impact accidents and estimates of injury severity obtained from dummy loads in side impact laboratory crash tests. The methodology for translating crash test dummy loads into the commonly used Abbreviated Injury Scale (AIS) Severity Code is proposed by the NHTSA OVSR Biomechanics research group. The paper describes briefly the various sources of data and the methodology used in correlating driver injuries in accidents to dummy loads in laboratory tests. This will be followed by a discussion of the methodology for analysis of the data and the results.

THE ACCIDENT DATA

Data from three sets of accident data files existing in NCSA have been used in this analysis. These data sources are the NCSS, the NASS-'79 and NASS-'80. The NCSS data collection effort was undertaken by NHTSA in which motor vehicle accidents involving a towaway were sampled in eight areas of the U.S. during January 1977 through March 1979. The cases were sampled according to the injury severity of the accident. The data gathered included information from medical records, autopsy reports as well as police accident reports. The raw data were weighted by the inverse of the sampling fractions to represent actual accident frequencies. AIS-76 was used by the investigators to code the occupant injury classification in NCSS.

The NASS data contain similar information from accidents sampled by teams in a number of sites (currently fifty-two sites) throughout the U.S. The site selection and accidents to be investigated are selected on the basis of probability sampling techniques. As only ten of the sites were operational in 1979 and 1980, the sample size of accidents investigated during those years are small. From these, NASS estimated the number of police-reported traffic accidents, their crash mode and severity and occupant injury information.

In this analysis, a subset of the NCSS and NASS data was used. These data pertain to left side impacts to passenger cars with driver injury. Lateral location of vehicle deformation and accident classification codes were used to sort the data from the entire files. The accident data included all cases in which a vehicle was impacted on the

left side, where the side deformation areas were forward of the left front door or the door itself. Specifically, SAE J224 collision deformation codes for lateral location F, D, P, Y and Z were selected. The direction of principal force during impact was limited to 7-11 clock directions. The information retrieved from the files included the resultant vehicle velocity change (delta-V) estimated by the "CRASH" computer program on the basis of damage measurements, the struck vehicle weight, the two major AIS codes and the overall AIS of the driver as well as the associated body regions and treatment/mortality information.

In NASS-'79, AIS-76 was utilized to code occupant injury levels. In NASS-'80, however, a new injury coding, AIS-80 was adopted. The use of AIS-80 compared to AIS-76 will cause injuries to be coded differently for the head through all AIS levels, making the comparison of head injury in NASS-'79 to NASS-'80 difficult. For the chest, AIS-80 treats rib fractures differently from AIS-76. Whereas a rib fracture would be coded as an AIS 2 in AIS-76, it would be coded as an AIS 1 in AIS-80. Therefore when comparing AIS 1 and AIS 2 chest injury frequencies in NASS-'79 to NASS-'80, these two injury levels should be combined. That is, the AIS $\leq$ 2 injury frequencies of the two files should be compared.

The accident data obtained from the NCSS and NASS-'79 and NASS-'80 files were sorted for delta-V ranges, for driver body regions injured and AIS severity in single vehicle and two vehicle side impact accidents. The percentage of single vehicle side impact cases being small, the data for the single and two vehicle crashes were combined for the purpose of this analysis. Using the Statistical Analysis System (SAS) computer program, the number of drivers sustaining injuries at each AIS level was determined. The cases were further partitioned into various delta-V groups. The delta-Vs were grouped as 1-8 mph, 9-16 mph, 17-24 mph, 25-32 mph, 33-40 mph and $\geq$ 41 mph. Since it was observed that for a significant number of cases, the injuries were of unknown severity, it was decided to use the estimated maximum AIS available in the data files. These are determined by a procedure for allocating missing maximum AIS (3) developed for NASS.

In all of the accident data files used, there were approximately fifty percent of the cases where the delta-Vs were unknown for side impacts. This percentage of unknown delta-Vs in the side impact cases is about the same as for all accidents, and therefore, the data in this crash mode should not be biased, compared to the overall file. It is likely that many of the side impact accidents are sideswipes in which the colliding vehicles do not reach a common velocity. In such cases, the "CRASH" algorithm utilized to estimate delta-V in NCSS and NASS does not allow computations of the delta-V. In other cases, due to the unavailability of vehicles for inspection and damage measurements, insufficient data are available for the delta-V calculation. In grouping the cases by delta-Vs, the cases with unknown delta-V were excluded.

The "CRASH" algorithm generally tends to underestimate delta-V at low values and is fairly accurate at high delta-Vs. In the oblique side impact cases, where the direction of force is less than 45° from the longitudinal axis of the struck vehicle, the delta-V tends to be overestimated. Typical errors in delta-Vs calculated by "CRASH" range from ten to twenty-five percent. (4) Considering these factors, the delta-V interval for analysis of the accident data was selected to be 7 mph.

THE CRASH TEST DATA

The laboratory crash data were obtained from the NHTSA dynamic crash test catalog, as it existed in August, 1982. A total of 17 side impact tests were identified as potential sources of crash data. Of these, only the data for 13 tests were selected for inclusion in this analysis, as complete information was not available for the remaining. All the tests were angular impacts at an orientation of 300° (60° from straight ahead, towards the driver side) at nominal closing speeds in the range of 30-40 mph. The crash partner in all the tests except two was the NHTSA moving barrier (5) (this is a 3,450 pound barrier with stiffness characteristics close to a U.S. medium sized car). The remaining two tests were car-to-car impacts. The struck vehicles were either Volkswagen Rabbits or Chevrolet Citations—some baseline and some modified. In all cases, the impact condition was designed to obtain the maximum penetration at the driver hip-point. Instrumented dummies were used to simulate the driver. In eleven tests, the Side Impact Dummy (SID) (6) developed by HSRI was utilized, while in two tests, the Association Peugeot-Renault (APR III) (7) dummy was used. The crash test conditions and resultant delta-V of the struck vehicle are illustrated in Table I.

The struck car resultant delta-Vs were obtained from a velocity-time trace of the vehicle floor pan tunnel for all the tests. The cut-off time for determining the velocity change in each case was ascertained from their respective acceleration traces. The delta-Vs were also computed from the conservation of momentum equations, which in all cases turned out to be higher than the velocity change obtained from the velocity-time traces. All of the tests had either the APR or the SID dummies in the front left driver seating position. The dummies were instrumented to measure the acceleration response of the left upper rib (LUR). This LUR acceleration response was utilized as an input for computation of the right upper rib (RUR) response. The computation approach was the use of a model based on digital convolution theory. The technique is described by Eppinger and Chan. (8) Utilizing the acceleration of the LUR and RUR, the maximum relative velocity between the left and right upper ribs was com-

TABLE I

Summary of Side Impact Laboratory Crash Test Results

No.	Struck Vehicle Make/Model	Test Config.	Test Type	Vehicle Weight (lbs)	Impact Angle Deg.	Closing Speed mph	Resultant Delta-V mph
1	'76 VW Rabbit	MBV	DEV	2444	300	39.8	18.6
2	'76 VW Rabbit	MBV	DEV	2485	300	39.1	17.5
3	'80 VW Rabbit	MBV	DEV	2456	300	40.1	22.8
4	'80 VW Rabbit	MBV	DEV	2477	300	39.2	16.6
5	'79 Chev Citation	MBV	BAS	3070	300	29.9	11.0
6	'80 Chev Citation	MBV	BAS	3089	300	35.3	13.3
7	'80 Chev Citation	MBV	BAS	3120	300	39.7	14.2
8	'80 Chev Citation	VTV	BAS	3090	300	29.4	11.1
9	'80 Chev Citation	MBV	MOD	3090	300	40.2	19.2
10	'80 Chev Citation	MBV	BAS	3096	300	39.6	17.0
11	'76 VW Rabbit	VTV	MOD	2436	300	37.5	17.0
12	'80 Chev Citation	MBV	MOD	3102	300	40.1	17.0
13	'80 Chev Citation	MBV	MOD	3987	300	40.1	17.0

NOTE: MBV — Moving Barrier into Vehicle
VTV — Vehicle to Vehicle
MOD — Modified Vehicle Test
DEV — Developmental Test
BAS — Baseline Test

puted by integrating the difference between the LUR and RUR accelerations. Similarly for the head, the head acceleration was used in a two-mass model of the head, to obtain the Mean Strain Criteria (MSC). (9)

In order to estimate injury severity from measured dummy parameters during staged collisions, the NHTSA Biomechanics group has proposed injury criteria for selected body areas. In this, several body areas such as head, face, neck, thorax, abdomen, pelvis, etc. have been addressed. For each, approximate "bogie" values of body area response which relate to an AIS severity level have been proposed. From dummy acceleration measures for the chest and head, the AIS severity level for each was computed utilizing the Eppinger equation (9) for the chest and the MSC for the head.

The dummy AIS for the chest and head in the crash tests, along with the computed maximum relative velocity between LUR and RUR and the MSC are given in Table II. Additionally, the Head Injury Criterion (HIC) values are included, though not used for AIS predictions. While it is recognized that several of the proposed injury criteria in reference 9 based on dummy measures should be considered simultaneously in conclusively establishing injury severity, the available data preclude consideration of any injury and computations of AIS other than that for the head and the chest. Therefore, the comparison of the accident data and the laboratory crash test data is made, keeping in mind that many of the proposed injury criteria are being omitted in this analysis.

RESULTS AND DISCUSSION

Before addressing the issue of relating laboratory test results to real-world accident in driver side impacts, a number of observations on this crash configuration are beneficial. National estimates for maximum AIS for drivers in single and two vehicle accidents from the NASS-'79 and NASS-'80 data, along with national estimates of the number of fatalities which occurred in those accidents, are given in Table III. In the left side impact modes considered, forty percent of the drivers remained uninjured (AIS = 0) in 1979. The comparable figure for 1980 was forty-eight percent. Fatalities varied from 1.1 percent in 1979 to 0.52 percent in 1980. Drivers receiving injuries of AIS 3 or higher were about 5.9 percent in 1979, while in 1980, this proportion was 3.6 percent. In both the years, among drivers injured, the injury severity for about ninety percent was AIS 2 or less.

To describe the AIS distribution of drivers injured in this crash mode, the estimated maximum AIS for various delta-Vs are presented in Figure 1 (NCSS), Figure 2

TABLE II

Summary of Side Impact Laboratory Crash Test Results

No.	Dummy Type	Dummy Peak 'G' Left Upper Rib	Peak Rib Relative Velocity FPS	AIS		HIC	MSC In./In.
				Chest	Head		
1	APR III	169.1	26.86	2	1	266	.002123
2	SID	72.7	22.62	2	4	777	.007703
3	SID	186.2	33.92	3	4	1414	.00628
4	APR III	101.1	52.14	4	1	153	.002218
5	SID	63.8	54.15	4	1	116	.001754
6	SID	62.3	59.10	5	3	346	.004820
7	SID	87.5	68.92	5	2	456	.003463
8	SID	69.6	26.20	2	2	257	.003684
9	SID	115.0	24.83	2	1	291	.002239
10	SID	97.5	27.27	2	2	780	.003524
11	SID	29.6	12.60	1	1	288	.001627
12	SID	73.0	24.89	2	2	707	.003653
13	SID	67.4	32.94	2	N/A	N/A	N/A

(NASS-'79), and Figure 3 (NASS-'80). The values on the vertical axis of these three figures are the percent of drivers with injuries at injury levels of AIS 1 through AIS 6, in each of the delta-V ranges. The population on which the percentages are based is the total number of *all* injured drivers, AIS 1 through AIS 6 and non-injured. AIS 5 and 6 occurred infrequently in most of the delta-V groups, therefore they are not shown in Figures 1 through 3. The NCSS data (Figure 1) illustrate that most of the injuries occur at a delta-V in the range of 9-16 mph. However, for the NASS-'79 data in Figure 2, most of the injuries occur in the delta-V range of 17-24 mph. NASS-'80 data, as illustrated in Figure 3, indicate that most of the injuries again occur in the 9-16 mph delta-V range. There is no simple explanation for these shifts. As noted earlier, the change from AIS-76 to AIS-80 will have an effect on injury coding. These three figures indicate that a large portion of the side impact injury problem is in the two delta-V ranges of 9-16 mph and 17-24 mph.

As a complement to Figures 1, 2 and 3, Figure 4 presents the percentage of uninjured drivers in the NCSS and the NASS data for the delta-V ranges. At a low delta-V in the range of 1-8 mph a substantially higher number of drivers remain uninjured in the NCSS than in the NASS. This is probably due to the reporting thresholds of NASS and NCSS. In NCSS, the threshold was a tow-

TABLE III

National Estimates of Maximum AIS for Drivers in Single & Two Vehicle Driver Side Impacts

Source of Data	AIS							Fatals	Non-Fatals	Total
	0	1	2	3	4	5	6			
NASS 1979	117,475	142,955	15,592	13,259	968	1,057	2,026	3,171	290,161	293,332
NASS 1980	109,154	93,781	14,330	6,009	941	475	641	1,175	224,116	225,331

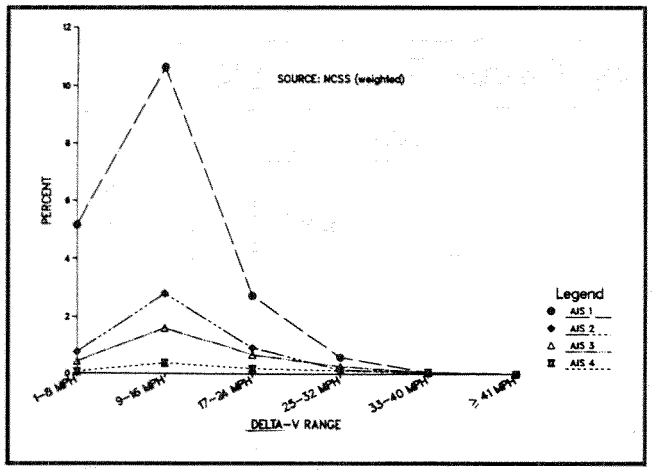


Figure 1. AIS distribution for driver injury in side impacts.

NOTE: Continuous curves plotted in this and subsequent figures are based upon discrete data points.

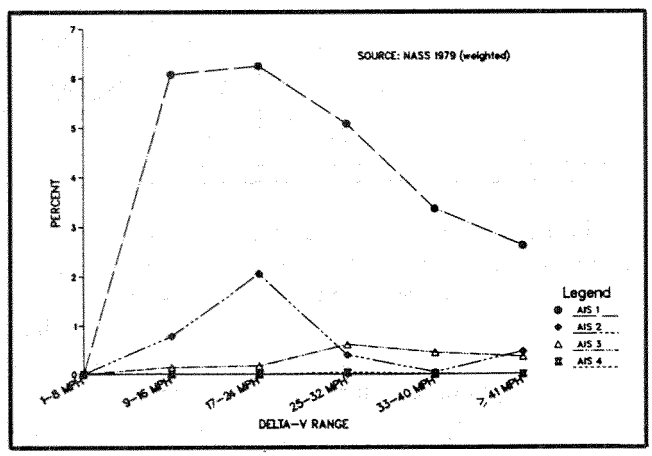


Figure 2. AIS distribution for driver injury in side impacts.

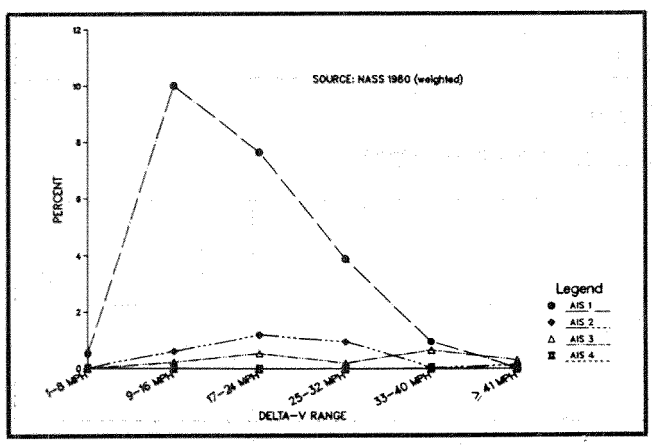


Figure 3. AIS distribution for driver injury in side impacts.

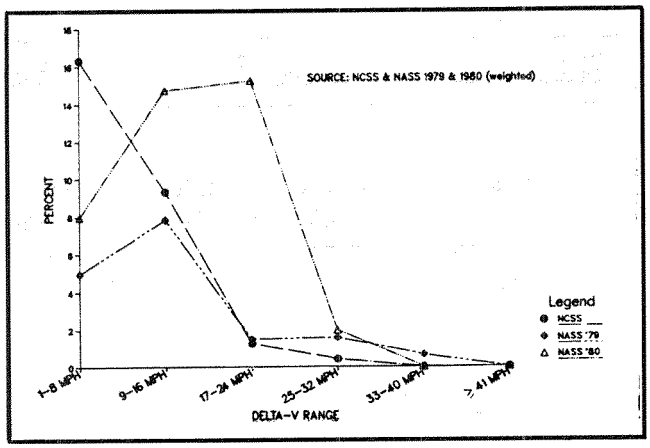


Figure 4. Distribution of uninjured drivers in side impacts.

away accident, regardless of occupant injury. In NASS, the threshold is police reported accidents. Since most accidents are not investigated by police unless injury is involved, a lower percentage of non-injured drivers would be expected at a low delta-V in the NASS data base. At the higher delta-Vs; i.e., above the 9-16 mph, the towaway or police reporting threshold won't make as much difference as indicated by the NCSS and NASS-'79 data in Figure 4. An explanation for the percent of uninjured drivers in NASS-'80 is not apparent. Perhaps the change from AIS-76 to AIS-80 would cause a shift to a larger percent of uninjured drivers, but not the magnitude illustrated in Figure 4. This discrepancy may be due to the differences in the sample size in the raw data. The 1980 NASS unweighted data for the crash mode under consideration had less than half the number of cases investigated in 1979. Consequently, when partitioned for AIS and delta-Vs, the frequency of cases become small and thus subject to error.

Figures 1, 2 and 3 illustrate that the delta-Vs of 9-16 mph and 17-24 mph represent the two ranges of velocity change at which the bulk of AIS injuries of varying severities occurred in the accident data. Coincidentally, the laboratory crash data were available for only these ranges of delta-Vs. Therefore, comparisons made between the chest and head injuries in real-world accidents and laboratory crashes for these two delta-V groups have importance, in that a significant number of injuries are occurring in these groups.

Figures 5 and 6 show the chest injury severities in real-world left side impact crashes in the NCSS and NASS data bases at 9-16 and 17-24 mph delta-Vs, respectively. As illustrated in Figure 5, for delta-V of 9-16 mph all the chest injuries are AIS 1 in the NASS data base. In Figure 5, for the NCSS data, approximately seventy percent of the chest injuries are AIS $\leq$ 2. While the NASS data show no significant chest injury (AIS $\geq$ 2) to the driver at 9-16 mph delta-V, the NCSS data chest injuries of AIS

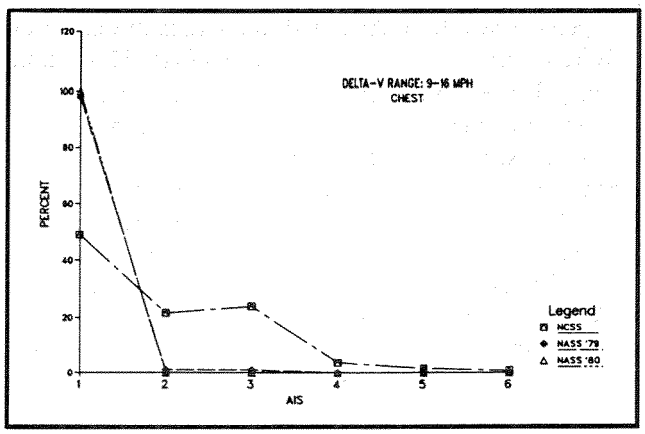


Figure 5. Comparison of driver AIS in real world crashes.

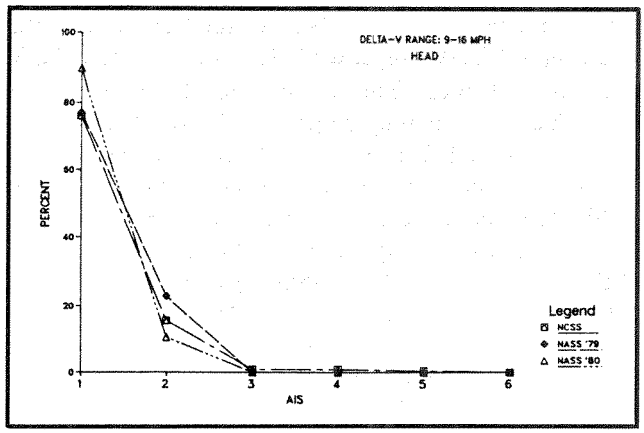


Figure 7. Comparison of driver AIS in real world crashes.

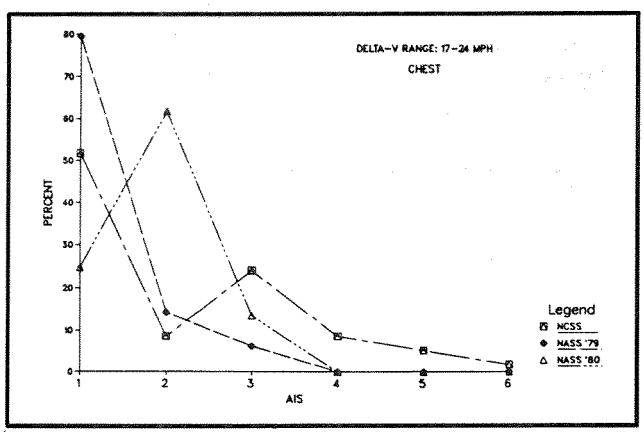


Figure 6. Comparison of driver AIS in real world crashes.

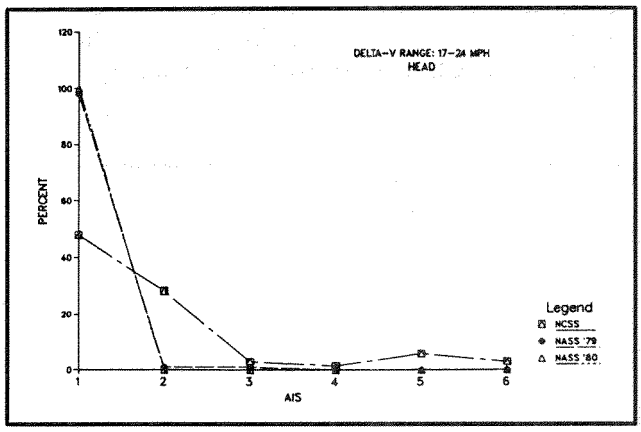


Figure 8. Comparison of driver AIS in real world crashes.

4 or greater account for about five percent of all the chest injuries in this delta-V range. One possible explanation is that the NCSS data, involving towaway accidents, result in a crash environment which requires more definition than simply the delta-V. Other crash factors may also be causing injury, thus resulting in a risk of more severe AIS. Figure 6 illustrates the distribution of the chest injury severities in NASS and NCSS at 17-24 mph delta-V. In this delta-V range, ninety percent of the NCSS and one-hundred percent of the NASS driver chest injuries are of AIS $\leq$ 3. At this higher delta-V, NCSS and NASS data are becoming more similar as would be expected, since the towaway bias is less important. The NCSS and NASS-'79 data show a higher percentage of chest injuries of AIS 1 compared to NASS-'80. When the severities of AIS 1 and 2 are combined, however, all the data bases are in good agreement. Considering the fact that the AIS coding in 1980 is slightly different from that used in 1979, the discrepancy seen in AIS 1 and 2 in the NASS-'79 and NASS-'80 data is not unreasonable.

Figures 7 and 8 show the head injury severities in real-world side impacts at 9-16 mph and 17-24 mph delta-Vs, respectively. In the 9-16 mph delta-V crashes (Figure 7), the NCSS and NASS data are in close agreement. Ninety-two to ninety-eight percent of the head injuries in this delta-V range were AIS $\leq$ 2. In 17-24 mph delta-V crashes (Figure 8), essentially all of the head injuries in NASS were AIS 1, while for the NCSS, approximately seventy-five percent of the head injuries were AIS $\leq$ 2. Risk of AIS $\geq$ 3 head injury is 0 in 9-16 mph and 17-24 mph delta-V crashes in the NASS data, and about two percent in the NCSS data at 9-16 mph. In 17-24 mph delta-V crashes, the NCSS data indicate the risk of AIS $\geq$ 3 head injury to be quite large—about twenty-five percent.

DUMMY HEAD AND CHEST "INJURIES" IN SIMULATED CRASHES

As discussed previously, the laboratory crash data provided the data for the chest and head AIS calculation for

the two ranges of delta-Vs. Nine of the tests were in the 17-24 mph delta-V range, while four were in the delta-V range of 9-16 mph. The distribution of the chest AIS levels, based on dummy responses, for the two delta-V groups is presented in Figure 9. In the 9-16 mph delta-V range, the laboratory results indicate that chest injuries of higher severity were more likely than those of lower severity. That is, twenty-five percent of the chest injuries at this delta-V were AIS 2, while AIS 4 and 5 accounted for seventy-five percent of injuries. However, it must be recognized that data from only four tests are included in the 9-16 mph delta-V range. Such a small sample, when used to develop a frequency distribution can lead to invalid conclusions. In the 17-24 mph delta-V category, AIS $\leq$ 2 chest injury occurred seventy-seven percent of the time, with the remaining at AIS 3 or 4. The distribution of head AIS levels, based on dummy responses for the two delta-V groups is presented in Figure 10. In the 9-16 mph delta-V range, seventy-five percent of the head injuries are at AIS 2 or less with the remaining twenty-five percent at AIS 3. As noted, these data are based on only four tests. In the higher delta-V range, 17-24 mph, seventy-five percent of the head injuries are at AIS 2 or less, the remaining twenty-five percent being AIS 4.

Comparisons of chest and head injuries from the accident data and the staged laboratory tests at 17-24 mph delta-V are presented in Figures 11 and 12, respectively. In Figure 11, the distribution of chest injuries indicated in the NASS-'80 data base and the laboratory crashes are strikingly similar. The frequency of occurrence of AIS 1, AIS 2, and AIS 3 are approximately the same between NASS-'80 and the laboratory crashes. However, while the NASS data do not contain any chest AIS greater than 3, the laboratory test data resulted in approximately eleven percent of the chest injuries occurring at AIS 3 and AIS 4 respectively. Averaging all of the real-world accident data—that is, NASS-'79, NASS-'80, and NCSS, eighty percent of the chest injuries were of AIS 2 or less. In the laboratory tests, seventy-eight percent of chest injuries, as predicted by the dummy, were AIS 2 or less. Figure

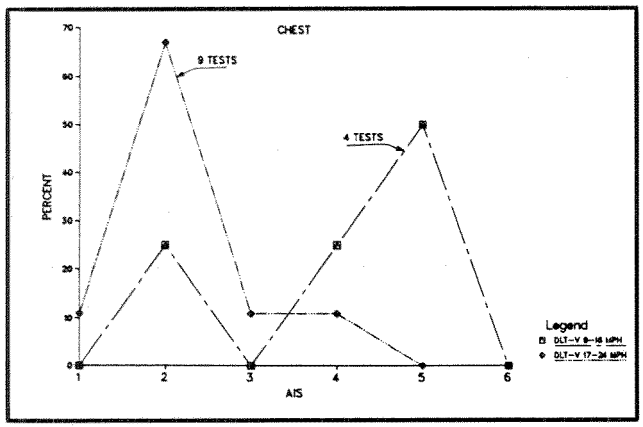


Figure 9. Comparison of driver AIS in simulated crashes.

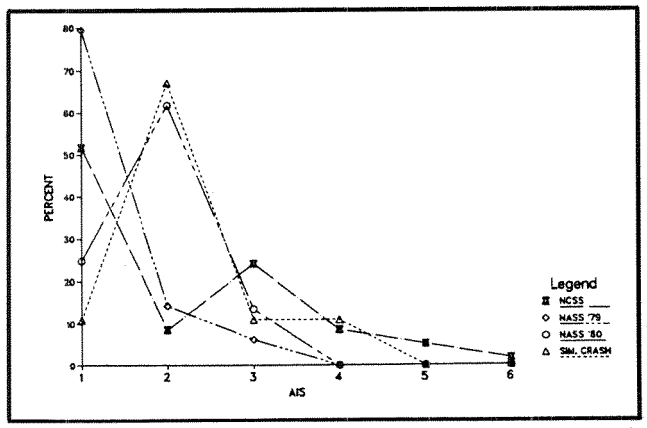


Figure 11. Comparison of chest AIS for 17-24 mph delta-V.

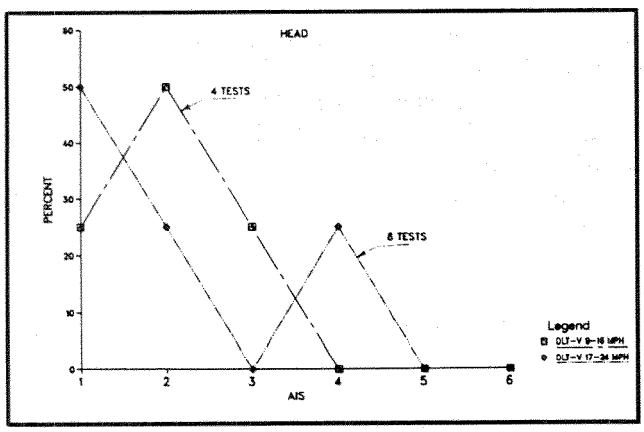


Figure 10. Comparison of driver AIS in simulated crashes.

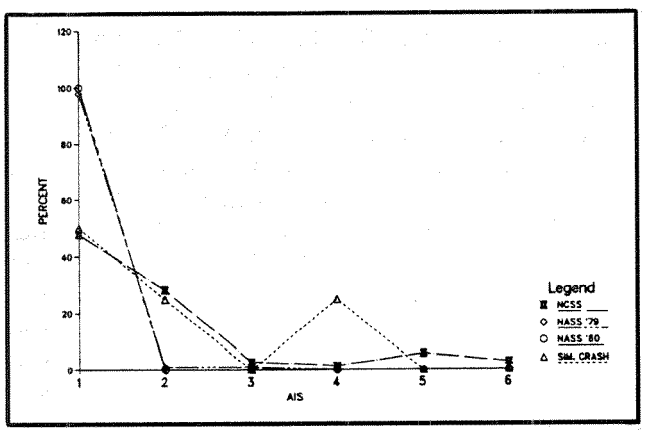


Figure 12. Comparison of head AIS for 17-24 mph delta-V.

12 compares the driver head injuries in the accident data and the dummy predicted head AIS for the laboratory crash tests in the 17-24 mph delta-V category. All of the head injuries in the NASS-'79 and NASS-'80 data are minor at a severity of AIS 1. In contrast to the NASS data, approximately seventy-five percent of the head injuries indicated in NCSS and seventy-five percent of the dummy predicted head AIS levels were AIS $\leq$ 3 in the 17-24 mph delta-V range.

CONCLUSIONS AND RECOMMENDATIONS

General

The basis for conducting the analysis presented in this paper was to determine if the outcome of real-world motor vehicle accidents—body regions injured and level of injury severity—can be related to dummy measurements in laboratory crash tests. Based on the result of a small component of the problem, driver side impacts with a delta-V of 17-24 mph, it appears that a relationship does exist. The data to support this conclusion are:

1. In seventy-eight percent of the laboratory tests in this crash severity range, the dummy AIS prediction was AIS $\leq$ 2, while in real-world crashes of similar severity, eighty percent of the drivers suffered AIS $\leq$ 2.
2. In both the laboratory crash tests and the real-world accidents, there was a very low probability of AIS $\geq$ 4 in this crash severity range.

On the basis of this result, laboratory crash tests should be continued and utilized to assess the crashworthiness of baseline cars as well as direct researchers towards methods of improving crashworthiness by developing appropriate countermeasures.

It is noted, however, that both a laboratory crash test as well as a specific real-world crash environment will result in a range of outcomes; i.e., dummy and occupant injury levels. Therefore, the results of one crash test or one accident should not be used to characterize the crashworthiness performance of a motor vehicle. A substantial number of events must take place before a safety researcher can be confident that he knows the injury distribution, both to specific body components as well as AIS level. As a corollary to this, it is the opinion of the authors that careful engineering analysis, evaluation and judgment are necessary components in developing countermeasures for vehicle crashworthiness. Full-scale crash tests certainly have their place in evaluating crashworthiness and improving vehicle safety. However, extreme care must be exercised in predicting real-world performance; i.e., changes in the AIS distribution, on the basis of a small number of tests.

Specific

While significant advances have been made in recent years to improve the tools necessary to relate laboratory crash test results to real-world accidents, substantial research remains to be done.

1. Accident data indicate a significant amount of injury to the neck. Inasmuch as a test device to evaluate neck injury in laboratory crashes does not exist, this problem was not analyzed in this paper. It is critical that biomechanics research continue and a test device to predict neck injury be developed, so that this significant safety problem can be addressed.
2. A significant amount of accidents in the NASS and NCSS data file did not have a delta-V calculation. In certain conditions such as sideswipes, the delta-Vs cannot be computed by the algorithms currently utilized. It is imperative that valid comparisons require delta-Vs in all cases where any appreciable injury has occurred. Therefore, efforts must be made to improve the delta-V computation algorithm.
3. A critical component missing for frontal crashworthiness evaluation is a barrier which provides a more realistic crash environment for the vehicle being tested. Currently, this is a major problem in frontal crash testing, and makes a comparison of real-world frontal crashes to laboratory frontal crashes essentially impossible. Although the delta-V is simulated in the laboratory, the time over which it occurs is not. Additionally, the fixed barrier of essentially infinite mass does not allow an acceptable crashworthiness evaluation of vehicles with different weights and structural characteristics. The development of such a barrier should be of high priority in vehicle safety research.

REFERENCES

1. Gimotty, P. A., Campbell, K. L., Chirachavala, T., Carsten, O., and O'Day, J., "Statistical Analysis of the National Crash Severity Study Data," NHTSA Report DOT-HS-805-561, Washington, D.C., August 1980.
2. COMSIS Corporation, "Report on Traffic Accidents and Injuries for 1979-1980—The National Accident Sampling System," Washington, D.C., February 1982.
3. Partyka, S., "A System for Allocation of Missing Maximum AIS," unpublished NHTSA document, Washington, D.C., November 1981.
4. Smith, R. A. and Noga, J. T., "Accuracy in Severity of Crash," NHTSA Technical Report, DOT-HS-806-152, Washington, D.C., March 1982.
5. Davis, S. and Ragland, C., "Development of a De-

formable Side Impact Moving Barrier," Proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles," Wolfsburg, West Germany, October 1980.
6. Morgan, R. M. and Water, H. P., "Comparison of Two Promising Side Impact Dummies," Proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles, Wolfsburg, West Germany, October 1980.
7. Fayon, A. and Tarrière, C., et al., "Development and Performances of the APR Dummy (APROD)," Proceedings of the Eighth International Technical Conference on Experimental Safety Vehicles, Wolfsburg, West Germany, October 1980.
8. Eppinger, R. H. and Han-Sun Chan, "Thoracic Injury Prediction via Digital Convolution Theory," Paper No. 811010, Proceedings of Twenty-Fifth Stapp Car Crash Conference, San Francisco, California, September 1981.
9. Eppinger, R. H., "Proposed Injury Criteria and Mathematical Analogs for Selected Body Areas," unpublished NHTSA document, Washington, D.C., July 1982.
10. Burgett, A. and Brubaker, William, "The Role of the Side of the Motor Vehicle in Crash Protection," Paper No. 820245, Society of Automotive Engineers International Congress and Exposition, Detroit, Michigan, February 1982.

The Use of Insurance Material to Study Traffic Safety

ÅKE MYGREN
Karolinska Hospital

BERTIL ALDMAN
Chalmers University of Technology

HANS GUSTAFSSON
Folksam Insurance Group

CLAES TINGVALL
Folksam Insurance Group

JAN WERSÄLL
Karolinska Hospital

ABSTRACT

Road traffic accident prevention and control require a multidisciplinary approach as well as the application of many sciences. One of the most difficult problems in studying road traffic accidents is to identify reliable and meaningful information. One possibility to study traffic accidents with and without personal injuries is to use the reports from an insurance company. Folksam, the largest motor insurance company in Sweden, has during the last decade systematically studied traffic accidents.

By studying all accidents during one year a lot of information has been obtained.

The injury frequency increases from 1.5 to 3.0% when the service weight of the car decreases from 1,300 kg to 800 kg. The safety development that private cars have undergone during the last two decades has, however, influenced the injury frequency in a positive way.

In this study the decrease in injury frequency due to seat belt use is shown as well as the redistribution of injuries. The main decrease is concentrated to head injuries which decrease is due to seat belt use among front seat occupants.

An unbelted rear seat passenger has a higher injury severity than an unbelted front seat passenger and it is shown that an unbelted rear seat passenger is a considerable risk for the front seat occupant.

BACKGROUND

Road traffic accident prevention and control require a multidisciplinary approach as well as the application of many skills and tasks, such as epidemiology, biostatistics, communication science, economy, sociology, and engineering.

One of the most difficult problems in studying road traffic accidents is to identify reliable and meaningful information. There are many examples where international comparisons become difficult, e.g., the definition of an accident or a serious or minor injury varies from country to country. Data are often inadequate as well as being unreliable and incomplete.

Traffic environment is under the influence of continuous changes. Some of these are the results of efforts to make road traffic safer, such as safety regulations, constructions of new, safer cars, use of safety belts, etc. Others are consequences of unforeseen international changes, such as the energy crisis that has given rise to a worldwide tendency to downsize cars. It is, therefore, important to have continuous information about the outcome of such changes by studying actual accidents. There are many ways to study such changes from an epidemiological point of view. The use of hospital records is one way, in-depth studies of all accidents from a representative part of the

country is another. However, one of the best ways is to use an insurance material. In an insurance material both mortality and morbidity can be evaluated. Furthermore, as information is available both from accidents with and without injured people, there is a possibility to study the safety level of different types of cars, the influence of the age of the driver, etc. Economic evaluation of the consequences, both direct costs for the insurance company and indirect costs for society, can be made. Information that is normally stored can be completed through questionnaires and telephone calls. In a follow-up it is possible to see the outcome of curative and rehabilitative activities.

Folksam, the largest motor insurance company in Sweden, has accident prevention as an overall goal and has during the last decade systematically studied traffic accidents.

The aim of this study was to show some of the possibilities to study epidemiology by using an insurance material. This presentation will be focused on five specific questions.

1. How does the size of the car influence the type and the frequency of bodily injuries?
2. Is there any difference in the driver's injuries when he has driven a new car compared to an old one?
3. How does the seat belt change the injury panorama in different severity grades of accidents?
4. Have all unbelted rear seat passengers the same injury severity as a front seat occupant?
5. Can an unbelted rear seat passenger influence the injury risk among front seat occupants?

MATERIAL AND METHOD

The material consists of cases of damage with claims for compensation on the compulsory third party insurance. During the studied period (1976-07-01—1977-06-30) 80,891 accidents occurred that were reported to Folksam under tariff 01 (private cars for personal use only). The distribution of the accidents can be seen from Table 1. The number of private cars insured with Folksam during the studied period can be seen from Table 2. The distribution of the injured is reported in Figure 1.

Totally, 2,875 persons were injured or killed inside the car. For 109 persons (106 injured and 3 killed) the position in the car is unknown.

Table 1. The total number of private cars involved in accidents broken down by type of accident.

Collision with more than 1 vehicle involved	77,268
Other types of accidents	3,623

Table 2. Number of private cars insured with Folksam during the studied period (1976-07-01—1977-06-30).

Number of insurances under annual risk	Number of accidents with personal injuries (tariff 01)
711,989*	2,271

* Annual risk means that the duration of each insurance is counted as part of a calendar year. E.g. an insurance accepted on September 1st and in force for the rest of the year will get an annual risk of 1/3 = 0.333.

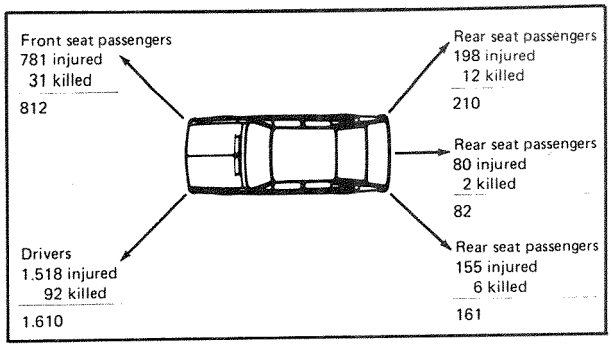


Figure 1. Distribution of injured car occupants.

RESULTS

Car Weight

Injury frequency among drivers is twice as high in a car with a weight of 800 kg compared to a car weighing 1,400 kg (Table 3 and Figure 2).

Year Model and Production Start

Car models have different production starts. A model can be made for many years, e.g., several year models are practically identical. This means that a row of year models with the same production start has the same safety level apart from minor modifications. The influence of

Table 3. Percentage share of injured drivers distributed on car weight.

Weight in kg	No. of involved vehicles	No. of injured drivers	% share of injured drivers
– 749	189	8	4.2
750– 849	2,132	61	2.9
850– 949	9,853	267	2.7
950–1,049	14,195	333	2.3
1,050–1,149	17,955	358	2.0
1,150–1,249	11,332	202	1.8
1,250–1,349	15,264	219	1.4
1,350–1,449	5,267	86	1.6
1,450–	1,255	17	1.4
Unknown	3,449	59	1.7
Totally	80,891	1,610	2.0

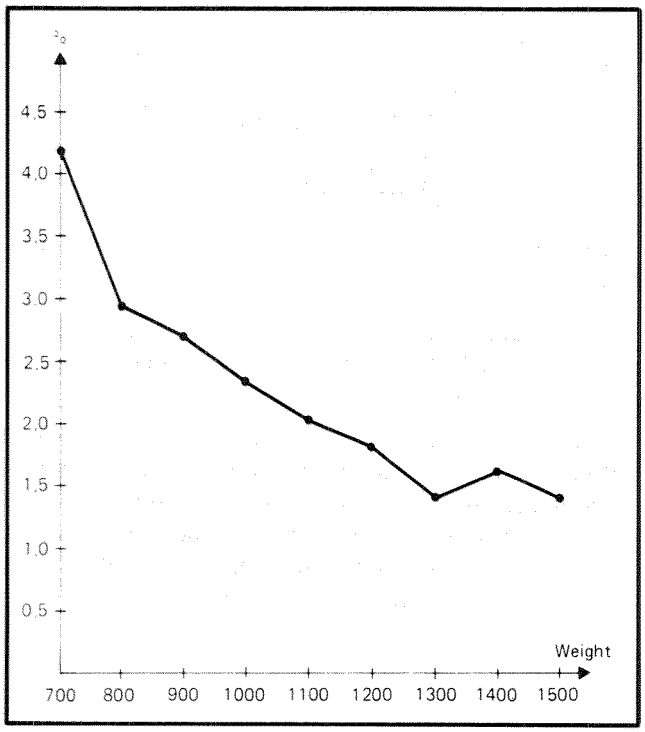


Figure 2. Percentage share of injured drivers distributed on car weight.

the year model (the age of the car) and the production start (the safety level of the car) can be seen from Figure 3 and Tables 4 and 5.

There is a clear tendency showing that the injury frequency decreases the newer the car. The tendency is the same for different production starts but the figures are somewhat inhomogeneous due to the fact that some years there are few car models with new production starts. However, a deep analysis has shown that the production start has a greater influence on car safety than the year model.

Injury Panorama

Injured drivers in small cars have more injuries in all body regions apart from the face. Injuries to the face are often caused by the steering wheel and in most cars the distance to the steering wheel is the same irrespective of the size of the car. Injuries to the rest of the body are due to the fact that the interior of the car is closer to the body in smaller cars resulting in a violent contact with the body in case of an accident.

The Influence of Engine Mounting and Type of Drive

The cars in the study are divided into 3 groups according to engine mounting and type of drive. In Tables 6-8 the injury frequency among drivers is shown for cars with front engine mounting and front or rear drive and with rear engine mounting and rear drive.

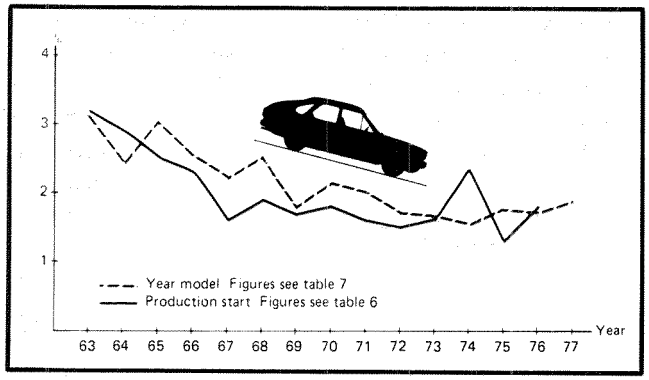


Figure 3. Injury frequency among drivers at different year models and production starts.

Among cars weighing less than 1,100 kg the injury frequency among drivers is the lowest for cars with front engine mounting and front drive. For cars over 1,100 kg, cars with front engine mounting and rear drive have the lowest injury frequency.

Injury Severity Correlated to Car Weight, Year Model, and Production Start

Injury frequency is a way to calculate the risk for bodily injuries in traffic accidents. This measure does not indicate the degree of severity of the injuries sustained. In order to further elucidate the degrees of severity, we have endeavoured to find the answers to the following questions:

—Is the degree of severity higher in small cars than in large ones?

Table 4. Number of vehicles involved in accidents broken down by production start.

Production start	No. of private cars
1960 and earlier	13,257
1961	962
1962	2,545
1963	1,976
1964	279
1965	6,770
1966	2,620
1967	15,181
1968	3,768
1969	8,036
1970	1,844
1971	5,253
1972	4,562
1973	3,431
1974	1,182
1975	4,559
1976	874
1977	343
Unknown	3,449
Totally	80,891

Table 5. Number of vehicles involved in accidents broken down by year model.

Year model	No. of private cars
1963	3,637
1964	2,392
1965	3,718
1966	4,009
1967	3,630
1968	4,569
1969	6,431
1970	6,205
1971	6,031
1972	6,741
1973	7,582
1974	7,228
1975	10,252
1976	5,379
1977	2,176
Unknown	911
Totally	80,891

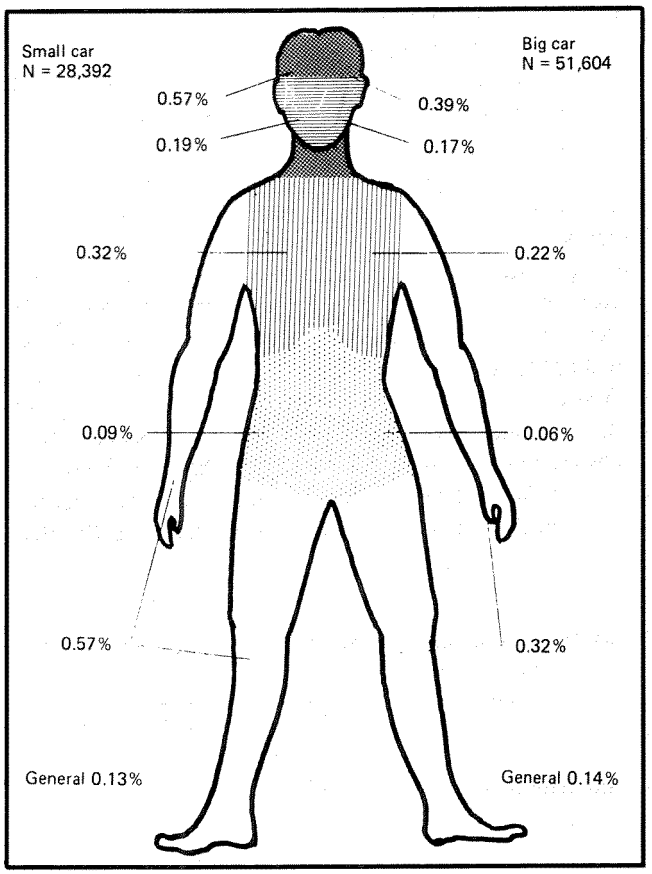


Figure 4. Injury panorama among drivers, a comparison between small and big cars.

Table 6. Injury frequency among drivers related to engine mounting/drive and production start. Car weight below 1,100 kg.

Production start	Injury frequency among drivers: Front engine mounting/ rear drive	Front engine mounting/ front drive	Rear engine mounting/ rear drive
1960–1966	3.0 %	2.8 %	3.8 %
1967–1971	2.2 %	1.9 %	2.0 %
1972–	2.3 %	1.7 %	–

Table 7. Injury frequency among drivers related to engine mounting/drive and production start. Car weight 1,100 kg. and over.

Production start	Injury frequency among drivers: Front engine mounting/ rear drive	Front engine mounting/ front drive	Rear engine mounting/ rear drive
1960–1966	2.2 %	1.8 %	2.6 %
1967–1971	1.5 %	1.8 %	–
1972–	1.4 %	–	–

Table 8. Injury frequency among drivers related to engine mounting/drive and car weight.

Car weight	Injury frequency among drivers: Front engine mounting/ rear drive	Front engine mounting/ front drive	Rear engine mounting/ rear drive
– 849	3.5 %	2.6 %	4.8 %
850–1049	2.5 %	2.2 %	3.3 %
1050–1449	1.7 %	1.8 %	2.4 %
1450–	1.4 %	–	–

—Is the degree of severity higher in old cars than in new ones?
—Does the distribution of injuries on different body areas differ for small and large cars?
—What effect has the safety belt on car safety?

The cars involved in accidents in this study have been divided into different groups concerning their production start. In group 1 production start earlier than 1972 is considered old, production start later or equal to 1972 is a new one. In group 2 an old car has a production start before 1967 and a new one equal or later than 1967. A heavy car is determined by 1,100 kg or more and a light one by less than 1,100 kg.

Big, new cars have the lowest injury risk for all severity grades ($>$ 1,100 kg, production start $>$ 1972 and $>$ 1967 respectively). Small, old cars have the highest injury risk for all severity grades ($<$ 1,100 kg, production start $<$ 1972 and $<$ 1967 respectively). The injury risk for small, new cars almost reaches the safety level of big, old cars (Figures 5-6 and Tables 9-10).

Influence of Seat Belts

Table 11 shows the belt usage rate among the different types of injured car occupants in the present study. All cases where the belt usage is uncertain are in the unknown

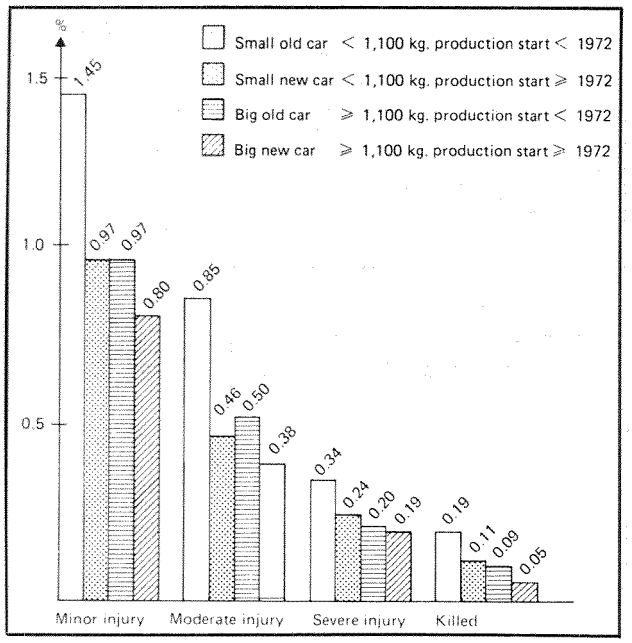


Figure 5. Injury frequency among drivers in %, broken down by production start, car size, and degree of severity, production start < 1972 and ≥ 1972.

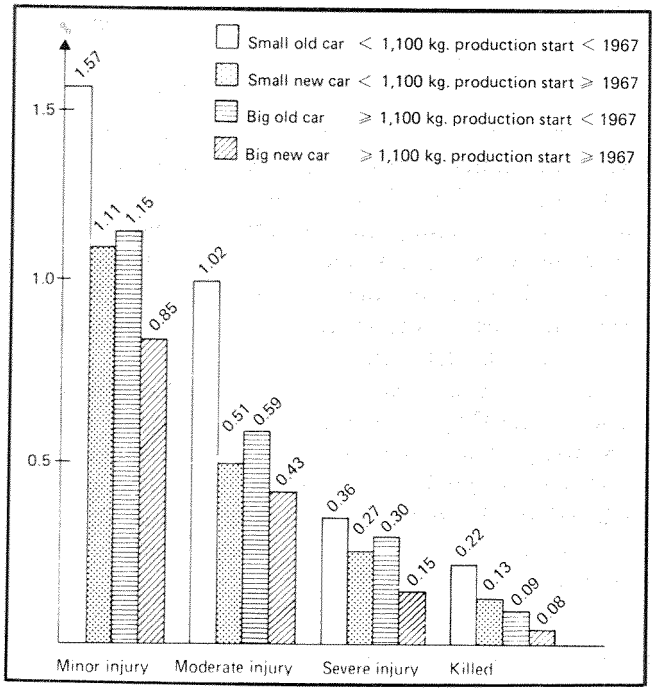


Figure 6. Injury frequency among drivers in %, broken down by production start, car size, and dgree of severity, production strt < 1967 and ≥ 1967.

Table 9. Risk figures for cars with production start < 1972 and ≥ 1972.

	Minor injury	Moderate injury	Severe injury	Killed
Big new cars	100	100	100	100
Big old cars	121	131	105	180
Small new cars	121	121	126	220
Small old cars	181	223	178	380

group. The belt usage rate is judged from police reports, hospital records, questionnaires, and telephone calls. The belt usage rate for front seat occupants in this study is 80%.

Seat Belt Effect

Comparison between Belted and Unbelted Drivers. Among the injured/killed belted drivers 58.2% had a very slight injury compared to 44.4% for injured/killed unbelted drivers. Severe injuries occur twice as often among unbelted drivers and these are killed three times more often than those belted. Injury severity increases with increased speed limits on the site of the accidents. Thus almost 1/3 of the injured/killed unbelted drivers got serious injuries or were killed when the speed limit exceeded 50 km/h on the site of the accident. Only 1% were killed and 5.1% seriously injured among the belted drivers when the speed limit was less or equal to 50 km/h.

Comparison between Belted and Unbelted Front Seat Passengers. The difference in injury severity between belted and unbelted front seat passengers is smaller compared to belted and unbelted drivers. No belted front seat passenger was killed when the speed limit was 50 km/h or less. Among the belted front seat passengers 50.5% had slight injuries compared to 51.2% for those unbelted. 40.3% of the belted front seat passengers had moderate to severe injuries compared to 45.6% for those unbelted.

Distribution of Personal Injuries for Different Body Regions and Injury Severity due to Seat Belt Effect. Another way to study the seat belt effect is to compare the dis-

Table 10. Risk figures for cars with production start < 1967 and ≥ 1967.

	Minor injury	Moderate injury	Severe injury	Killed
Big new cars	100	100	100	100
Big old cars	135	137	200	112
Small new cars	131	119	180	125
Small old cars	185	237	240	275

Table 11. Belt usage among drivers and passengers.

		Driver	Front seat passenger	Rear Seat passenger
Survivors	Belted	812	423	17
	Unbelted	169	123	243
	Belt usage unknown	535	203	49
Fatalities	Belted	27	14	1
	Unbelted	20	4	10
	Belt usage unknown	45	12	2
	< 14 years old	2	33	131
		1,610	812	453

tribution of injuries due to the seat belt use. Figures 7-8 show the injury severity for different body regions. The ISS has been divided into 4 groups:

Slight injuries (survivors)	1-3
Moderate injuries (survivors)	4-10
Severe injuries (survivors)	11-
Fatal injuries	

The body is divided into 6 regions: head and neck injuries, facial injuries, injuries to the extremities or to the pelvic girdle, chest injuries, abdominal injuries or pelvic contents, general injuries, e.g., burns.

All injuries have been classified according to the AIS-system where an AIS 1 is a very slight injury and AIS 6 is a fatal injury. To get a picture of the severity of all injuries to an injured person the ISS (Injury Severity Score) can be used. ISS is the sum of the squares of the three highest AIS on different body regions. Thus it is possible to judge to what extent an injury to a certain body region contributes to the ISS. In the figures the contribution in percent for each injury can be calculated.

For example, if an injured person has got the following injuries head AIS 3, arm AIS 2, stomach AIS 2, the ISS will be 17. If the person survives, he belongs to the group of severely injured. The head has AIS 3 and its contribution to the ISS is 9. 9 out of 17 is 53%. The corresponding figures for arm will be 4 out of 17 which is 23.5% and the same for the stomach. If a person has got only 1 injury, it will contribute 100% to the ISS sum. In Figures 7-8 can be seen that the redistribution of injury for different body regions and injury severity due to seat belt use is mainly concentrated to a decrease of head injuries for serious and fatal injuries, while facial injuries increase in severity more for belted than unbelted drivers.

Belt Usage in the Rear Seat. Because of rising fuel prices and propaganda for ride-sharing, we can expect the number of occupants per car to increase. How safe are you then in the rear seat? A comparison of the degrees of severity for all injuries between unbelted front seat and rear seat passengers shows that the latter have a higher share of severe injuries (see Table 12).

Norin, Tingvall et al. 1980 showed that the injury fre-

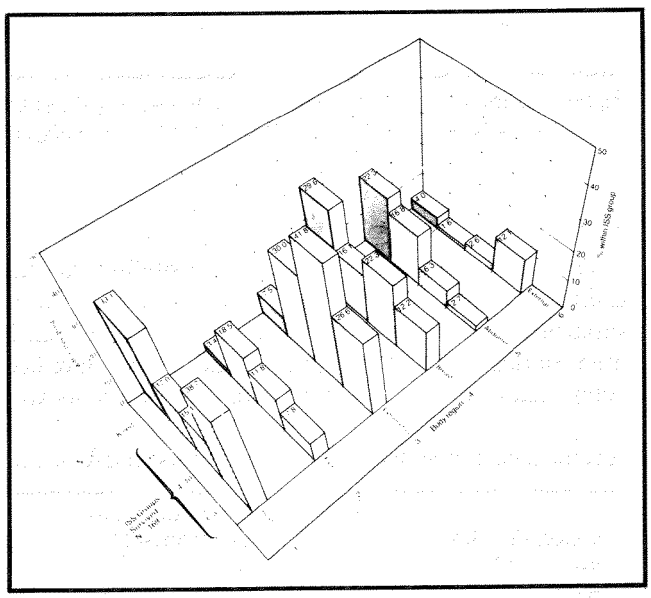


Figure 7a. Injuries distributed according to severity (ISS) and body region for belted drivers.

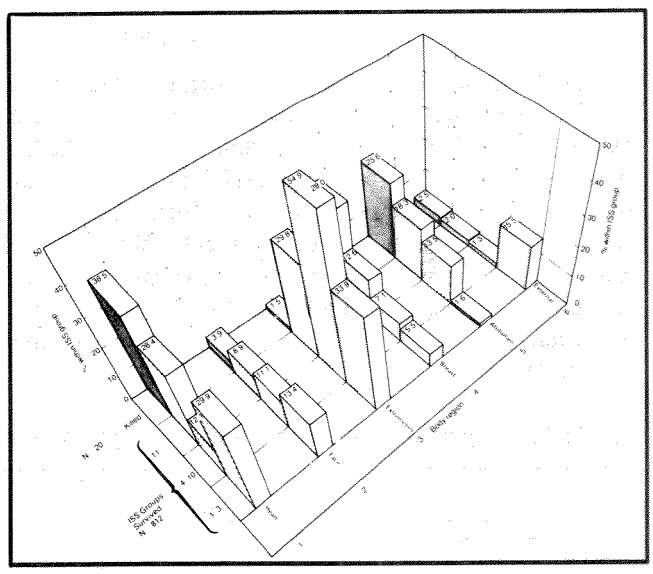


Figure 7b. Injuries distributed according to severity (ISS) and body region for unbelted drivers.

Table 12. Percentage distribution of injuries among unbelted drivers and front seat passengers compared to unbelted rear seat passengers.

Position	Degree of severity in % for different ISS intervals		
	1 - 3	4 - 10	11 -
Unbelted drivers	49 %	29 %	22 %
Unbelted front seat pass.	54 %	35 %	11 %
Unbelted rear seat pass.	49 %	33 %	18 %

quency as well as the injury severity are similar for all occupants' positions if unbelted for individuals over 15 years of age. This was also found by Andersson. These studies were made on Volvo and Saab cars respectively involved in accidents over a certain repair cost limit. In the present study it can be shown that the injury severity is similar for the 3 groups of unbelted occupants.

Experimental as well as single case studies have shown that rear seat passengers become an increased risk for front seat occupants when rear seat passengers move forward against front seat occupants in an accident. This risk primarily occurs when the collision direction is frontal or almost frontal.

In the present study this effect called the "rucksack effect", is defined as when an injured rear seat passenger in a collision direction 10-2 (in a clock diagram) sitting at the same side of the car as the front seat occupant affects the injury risk of the front seat occupant. Four different situations have been studied. For one of them the injury frequency should be affected according to the definition of Table 13.

In the three groups according to the definitions "not affected by rear seat passengers" the hypothesis of different proportions of injured front seat occupants can be rejected.

$$\chi 2 = 1.08 < \chi 2\ (2)\ 0.05 = 5.99$$

The difference between the proportion affected and unaffected groups is statistically significant ($t < 4.77$ $t\ 0.05 = 1.96$). The conclusion is that apart from the fact that both the injury frequency and injury severity are similar for front and rear seat occupants, there is, according to the definition of the rucksack effect, a higher risk for injury for a front seat occupant when an unbelted rear seat passenger is sitting behind in a frontal collision. The average number of injuries and the injury panorama are similar.

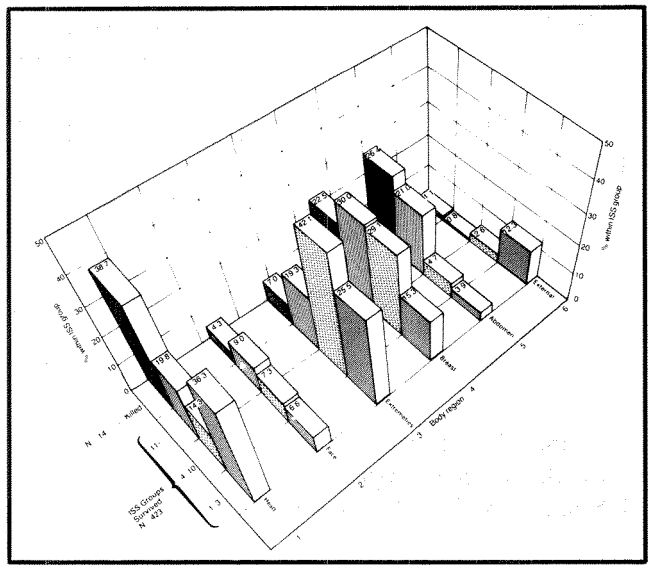


Figure 8a. Injuries distributed according to severity (ISS) and body region for belted front seat passengers.

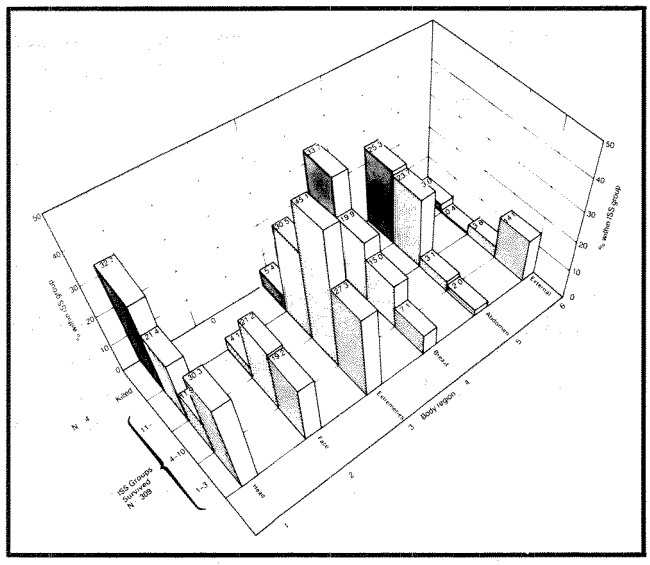


Figure 8b. Injuries distributed according to severity (ISS) and body region for unbelted front seat passengers.

DISCUSSION

This paper has shown some of the possibilities to study traffic accidents using an insurance material. In the insurance records there are a lot of basic data that can be used. In this study all available data about cars have been completed by using car weight, production start, location

Table 13. Proportion of injured front seat occupants for different combinations of seating position and collision directions.

Front seat occupant	Occupants combination vs. rear seat occupants	Collision direction frontal (10-2)	Collision direction save frontal including roll-over
	Diagonal side	32/88 = 36.4%	24/80 = 30.0%
	Same side	75/132 = 56.8%	48/150 = 32.0%

of the engine and type of driving. In cars where persons that have sustained injury deeper investigation has been made; hospital records, police reports, and questionnaires have completed the information about car belt use and personal injury.

The rising number of small cars and their ability to adequately protect their occupants are continuing concerns of vehicle and highway safety experts. The physics of smaller cars prevent them from offering as much car protection in every situation as larger cars. This study shows that small cars have a higher injury frequency than big cars but the difference decreases when a small, new car is compared to a big, old one. As to year model and production start it is evident that the latter has more influence on injury frequency. Production start means a fundamental change of the construction of the car and many changes are intended to increase the safety level. Different year models with the same production start have only minor changes. These changes have less influence on car safety than the fundamental ones for different production starts.

It has also been shown that the seat belt diminishes the injury severity both for the driver and the front seat passenger. The seat belt makes a redistribution of injuries for different body regions and this redistribution is mainly concentrated to a decrease in head injuries, serious and fatal ones. Head injuries are the main killer for all types of traffic accidents and the importance of seat belts is obvious. Few rear seat passengers were belted and an unbelted rear seat passenger had the same injury severity as an unbelted front seat occupant. Furthermore, it is shown that a rear seat passenger who is not belted is a considerable risk for front seat occupants in case of an accident.

CONCLUSIONS

It is hoped that this paper has shown clearly that an insurance material has an enormous potential for amassing information about traffic accidents, especially when vehicle construction is linked to medical data. It is important to study the effect of changes in traffic environment in order to improve positive trends and to stop negative ones. Trends shown in this study are:

1. Small cars have a higher injury frequency than big cars.
2. Small cars have a higher injury severity compared to big cars.
3. Drivers in small cars have more injuries in all body areas except for the face. Face injuries are often caused by the steering wheel. An improvement of the steering wheel construction is desirable.
4. The difference in injury severity and injury frequency is levelled out for new cars. The efforts to make the interior of the car safer have been successful.
5. Unbelted rear seat occupants have the same injury severity as unbelted front seat occupants.
6. Unbelted rear seat occupants are a considerable risk for front seat occupants.

REFERENCES

1. Joksch, Hans; Analysis of the Future Effects of Full Shortage & Increased Usage upon Traffic Death & Injuries, US Department of Transportation, Jan. 1976 Report Nr:DOT-Tsc-OST-75-21.
2. O'Neill, Brian; Ginsburg, Marvin; Robertsson, Leon; The Effects of Vehicle Size on Passenger Car Occupant Death Rates, Society of Automotive Engineers Passenger Car Meeting, Sept. 1977.
3. The Costs of Automobile Safety Regulations, US Department of Transportaton.
4. Norin, H., Nilsson-Ehle, Saratek, E., Tingvall, C.; Bilbältets skadereducerande effekt hos baksätesåkande, Rapport från Volvo Personvagnar AB och Trafiksäkerhetsverket.
5. Bohlin, N. I.; A Statistical Analysis of 28,000 Accident Cases with Emphasis on Occupant Restraint Value; 11th Stapp Car Crash Conference 1967.

Pedestrian Injury Accidents

Report by a working group of
THE EUROPEAN EXPERIMENTAL
VEHICLE COMMITTEE

ABSTRACT

The European Experimental Vehicle Committee set up a working group to examine how car design could take into consideration pedestrian accidents in European countries. This report, prepared by the group, deals with pedestrian accidents statistics and description, injury mechanisms and human tolerances, improvement of vehicle design, test and assessment methods. It states some priorities for action and recommends a number of topics for further research.

FOREWORD

Reducing pedestrian accidents is a very important task to improve traffic safety. One of the most important countermeasures is to reduce the actual driven speed of cars, specially in built up areas, since only few fatal accidents occur below 30 km/h and many accidents above 50 Km/h are fatal. This report is not concerned with this matter, but discusses—according to the general task of the EEVC—appropriate means applied on vehicles to lower the severity of pedestrian injuries.

INTRODUCTION

Conscious that accidents in which pedestrians are struck by cars constitute one of the major problems to be taken into consideration in designing safer vehicles, the EEVC in 1980 set up a Working Group on pedestrians injury accidents, giving to it the following terms of references.

To review the available accident data concerning injuries to pedestrians of different ages involved in road accidents in Europe and make recommendations including priorities for action, for reducing the numbers and severity of such injuries. The group will start its work after the October 1980 meeting of the ESV-Conference and will report to the EEVC by October 1981.

The Report prepared by the Group, in order to meet this requirement, is broken down into the following parts:

- Summary
- Priority for action
- Recommendations for future research
- Chapter 1: Pedestrian accident statistics in relation to the overall accident situation.
- Chapter 2: Description of pedestrian accidents.
- Chapter 3: Current knowledge in injury mechanisms and human tolerances.
- Chapter 4: Increasing pedestrian safety by improvement of vehicle design.
- Chapter 5: Test and assessment methods.

SUMMARY

Importance of the Problem

In the countries studied, pedestrian fatalities ranged between 13 and 33% of the entire number of people killed in traffic accidents, children of less than 10 years and adults of more than 60 years being particularly involved. The data also show that injured pedestrians represent an important percentage of all traffic accident casualties. The uncertainties concerning data acquisition and the disparities of definitions between countries makes it more difficult however, to determine a quantitative valuation for this aspect, despite the serious consequences of permanent disability and the cost of recovery from injury.

The difficulties that exist in obtaining accurate and compatible accident data, which depends upon the cooperation of many different organisations in each country (police, hospitals, etc.) are fully realised; nevertheless the group considers that further attention should be paid to this problem in order to provide data that are more useful.

Description of the Accidents

The study of the statistics of different European countries shows that the pedestrians killed or injured in accidents are especially either children or old people. Figures 1.1. to 1.4. show that age groups 5 to 15 years and more than 60 years are clearly over-represented (the first group especially under "injured", the last one under "killed").

The vehicle hitting the pedestrian is a passenger car in the large majority of the cases (at least 80%).

There is no accurate and reliable information available on the distribution of the vehicle speed at the moment of impact because a simple and precise method of determining this quantity does not exist for real world pedestrian accidents. Some values are published however and it seems that the 50th percentile of the speed of impact of the vehicles involved in the pedestrian accidents is included in the range 16/36 km/h and the 90th percentile in the range of 44/58 km/h.

As for other types of accidents, the speed of the vehicle is a major factor that influences the severity of the resulting injury and measures which tend to reduce this speed are always helpful in terms of pedestrian safety.

Pedestrian body areas, most frequently injured are head

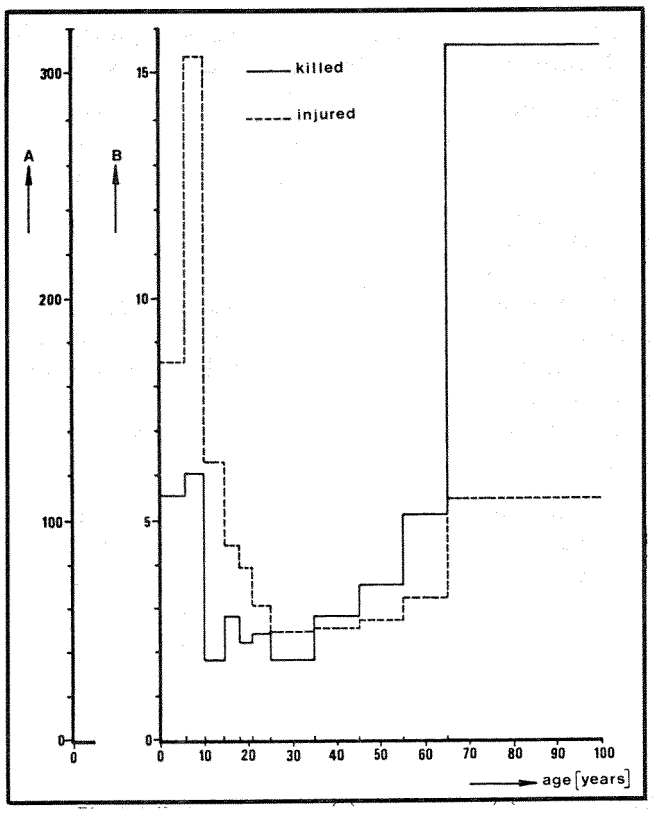


Figure 1.1. Number of killed (B) and injured (A) pedestrians per 100.000 people of the different age groups. Federal Republic of Germany 1979 [9]*.

* Mind the different scales for A (injured pedestrians).

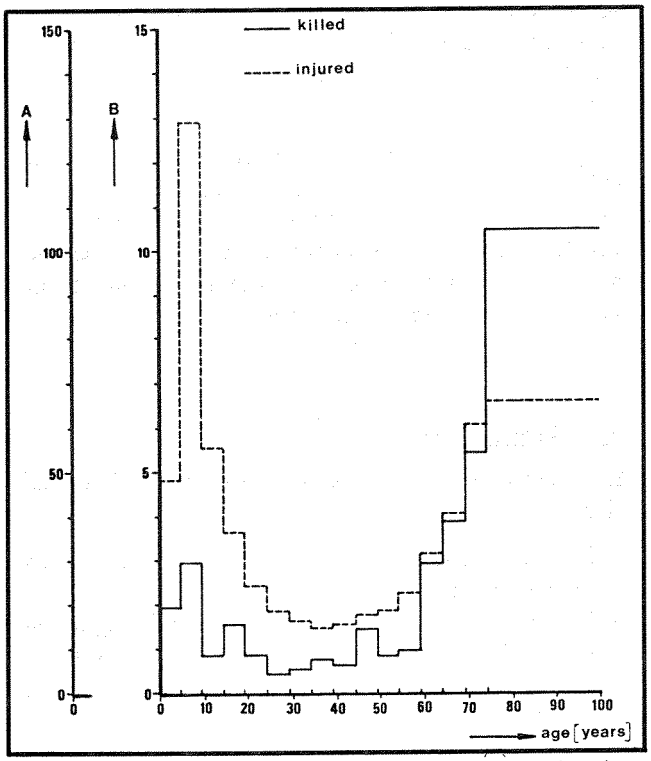


Figure 1.2. Number of killed (B) and injured (A) pedestrians per 100.000 people of the different age groups. The Netherlands 1979 [4]*.

*Mind the different scales for A (injured pedestrians).

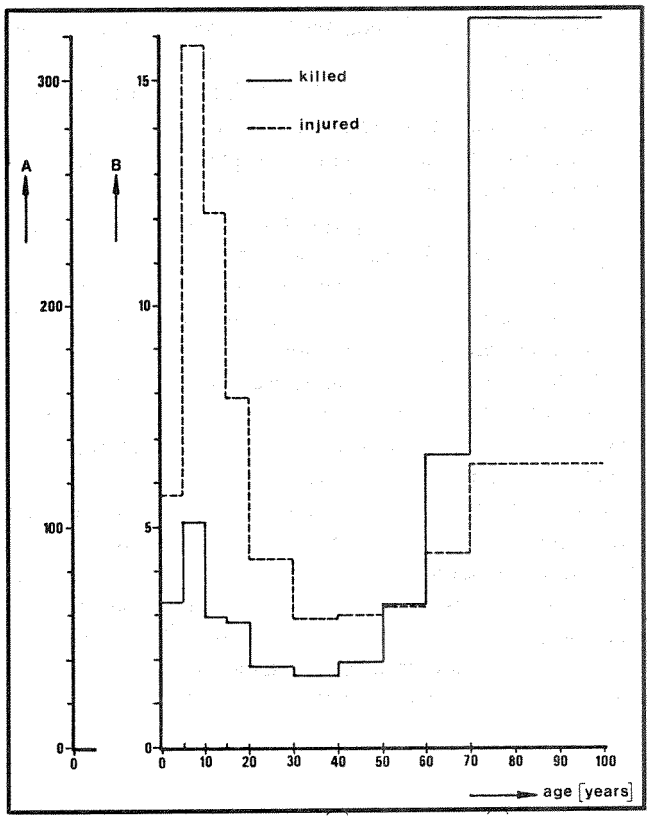


Figure 1.3. Number of killed (B) and injured (A) pedestrians per 100.000 people of the different age groups. Great Britain 1978 [6/7]*.

*Mind the different scales for A (injured pedestrians).

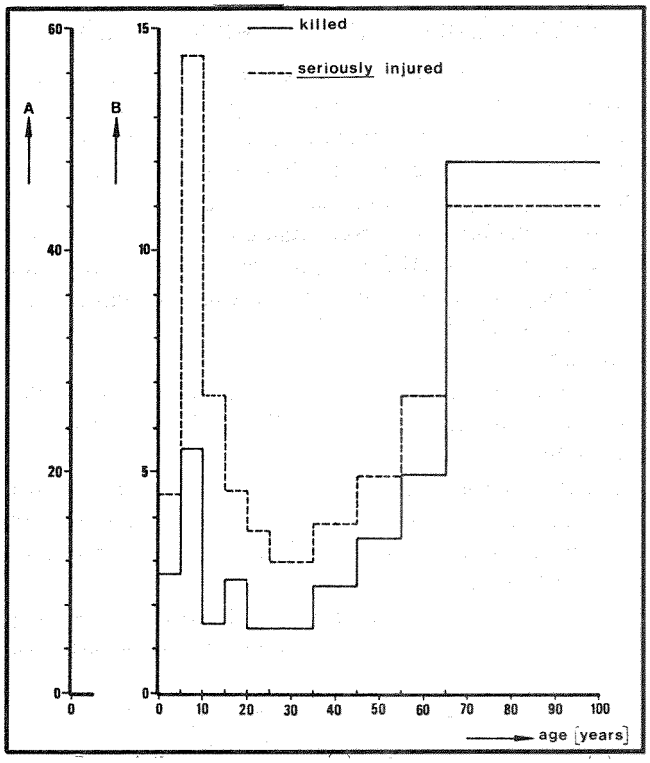


Figure 1.4. Number of killed (B) and seriously injured (A) pedestrians per 100.000 people of the different age groups. France 1978 [8]*.

*Mind the different scales for A (injured pedestrians).

and lower limbs, followed by the arms, the thorax and the pelvis. If we consider only the severe injuries, the order of the three areas is different but the head and the lower limbs stay more frequently involved.

The cause of injuries (vehicle or ground) is difficult to determine in real world accidents because the same area of the body can successively strike both the vehicle and the ground; also an impact with the ground generally leaves no trace. The data suggest however that above a value of impact speed (possibly between 20 and 30 km/h) the vehicle is the leading cause of injury.

Injuries caused by the vehicle are especially attributable to the bumper or bonnet leading edge striking the lower body regions, while injuries to the head result from impacts to the bonnet or the windscreen area.

The shape of the front of the car has an influence on the pedestrian kinematics, not only on its trajectory but also on the velocity of each body segment. The kinematics of a pedestrian is a major factor in determining the occurrence of contacts between the different body segments of a pedestrian and areas of a vehicle, or the ground and also the impact velocity of these contacts.

The shape of the front of the vehicle is therefore important because it can influence the location, occurrence and severity of impacts to different body segments against a vehicle and the ground.

Tolerance Limits and Estimation Criteria

The choice of criteria to allow an estimation of the pedestrian protection performance of a vehicle, will be dependent on the type of simulation chosen. For a complete assessment the criteria should consider the head, the thorax, the pelvis and the lower limbs.

Head criterion. The current standard for assessing head impact severity is HIC with a tolerance limit of 1000. The Group considers however that a more complete understanding of injury and tolerance levels of the head is necessary.

Thoracic criterion. A criterion of deflection seems the most pertinent and the value of 30% deflection would be acceptable.

Pelvis criterion. A value of a limited strength seems more realistic than a value of acceleration. It is anticipated that current research will determine a suitable value in the near future.

Tolerance for the lower limbs is related to the bending moment at any section of the limb, but the location of the maximum bending moment is difficult to predict and its position may change for different shapes of car front. Measurement of this quantity is therefore difficult and a possible solution is to equip dummies with frangible lower limbs which fail at a chosen level, that corresponds to the tolerance.

Reduction of the Severity of Accidents by Improvement of the Conception of the Vehicle

The analysis of accidents and of injury mechanisms shows the importance of the kinematics of a pedestrian during an accident. Compared with car occupants whose position at the moment of an accident is roughly always the same, the pedestrian can be hit by different elements of the car and in varied configurations; the position in which he falls to the ground is also variable. This complexity is worsened by the variety of the victim's stature, particularly with respect to the considerable proportion of children involved.

The characteristics of car design must therefore be considered under two requirements:

—their influence on the general kinematics of an impacted pedestrian which mainly depends on their geometric definition (shape of the front end of the car). The kinematic response directly controls the impact speed of the head, for example against the bonnet, the windscreen or its frame;
—their behaviour in the direct impact against areas of the body, which is related to their stiffness and their capacity of energy absorption.

Some improvements of the design of the vehicles can bring safety benefits in two ways:

—by localised improvements in the behaviour under impact of the most aggressive components;
—a more general and widespread improvement may result from controlling the kinematics, in particular by limiting the impact speed of the head and the rotational speed of the body.

The published data concerning the relationship between a vehicle's configuration and the kinematics of an impacted pedestrian do not allow precise conclusions to be drawn. A more uniform definition of characteristic vehicle shapes and dimensions would be a starting point from which to make progress in this field.

Crash Simulation

There are three main ways of pedestrian accident simulation:

—the full-scale tests in which a vehicle hits a dummy (or possibly a cadaver);
—the rig tests in which an impactor simulating a segment of human body hits a chosen area of a vehicle;
—the mathematical modelling of a vehicle hitting a pedestrian.

Full-scale tests use dummies to represent a pedestrian and to assess the interaction between the vehicle and the pedestrian. The tests are complicated, have poor repeat-

ability and their high cost makes an extensive series of tests very expensive.

The value and scope of this form of test is to a large extent restricted by the limitations of the design of existing pedestrian dummies (realism, reproducibility, faithfulness). Work in progress on dummies for side impact work should assist in the design of pedestrian dummies that have a more realistic performance.

Rig tests cannot give a global view of the safety potential of a vehicle for a pedestrian and in particular give no evaluation of the kinematics; moreover, the values of criteria to be taken into consideration have to be determined empirically from full-scale tests. However, the results of these tests depend on the behaviour of the dummies which will, therefore, also influence the rig test criteria. In the case of a regulation, rig tests could have the advantage of being simple, reproducible and could classify the capabilities of energy absorption of several components of the vehicles.

Mathematical models are very interesting tools because they have a perfect repeatability and they therefore enable an assessment of the influence of even minor modifications to a vehicle. They are cheap in use and can even be used before the vehicle is actually produced. However, they can give good results only if they are correctly validated. Since the validation is principally based on the results of full-scale tests, mathematical models suffer from the previously discussed limitations of existing dummies and further development and validation will be necessary, particularly in order to reproduce improved test methods.

No single method, from amongst the three proposed above can give an overall evaluation of the safety offered by a vehicle in its interaction with pedestrians, but all three methods can be looked upon as being complementary.

—Because of their low cost, component tests make it possible to verify a larger number of situations than the full-scale tests.
—The mathematical model makes it possible to perform full-scale tests in what are, *a priori*, the most critical configurations for pedestrian protection: inversely, the full-scale test is necessary to validate the kinematics established by the mathematical model.
—The mathematical model provides impact speeds to be taken into consideration in component testing: inversely, certain parameters of the model (characteristics of rigidity) must be measured by means of component testing.

PRIORITIES FOR ACTION

The Working Group has examined the possibilities of pointing out avenues for immediate action that would lead to improvements for vehicles in terms of pedestrian safety.

The Group has run up against the difficulty of the complexity of this problem particularly with regard to the very different size of victims (children, elderly people) and that of very different injury types (of which the most frequent are those to the lower extremities and to the head).

Thus, the only improvements to the car that the Group can at this moment encourage, concern the following:

1) the use of energy-absorbing materials in the front structures of cars;
2) the elimination or masking/concealing of car features that are aggressive by their rigidity or their shape (windscreen frame and scuttle, A-pillars. . .).

Even though it is not possible on the basis of these general recommendations to propose definitive rules for vehicle construction, vehicle manufacturers should be encouraged to take account of the above general recommendations for development when making improvements to their vehicles.

In parallel, the more in-depth research indicated in the following recommendations, which is necessary before establishing a regulatory test procedure concerning pedestrian safety, should be undertaken.

RECOMMENDATIONS FOR FUTURE RESEARCH

1. More notice should be given to pedestrian accidents, especially to:
   —accident registration systems;
   —standardisation of definitions and registration to give data that are more useful and also directly comparable internationally.
2. The safety benefits to be expected from improvements in vehicle design seem to be most important for the speed range up to 40 km/h, and research should be focused on that speed range.
3. More attention should be paid to long-term consequences of injuries; this is considered a deficiency of existing injury-scaling systems (like AIS). In pedestrian casualties even "minor" (e.g., ligament) injuries seem to be important under this respect.
4. Further research is needed into injury producing mechanisms (e.g., the influence of translational and rotational accelerations on the brain) in order to develop more pertinent protection criteria for head injuries.
5. The present knowledge on lower limb tolerance levels is not satisfactory and a more precise range of values should be determined for this tolerance. The influence of mss, height and ge on the tolerance limits should be determined.
6. Further research is needed on the influence of vehicle characteristics (shape, stiffness of impacted parts. . .) on the victim's kinematics and the resulting injury

patterns and severity. A uniform definition of characteristic vehicle shapes and dimension parameters must be developed.
7. The dummies presently available are not satisfactory for reproducing pedestrian kinematics and further research is needed to obtain dummies that give a more realistic representation of pedestrians.
8. When using human substitutes for pedestrian protection research and tests, examples should be chosen that represent the age, height, . . . of pedestrians most frequently involved in accidents. These differ from the 50th percentile male commonly used in vehicle occupant and pedestrian tests.
9. Available mathematical models should be further validated.

CHAPTER 1. PEDESTRIAN ACCIDENT STATISTICS IN RELATION TO THE OVERALL ACCIDENT SITUATION

SUMMARY

Tables are given of numbers of killed, seriously and slightly injured pedestrians and other road users for the countries participating in this Working Group* for the years 1975 to 1979, (statistics for 1980 are generally not yet available). Some information is also given for Italy. Finally an age distribution for killed and injured pedestrians is included for the year 1979.

Differences in the definitions of some of the terms used by the various sources of statistical information are discussed.

Sources and Definitions

Sources

Statistical material for this chapter comes from the official national statistical authorities, i.e., for:

—Federal Republic of Germany "Statistisches Bundesamt"
—France: "Statistiques Nationales"
—The Netherlands: "Centraal Bureau voor de Statistiek"
—Sweden: "Official Statistics of Sweden" and "Swedish Road Office"
—United Kingdom: "National Road Accident Statistics"
—Italy: "Ministero dei Trasporti".

* Federal Republic of Germany, The Netherlands, Sweden, the United Kingdom and France.

Definitions

Part of the differences between the numbers who were killed or injured in the different countries can be ascribed to differences in definitions, and some of these are therefore given:

The definition of traffic accidents [2]:
Accidents included are those:

(a) which occurred or originated on a highway or street open to public traffic,
(b) which resulted in one or more persons being killed or injured, and
(c) in which at least one moving vehicle was involved.

These accidents therefore include collisions between vehicles, between vehicles and pedestrians, and between vehicles and animals or fixed obstacles.

Single vehicle accidents, in which one vehicle (and no other road user) was involved, are excluded.

Multi-vehicle collisions are counted as only one accident, provided that the successive collisions happen at very short intervals.

The definitions of a *pedestrian* differ in some countries. For instance in the United Kingdom [3] and The Netherlands [4] it includes persons riding toy cycles on the footpath, persons pushing for instance bicycles, but in Germany these groups are not included [5].

Definitions of "*traffic accident death*" are generally the same for most of these countries; they concern victims who die within 30 days of a traffic accident, with the exception of France and Italy where a period respectively of 6 and 7 days is used. Comparable figures can be calculated, for which a factor of 1,09 for France and 1,07 for Italy for all road users is used [1]. Care must be taken when using this factor for a specific group of road users, for instance pedestrians.

Greater differences exist in the definitions of *seriously* and *slightly injured.* In *Germany* and *The Netherlands* the criterion is whether the victim has been hospitalized (in-patient) or not and in *France* whether the duration of the hospitalisation is more or less than 5 days. In the United Kingdom and Sweden no precise definition exists for all cases: A casualty detained in hospital as an in-patient should always be classified as serious. Examples of (other) serious injuries are: fracture, internal injury, severe cuts, crushing, concussion, severe shock requiring hospital treatment, injuries to casualties who die more than 30 days after an accident.

Slight injury: any non-fatal injury not classified as serious.

Examples are: sprains, bruises, minor cuts, slight shock.

There are however some other factors which cause a part of the differences in the numbers presented by the countries.

—Criteria for hospitalisation differ from country to

country, and even between hospitals within countries.

—National statistical authorities get their information from police reports. Presence of policemen therefore is a condition for admission into the databank, this presence being strongly influenced by the seriousness of the accident.

Less serious accidents are often not reported to or by the police: this is more common in some countries than in others. It is safer to compare the relative proportion of injured pedestrians because the above-mentioned differences between countries may apply a great extent to both pedestrians and other casualties.

Reporting of traffic fatalities will be about 100 percent, so comparisons based on the number of deaths will be far more reliable than those based on the number injured.

Numbers

Although it seems to be difficult to compare the numbers of the injured road users for the different countries, it follows from the numbers of the fatalities that the pedestrian accident situation is an important one (Table 1.1.).

The proportional share of killed pedestrians shows remarkable differences from 13,3% in the Netherlands to 33,3% in the United Kingdom in 1979. For the other countries the figures are:

Germany	23,9%
Sweden	22,7%
France	17,1%
Italy	21,5%

This may be partially explained by a difference in the modal split. For instance in The Netherlands the bicycle is very popular and as a result of this high exposure, many bicyclists are injured and killed in accidents (in 1979 more bicyclists than pedestrians were killed: 19,9% against 13,3%). The number of seriously and slightly injured casualties, show the same tendencies (Tables 1.2., 1.3.): 11,9% in The Netherlands against 22,8% in the United Kingdom for seriously injured pedestrians; for slightly injured the figures are 8,5% against 18,7% (all figures for 1979).

The less serious the injuries, the lower is the relative pedestrian share. A possible explanation: pedestrian accidents generally lead to more life-threatening injuries than other accidents. Another reason may be that with pedestrian accidents generally there will be less damage to the car (etc.) involved, which may result in less involvement of—and reporting by—the police, especially in cases of less serious injury.

Different tendencies during the years 1975 to 1979 can be recognised in the countries:

—France and United Kingdom: The total traffic death-toll varies from 1975 to 1979 whereas the pedestrian share falls off.

—Germany and The Netherlands: The total number varies from 1975 to 1978 and decreases in 1979. Furthermore the proportional share for pedestrians goes down.

—Sweden: The total number killed in traffic decreases from 1975 to 1978 and decreases sharply in 1979, while the percentage for pedestrians rises in that last year.

—Italy: The total number killed in traffic accidents decreases from 1975 to 1978, but rises in 1979, contrary to the other countries. The pedestrian share decreases in all these years.

Distribution of Pedestrian Casualties by Age

To know something more about the pedestrians that are killed or injured in road accidents, a distribution of casualties by age is made.

Age is one of the pedestrian parameters, which is easy to get, and is related (to some extent) to height and resistance against injury.

The distributions were not available on the same base for all the countries. Therefore a subdivision is made into a number of common classes:

Less than 15 years, 15 to 64 years and more than 64 years (Table 1.4.). The percentage of the fatalities in the 0.14 year group ranges from 9,0% in Sweden to 22,4% in The Netherlands. The age group 15-64 years, from 35,4% in Germany and The Netherlands, to 48,8% in France. And the elderly adults from 35,4% in France to 55,6% in Sweden. For the injured the age distribution generally shows an opposite tendency. With the exceptions of Sweden and Italy: the percentage of the injured in the age group 0-14 years is much higher than for elderly adults.

An indication of the risk that pedestrians from specific age groups have of being killed or injured in traffic accidents, may be obtained by relating the numbers killed or injured to the corresponding population in each age group.

Several other exposure measures such as miles travelled, or time in traffic are used in calculating risk factors. Discussion about the most suitable criteria is still going on.

Details of age distribution were available for France, Germany, The Netherlands and the United Kingdom (Table 1.5-1.8.; Figs. 1.1.-1.4.).

The number of casualties differ between the four countries, but there is a similar trend between them:

The elderly are over-represented in the death-toll, while the contrary is true for the injured.

Table 1.1. Fatally injured.

	France			Germany			The Netherlands			Sweden			United Kingdom			Italy		
Year	ped.	all	%	ped.	all	%	ped.	all	%	ped.	all	%	ped.	all	%	ped.	all	%
1975	2,517	12.996	19,5	3.973	14.870	26,7	396	2.321	17,1	240	1.172	20,5	2.344	6.366	36,8	2.317	9.511	24,4
1976	2.463	13.577	18,1	3.991	14.820	26,9	403	2.432	16,6	247	1.168	21,1	2.335	6.570	35.5	2.148	8.927	24,1
1977	2.362	12.961	18,2	3.748	14.978	25,0	384	2.583	14,9	181	1.031	17,6	2.313	6.614	35,0	1.919	8.221	23,3
1978	2.118	11.957	17,7	3.788	14.662	25,8	368	2.294	16,0	189	1.034	18,2	2.427	6.831	35,5	1.845	7.965	23,2
1979	2.091	12.197	17,1	3.159	13.222	23,9	263	1.977	13,3	178	0.782	22,7	2.118	6.352	33,3	1.787	8.318	21,5

Table 1.2. Severely injured.

1975	14.828	92.725	16,0	26.380	138.038	19,1	2.934	20.690	14,2	989	6.728	14,7	18.471	77.122	24,0	For Italy no separate data for serious and slight injuries available.
1976	13.647	91.539	14,9	27.035	145.728	18,6	2.697	21.156	12,7	926	6.679	13,9	18.295	79.531	23,0	
1977	13.692	92.246	14,8	27.292	153.735	17,8	2.735	22.572	12,1	910	6.529	13,9	19.170	81.681	23,5	
1978	13.128	86.927	15,1	26.598	153.310	17,3	2.607	21.505	12,1	871	6.431	13,5	18.912	82.518	22,9	
1979	13.494	90.006	15,0	24.546	146.526	16,8	2.258	18.984	11,9	844	5.589	15,1	18.329	80.544	22,8	

Table 1.3. Slightly injured.

1975	28.549	253.001	11,3	33.653	319.759	10,5	3.492	38.968	9,0	1.134	14.081	8,1	48.507	241.462	20,1	32.335	229.898	14,1
1976	27.450	256.206	10,7	34.195	334.853	10,2	3.436	41.114	8,4	1.142	15.164	7,5	47.879	253.572	18,9	30.702	217.976	14,1
1977	27.650	253.854	10,9	34.639	354.407	9,8	3.409	41.887	8,1	1.108	14.387	7,7	49.793	259.766	19,2	28.693	209.354	13,7
1978	26.912	240.813	11,2	33.015	355.334	9,3	3.313	40.571	8,2	1.085	14.142	7,7	48.956	260.446	18,8	27.720	207.556	13,4
1979	27.965	245.898	11,4	31.713	339.915	9,3	3.175	37.582	8,5	1.073	12.393	8,7	46.267	247.617	18,7	27.702	221.574	12,5

Note: Absolute and relative number of different categories of casualties for different countries for the years 1975-79 [3/4/5/8/10/11]. Care must be taken in interpreting these figures; see the remarks in chapter 1, paragraph 1.1.

Table 1.4. Absolute and relative number of different categories of casualties for different countries for three age groups. (1979) [3/4/5/8/10/11].

Age [years]	France						Germany						The Netherlands					
	Fatality	Percent	severe injury	Percent	Slight injury	Percent	Fatality	Percent	Severe injury	Percent	Slight injury	Percent	Fatality	Percent	Severe injury	Percent	Slight injury	Percent
0-14	330	15,8	4.028	29,9	9.918	35,4	471	14,9	9.644	39,4	12.003	38,1	59	22,4	1.126	50,1	1.372	43,3
15-64	1020	48,8	6.115	45,3	13.608	48,7	1203	38,1	9.330	38,1	14.552	46,2	93	35,4	.689	30,6	1.320	41,7
>64	741	35,4	3.351	24,8	4.439	15,9	1481	47,0	5.500	22,5	4.932	15,7	111	42,2	.434	19,3	.472	14,9
Total	2091	100	13.494	100	27.965	100	3155	100	24.474	100	31.487	100	263	100	2.249	100	3.164	100

Age [years]	Sweden						United Kingdom						Italy			
	Fatality	Percent	Severe injury	Percent	Slight injury	Percent	Fatality	Percent	Severe injury	Percent	Slight injury	Percent	Fatality	Percent	Injury	Percent
0-14	16	9,0	199	23,6	209	19,5	379	17,9	6.979	38,3	18.996	42,6	249	13,9	6.829	24,7
15-64	63	35,4	414	49,1	656	61,1	883	41,7	7.803	42,9	20.404	45,8	669	37,5	13.771	49,7
>64*	99	55,6	231	27,3	208	19,4	855	40,4	3.422	18,8	5.146	11,6	869	48,6	7.102	25,6
Total	178	100	844	100	1073	100	2117	100	18.204	100	44.546	100	1787	100	27.702	100

* For Italy the age group over 64 includes pedestrians of unknown age.

Table 1.5. Detailed data from West Germany 1979 [5/9].

Age group (from under ..... to ..... years)		Fatally injured pedestrians				Injured pedestrians				
		Male ♂	Females ♀	Σ	Per 100,000 persons	Slightly	Seriously	Σ	Per 100,000 persons	People in this age group
Children	< 6	118	78	196	5.6	3207	2836	6043	171.3	3,528,116
	6-10	101	81	182	6.0	5110	4148	9258	307.7	3,008,564
	10-15	57	36	93	1.8	3686	2660	6346	126.0	5,035,455
Adults	15-18	42	44	86	2.8	1675	1099	2774	89.3	3,106,566
	18-21	43	21	64	2.2	1379	900	2279	78.2	2,914,553
	21-25	74	12	86	2.4	1351	826	2177	61.3	3,551,247
	25-35	114	33	147	1.8	2601	1385	3986	49.3	8,079,867
	35-45	214	48	262	2.8	2957	1838	4795	51.4	9,335,784
	45-55	193	65	258	3.5	2427	1604	4031	54.1	7,453,323
	55-65	157	143	300	5.1	2162	1678	3840	65.7	5,845,819
Elderly	> 65	673	808	1481	15.6	4932	5500	10432	109.8	9,499,539
	Without information	3	—	3	—	139	50	189	—	
	Σ									61,358,833

Table 1.6. Number of killed and injured pedestrians; number of killed and injured pedestrians per 100,000 people of the different age groups in 1979 in The Netherlands [4].

Age [years]	Killed	Injured	People in this age group	Killed per 100.000	Injured per 100.000
0- 4	17	430	882,115	1,93	48,7
5- 9	32	1.391	1,079,301	2,96	128.9
10-14	10	677	1,222,704	0,82	55,4
15-19	19	452	1,247,665	1.52	36,2
20-24	10	286	1,191,238	0,84	24,0
25-29	5	208	1,146,856	0,44	18,1
30-34	6	191	1,187,724	0,51	16,1
35-39	7	136	915,761	0,76	14,9
40-44	5	124	804,944	0,62	15,4
45-49	11	134	767,397	1,43	17,5
50-54	6	136	727,818	0,82	18,7
55-59	7	160	719,816	0,97	22,2
60-64	17	182	582,351	2,92	31,3
65-69	21	221	540,279	3,89	40,9
70-74	24	270	443,627	5,41	60,9
75+	66	415	631,418	10,46	65,7
Total	263	5.439	14,091,014	1,87	38,6

Table 1.7. Detailed pedestrian injury data for Great Britain 1978 [6/7].

	Age group years	Fatally injured				Injured				People in age group (thousands)
		Male	Female	Σ	Per 100,000 persons	Slightly	Seriously	Σ	Per 100,000 persons	
Children	0-4	69	44	113	3.3	2880	1003	3883	113.9	3409
	5-9	138	78	216	5.1	9822	3591	13413	315.5	4251
	10-14	78	56	134	2.9	8282	2868	11150	240.9	4628
Adults	15-19	69	55	124	2.8	5199	1772	6971	157.5	4424
	20-29	93	45	138	1.8	4986	1705	6691	85.1	7857
	30-39	85	29	114	1.6	3246	1002	4248	58.4	7271
	40-49	75	48	123	1.9	2705	1053	3758	59.3	6339
	50-59	133	84	217	3.2	2900	1365	4265	63.9	6671
Elderly	60-69	199	175	374	6.6	3305	1669	4974	87.4	5692
	70+	385	482	867	16.4	3948	2786	6734	127.1	5295
	Without Information			7	—	1683	98	1781		
	Σ			2427	—	48956	18912	67868		55837

Table 1.8. Detailed pedestrian injury data for France 1978[8].

	Age group years	Fatally injured				Injured				People in age group
		Male	Female	Σ	Per 100,000 persons	Slightly	Seriously	Σ	Per 100,000 persons	
Children	0-4	72	28	100	2.7	1663	681	2344	62,6	3.741.779
	5-9	126	83	209	5.5	5180	2191	7371	194,0	3.798.586
	10-14	40	27	67	1.6	2761	1134	3895	92,1	4.227.843
Adults	15-19	65	44	109	2.6	1902	790	2692	63,1	4.269.154
	20-24	44	18	62	1.5	1683	606	2289	54,3	4.213.738
	25-34	86	34	120	1.5	2762	963	3725	45,4	8.208.785
	35-44	118	26	144	2.4	2140	928	3068	50,8	6.036.551
	45-54	164	62	226	3.5	2411	1260	3671	56,7	6.474.679
	55-64	152	77	229	4.9	2047	1202	3249	69,8	4.656.647
Elderly	> 65	424	428	852	11.1	4363	3373	7736	101,1	7.648.826
	Σ	1291	827	2118		26912	13128	40040		53.276.588

The difference in resistance to injuries will be the cause of that to a great extent; older people die more frequently as a result of an accident than do children, who comparatively tend to come away with (slight) injuries only.

The wide age distribution of injured pedestrians with peak levels for the age group < 15 years, brings into question the appropriate stature for a representative dummy (or model). The use of 50th percentile height of pedestrian accident victims has been reported as 1,60-1,65 m [6/26]*; the dummies in current use are 1,75 m high.

* Numbers refer to literature of chapter 2.

REFERENCES

1. Statistical Report on Trends in Road Accidents in 1979 CM(81)12. (European Conference of Ministers of Transport).
2. Statistics of Road Traffic Accidents in Europe 1979 United Nations 1980.
3. Department of Transport-Scottish Development Department Welsh Office. Accidents in Great Britain 1979, London 1981 (H. M. Stationery Office).
4. Statistiek van de verkeersongevallen op de openbare weg 1979. Centraal Bureau voor de Statistiek.

5. Strassenverkehrsunfälle 1979. Statistisches Bundesamt Wiesbaden. Statistische Jahrbücher für die BRD.
6. Department of Transport, Scottish Development, Department Welsh Office. Road Accidents in Great Britain 1978, London 1980 (H. M. Stationery Office).
7. Central Statistical Office, Annual Abstract of Statistics 1980 Edition. London 1980 (H. M. Stationery Office).
8. France, Ministère des Transports, Direction des Routes et de la Circulation Routière. Accidents corporels de la circulation routière 1979. Paris 1981.
9. Verkehr in Zahlen. Der Bundesminister für Verkehr DIW, Berlin, 1980.
10. Official statistics of Sweden and Sweden Road Safety Office.
11. Italy: Ministero dei Trasporti.

CHAPTER 2. DESCRIPTION OF PEDESTRIAN ACCIDENTS

SUMMARY

The purpose of this chapter is to determine the types of pedestrian accident that occur most frequently, and to identify the important features of car to pedestrian impacts.

The rate of involvement of cars in pedestrian accidents is first described and this is followed by the distribution of location of primary impacts on the car, after which a listing is given of body parts most frequently and/or most seriously injured. In a number of research projects (especially "in-depth, at the scene studies") an attempt has been made to establish the sections of a car which caused injury and a description of some published results is given in 2.4. In 2.5 some cumulative distributions of impact speeds, found in several publications, are described, while in 2.6 the chapter ends with some information, as to whether the car was braking or not before the accident.

Pedestrian Accidents and the Involvement of Cars

Distributions of crash partners can most frequently be found in in-depth studies.

In several of these studies the groups of pedestrians forming the samples were of different types. These differences are not only due to the differences between countries, but also due to the fact that the groups under study differ; for instance, in injury severity.

In [22] for 87,6% of the accidents studied, the pedestrian was struck by a car. The sample in this project consisted of pedestrians who were taken to a hospital.

In [15] the group is quoted in an insurance data base, and cars were claimed to have been involved in 80% of the cases. In [23] the group consisted of fatally injured pedestrians: the proportion for cars was 64%, only those cases were considered where one pedestrian collided with one vehicle.

As a general rule, the private car is in most cases the opponent for the pedestrian casualties.

Location of the Primary Impact

The next distribution which is of interest is the position of the pedestrian relative to the car, prior to impact. Details available are almost all concerned with the distribution of location of the first impact to the car (Figures 2.1. and 2.2.) with no correlation of the orientation of the pedestrian. Studies show that about 75% of the cases a pedestrian is impacted by the car front (as mentioned in chapter 1; differences in injury severity, of the group considered, may influence the resulting distributions).

In [18] a distribution of the location of primary contact to the pedestrian is given. In almost all these cases (92%)

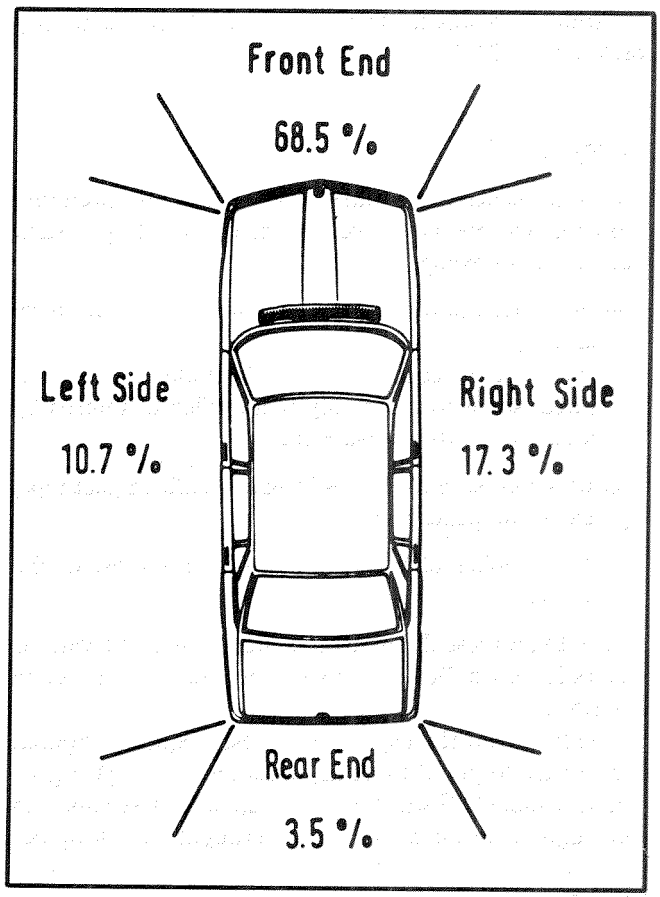


Figure 2.1. Location of primary impact for cars in pedestrian accidents [12].

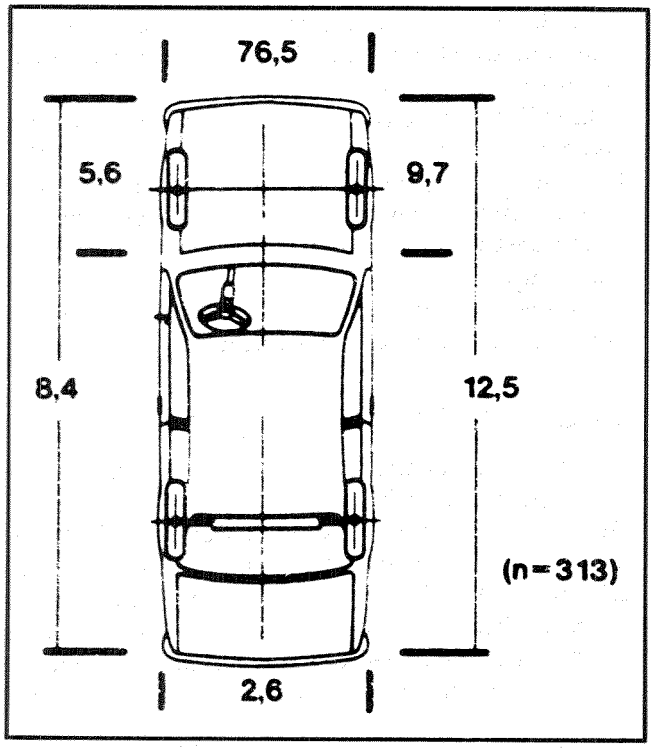


Figure 2.2. Location of primary impact for cars in pedestrian accidents [24].

the pedestrian was hit from the side. [6] gives a comparable figure: 91%.

Injury Distribution

Several pedestrian injury distributions in literature show remarkable differences. These are to a large extent due to the following:

—the groups of casualties under study differ in injury severity.
—some groups consist of all pedestrians killed or injured, some consider only those killed or injured by a conflict with a private car.

Others consist of casualties from a specific impact type, e.g., car front/pedestrian side.

—The number of body areas differs for most of the studies.

Due to all these differences, comparison of the various studies is very difficult, although some tendencies can be described:

The head and the legs are the most frequently injured body areas, followed by arms, chest and pelvis [16] [22].

One sample [22] was formed by 2,000 pedestrians who were injured in an accident and brought to a hospital, while another [16] consisted of all pedestrians who were brought to that group of hospitals that receives 95% of all the traffic casualty in-patients in The Netherlands.

Table 2.1. Percentage distribution of pedestrian's injured body segment.

	[16]	[22]
Head	44%	37%
Legs	31%	34%
Arms	10%	14%
Chest	6%	7%
Pelvis/Abdomen	9%	7%
Back	—	1%

The number of injuries in both studies are 100%

The percentages from the two studies are shown in Table 2.1. In both studies 100% represents the total number of injuries.

In [10] only pedestrians are considered who were impacted at the side by the front of a car. A division is made based on the Overall Injury Severity Scale. If all severities of injury are considered then the legs and the head are the most frequently injured body areas, followed by the arms, pelvis, chest and abdomen.

If only non-minor injuries are considered, the head

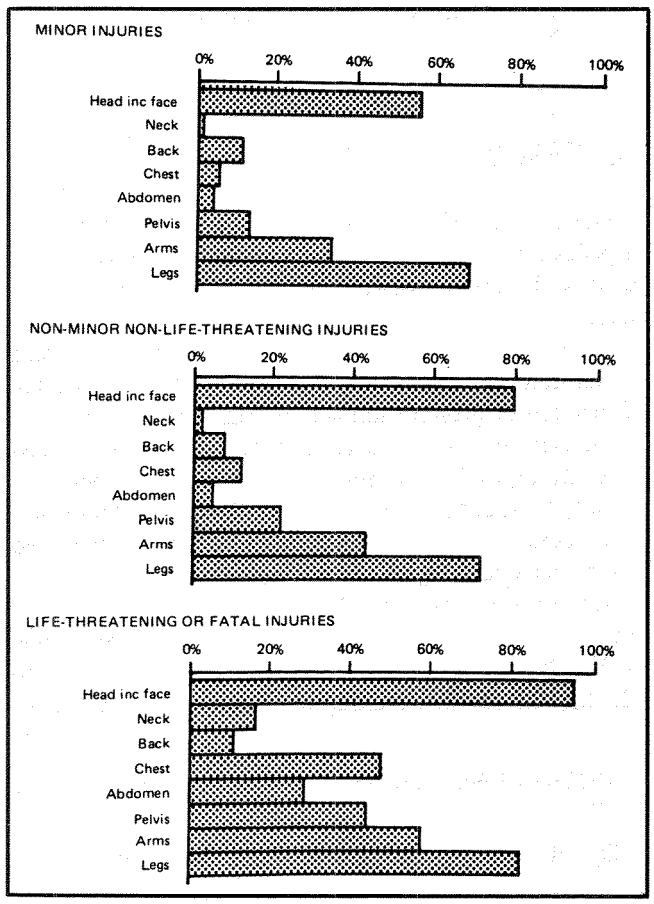
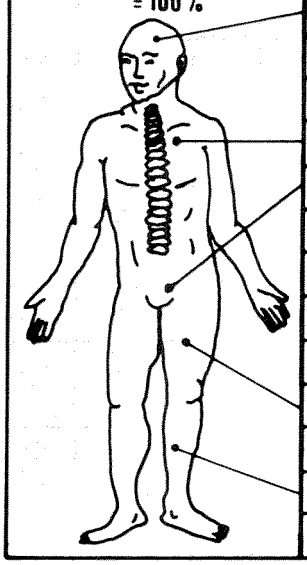


Figure 2.3. Patterns of injury by overall injury severity for 568 pedestirns with minor injuries, 739 pedestrins with non-minor non-life-threatening injuries, and 253 pedestrians with life-threatening or fatal injuries.—Frontal contacts, all injuries counted [10].



* Total: 321 Children (up to the Age of 15 Years) = 100%

Body Areas Injured \ Injury Severity	AIS 1		AIS 2		AIS 3		AIS4/5		AIS 6		Total Injuries per Body Area No.=100%	* %
	No.	%*	No.	%*	No.	%*	No.	%*	No.	%*		
Head	152	64.1	35	14.8	14	5.9	18	7.6	18	7.6	237	73.8
Cervical Spine	2	-	-	-	1	-	-	-	3	-	6	1.9
Dorsal/Lumbar Spine	5	-	-	-	2	-	-	-	-	-	7	2.2
Chest	4	33.3	2	16.7	2	25.0	3	25.0	-	-	12	3.7
Pelvis / Abdomen	40	51.9	10	13.0	19	24.7	8	10.4	-	-	77	24.0
Shoulder	13	-	11	-	-	-	-	-	-	-	24	7.5
Upper Arm	29	69.0	11	26.2	2	4.8	-	-	-	-	42	13.1
Forearm	7	-	5	-	-	-	-	-	-	-	12	3.7
Hand	15	-	5	-	-	-	-	-	-	-	20	6.2
Femur	26	32.9	46	58.2	7	8.9	-	-	-	-	79	24.6
Knee	34	-	5	-	-	-	-	-	-	-	39	12.1
Lower Leg	34	37.4	47	51.6	10	11.0	-	-	-	-	91	28.3
Foot	14	-	-	-	-	-	-	-	-	-	14	4.4

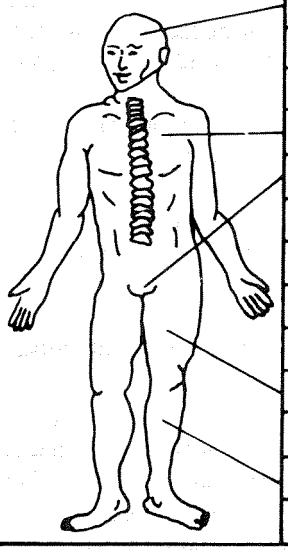
Figure 2.4. Injuries related to frequency and severity of children (up to the age of 15 years) (321 frontal car collisions) [15].

emerges as the body area most frequently injured, with the legs as the second and the pelvis as the third most frequently injured area.

A similar trend is shown in [15] where injuries are related to frequently severity and three age groups.

Injury Severity can be scored by several rating systems such as Abbreviated Injury Scale, Overall AIS, Injury Severity Score, etc. The ranges of the scales used in these systems go from no injury up to death, whilst the long term consequences of the injuries (for instance, temporary or permanent disability), are of little influence.

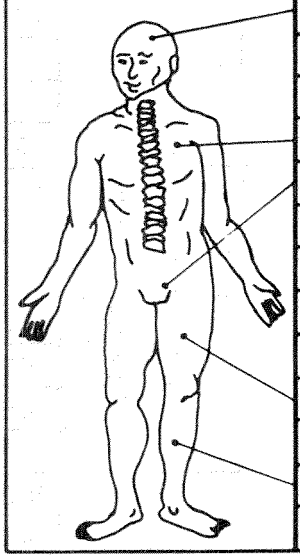
These factors are important with leg injuries, such as knee ligament injuries [1]. This kind of injury might be underreported.



* Total: 432 Adults (15-65 Years of Age) = 100%

Body Areas Injured \ Injury Severity	AIS 1		AIS 2		AIS 3		AIS4/5		AIS 6		Total Injuries per Body Area No.=100%	* %
	No.	%*	No.	%*	No.	%*	No.	%*	No.	%*		
Head	148	51.2	58	20.0	25	8.7	24	8.3	34	11.8	289	66.9
Cervical Spine	7	-	1	-	3	-	1	-	1	-	13	2.9
Dorsal/Lumbar Spine	14	-	1	-	6	-	2	-	-	-	23	5.3
Chest	21	44.8	7	14.9	12	25.5	2	4.2	5	10.6	47	10.9
Pelvis / Abdomen	48	55.3	3	3.4	33	37.9	2	2.3	1	1.1	87	20.1
Shoulder	31	-	15	-	1	-	-	-	-	-	47	10.9
Upper Arm	42	63.6	17	25.8	7	10.6	-	-	-	-	66	15.2
Forearm	14	-	5	-	3	-	-	-	-	-	22	5.1
Hand	32	-	5	-	2	-	-	-	-	-	39	9.1
Femur	60	58.3	26	25.2	17	16.5	-	-	-	-	103	23.8
Knee	76	-	11	-	11	-	-	-	-	-	98	22.6
Lower Leg	85	39.7	53	24.8	74	34.6	2	0.9	-	-	214	49.5
Foot	18	-	6	-	-	-	-	-	-	-	24	5.6

Figure 2.5. Injuries related to frequency and severity of adults (432 frontal car collisions) [15].



* Total: 207 Elderly Adults (65 Years and up) = 100%	Injury Severity / Body Areas Injured	AIS 1		AIS 2		AIS 3		AIS 4/5		AIS 6		Total Injuries per Body Area	*
		No.	%*	No.	%*	No.	%*	No.	%*	No.	%*	No. = 100%	%
	Head	58	40.6	35	24.5	5	3.5	16	11.2	29	20.2	143	69.1
	Cervical Spine	2	-	1	-	1	-	1	-	5	-	10	4.8
	Dorsal/Lumbar Spine	4	-	1	-	4	-	1	-	-	-	10	4.8
	Chest	16	44.4	5	13.9	6	16.7	2	5.6	7	19.4	36	17.4
	Pelvis / Abdomen	16	30.8	6	11.5	24	46.2	5	9.6	1	1.9	52	25.1
	Shoulder	12	-	10	45.5	-	-	-	-	-	-	22	10.6
	Upper Arm	10	41.7	11	45.8	3	12.5	-	-	-	-	24	11.6
	Forearm	6	-	5	-	1	-	-	-	-	-	12	5.8
	Hand	14	-	3	-	-	-	-	-	-	-	17	8.2
	Femur	21	44.7	14	29.8	12	25.5	-	-	-	-	47	22.7
	Knee	23	-	6	-	2	-	-	-	-	-	31	15.0
	Lower Leg	29	25.4	49	43.0	36	31.6	-	-	-	-	114	55.1
	Foot	28	-	6	-	2	-	-	-	-	-	36	17.4

Figure 2.6. Injuries related to frequency and severity of elderly adults (207 frontal car collisions) [15].

The Causes of Injuries

Ground contact versus contact with the car

The first interesting question is if the injury is caused by contact with the vehicle or with the ground. Much is written about this subject.

The main problem is that the body may hit both the car and the ground, so that it is difficult to establish the cause of specific injuries.

Methods of doing this are described in [5] and [8] where it is claimed that only careful in-depth at-the-scene study can provide the kind of data that are necessary to determine the cause of injury. In these studies the number of cases investigated are, however, very small.

The cause of surface wounds can usually be clearly determined but brain injuries are more difficult to analyse, because of the continuing discussion concerning the brain injury mechanism; whether it is the result of translational or rotational acceleration.

In most of the older studies, which are discussed in [2, 9,18,21], it is stated that the injuries occur as a result of secondary impact with the ground. More recent studies, discussed below, show a different result.

Lower limb injury:

With all the pedestrian/car front accidents there will be a lower limb/car contact. The more severe injuries to the lower limbs are generally caused by contact with the vehicle. The less serious injuries are caused by vehicle and ground in equal proportion [6, 10].

Head injury:

Whether a head/car impact occurs depends on several parameters such as impact speed, size of pedestrian/size of car, and form of car. For impact speeds below 20 km/h no head/car impact [5, 6] was found. In [2, 9, 14, 15, 18, 20] it is stated that the more severe injuries to the head are caused by the primary impact with the car.

Influence of rotational acceleration on brain injuries is still under discussion. The impact on the ground might have a greater effect on injury severity if rotational acceleration is an important parameter.

Although it is difficult and not always possible to establish the precise cause of an injury, careful at-the-scene accident investigations seem to prove that the more severe injuries to pedestrians are caused by impact with the car.

The results of some car/pedestrian accident simulations [4, 18] are in good agreement with this.

In [10] the share in total injury severity of ground and car impact, as a function of impact speed is as given in Figure 2.7.

By increasing the impact speed the injuries caused by the car become much more severe than those from ground impact.

Relation of impacted area on the car and pedestrian injury

Although the relationship between the section on a car that causes injury and the body region that is injured is dependent upon several parameters such as, pedestrian height/dimensions of the car, form of the car, impact speed (chapter 4); an overview of this relationship is given.

A number of studies only give distributions of parts of

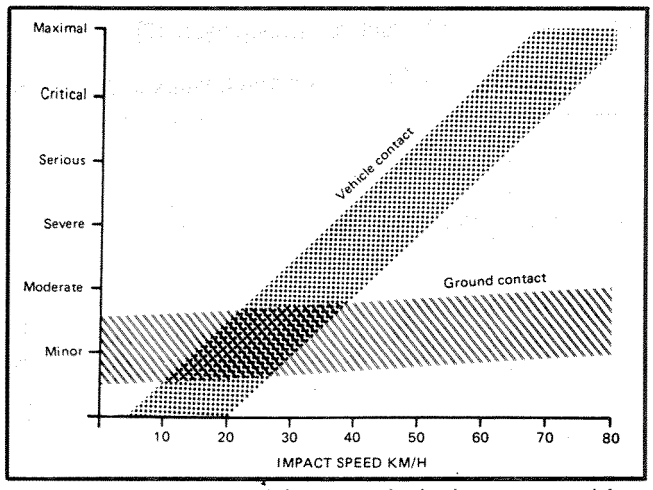


Figure 2.7. Predominant injury severity by impact speed for vehicle contact and ground contact injuries [10].

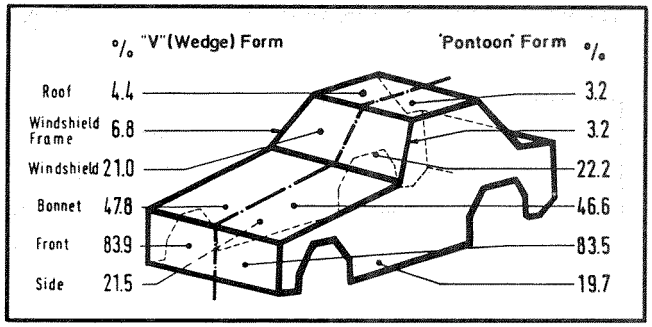


Figure 2.8. Definition "V-form," "Pontoon-form", see Figure 2.10.

Overall damage frequency of car body areas in frontal impact ("V" and "Pontoon") [12].

the car which are damaged as a result of an impact with a pedestrian. Other studies give information about the relationship between impact areas and injury. Figure 2.8 shows the damage frequency of car body areas in frontal impacts. The front is the part of the car most frequently damaged, followed by bonnet and windshield. But even though stiffer parts of the car may however not be damaged in an accident they can be the cause of severe injuries. Mere inspection of damage is not therefore enough.

Tables 2.2., 2.3 and 2.4. show from in-depth studies the relationship between body parts injured, divided into children, adults, and elderly adults, and the car body areas which caused the injury.

Despite the small numbers, it can be seen that the bumper front of the car is responsible for the lower limb

Table 2.2. Incidence of injury to children (aged under 15 years) by body region and by factors causing injury [7].

Numbers of children in sample = 96

Cause of injury / Body Region	Head	Back neck and spine	Chest	Abdomen	Pelvis	Upper limbs	Lower limbs	Total
Roof	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –
Windscreen glass	1 1 – –	– – – –	– – – –	– – – –	– – – –	1 – – –	– – – –	2 1 – –
Windscreen frame and scuttle	1 1 – –	– – – –	– – – –	– – – –	– – – –	1 – – –	– – – –	2 1 – –
Air grille	– – – –	– – – –	– – – –	– – – –	1 – – –	1 – – –	1 – – –	3 – – –
Top surface of bonnet or wings	18 13 3 2	– – – –	– – – –	1 1 – –	– – – –	2 – – –	– – – –	21 14 3 2
Bonnet front edge	– – – –	2 – – –	1 – – –	2 1 1 –	1 1 – –	3 – – –	9 3 – –	18 5 1 –
Wing loading edge and lights	– – – 1	– – – –	– – 1 –	1 1 1 –	2 4 1 –	– – – –	4 – – –	7 5 3 1
Front bumper	– – – –	1 – – –	– – – –	– – – –	– – – –	– – – –	14 10 8 –	15 10 8 –
Run over or ground (*)	31 11 2 –	2 – – –	2 – – –	– – – –	– – – –	23 3 – –	58 – – –	116 14 2 –
Other structures or not known	8 2 1 1	– – – 1	1 – – –	1 – – –	– – – –	7 2 1 –	13 – – –	30 4 2 2

Note: The four values shown at each combination of body region/causation, correspond to different severities of injury. The degrees of severity are AIS 1, 2, 3 and 4-6 arranged thus (1 2)
(3 4-6)

*Injury was attributed to "run over" in only 2 cases. These were both of severity AIS2.

Table 2.3. Incidence of injury to adult (aged 15 to 59 years) by body region and by factors causing injury [7].

Numbers of adults aged 15-60 years in sample = 63

Cause of injury / Body region	Head	Back Neck and Spine	Chest	Abdomen	Pelvis	Upper Limbs	Lower Limbs	Total
Roof	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –
Windscreen glass	9 2 – –	– – – –	– – – –	– – – –	– – – –	5 – – –	– – – –	14 2 – –
Windscreen frame and scuttle	5 8 1 8	– 1 – –	– – – –	– – – –	– – – –	2 – – –	– – – –	7 9 1 8
Air grille	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –	1 1 – –	1 1 – –
Top surface of bonnet or wings	2 2 – 2	1 – – –	1 – – –	– 1 – –	1 – – –	6 1 – –	– – – –	11 4 – 2
Bonnet front edge	– – – –	1 – – –	– – – –	– – – –	2 4 3 –	1 – – –	11 4 3 –	15 8 6 –
Wing loading edge and lights	– – – –	– – – –	– – – –	1 – – –	– – 1 –	– – – –	4 4 – –	5 4 1 –
Front bumper	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –	18 10 15 –	18 10 15 –
Run over or ground (*)	12 8 – 3	4 2 – –	2 – 1 1	1 – – 1	1 – 1 –	14 3 1 –	19 1 1 –	53 14 4 5
Other structures or not known	8 4 – 3	3 3 – 4	2 2 2 4	– – 2 5	1 – – –	16 6 1 –	18 2 1 –	48 17 6 16

Note: the four values shown at each combination of body region/causation, correspond to different severities of injury. The degrees of severity are AIS 1, 2, 3 and 4-6 arranged thus (1 2)
(3 4-6)

* Injury was attributed to "run over" in only 5 cases. The severity of these injuries were 1 of AIS 1; 3 of AIS 3 and 1 of AIS 5.

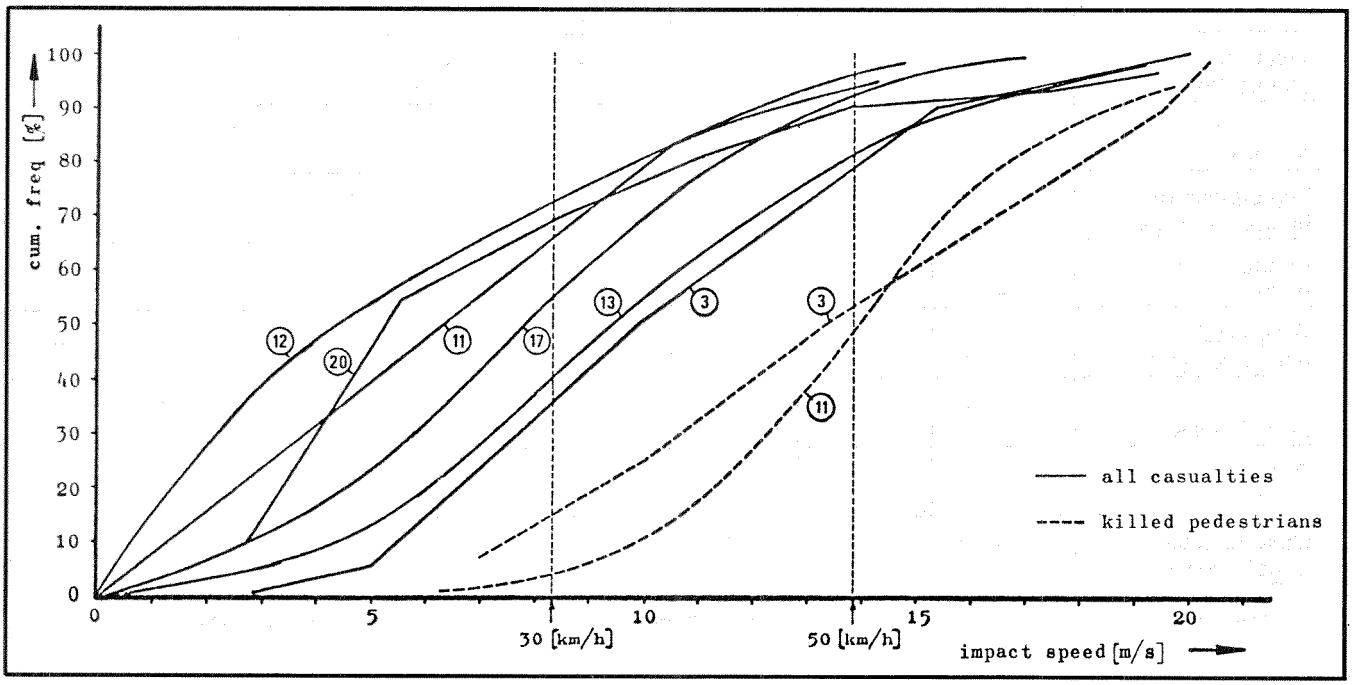


Figure 2.9. Cumulative distributions of impact speeds in pedestrian/car accidents by several studies [19].

Table 2.4. Incidence of injury to adults (aged 60 years or over) by body region and by factors causing injury [7].

Number of adults aged 60 years in sample = 52

Cause of injury / Body region	Head	Back neck and spine	Chest	Abdomen	Pelvis	Upper limbs	Lower limbs	Total
Roof	– 1 – 1	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –	– 1 – 1
Windscreen glass	– 4 1 –	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –	– 4 1 –
Windscreen frame and scuttle	– 3 3 7	– – 1 –	– – – 2	– – – –	– – – –	– 3 – –	– – – –	– 6 4 9
Air grille	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –
Top surface of bonnet or wings	7 5 2 1	– – – –	1 1 1 2	– – – –	– – – –	1 4 – –	– – – –	9 10 3 3
Bonnet front edge	– – – –	– – – –	– – – –	– 1 1 –	– 4 10 –	– – – –	6 8 7 –	6 13 18 –
Wing loading edge and lights	– – – –	– – – –	– – – –	– – – –	– – 2 –	– – – –	1 1 3 –	1 1 5 –
Front bumper	– – – –	– – – –	– – – –	– – – –	– – – –	– – – –	13 15 25 –	13 15 25 –
ground	9 6 1 6	1 – – –	– – – –	– – – –	– – – –	20 1 – –	21 1 – –	51 8 1 6
Other structures or not known	11 3 – 5	– 3 4 5	1 2 4 1	– 1 1 –	– – 1 –	7 4 1 –	13 5 2 –	32 18 13 11

Note: the four values shown at each combination of body region/causation, correspond to different severities of injury. The degrees of severity are AIS 1, 2, 3 and 4-6 arranged thus (1 2)
(3 4-6)

injuries, while the "wing leading edge and lights" are responsible for pelvis and lower limb injuries, except for the children who also sustain chest and head injuries.

The "top surface of bonnet and wings" are the cause of many of the head injuries to the children and also to some of the elderly adults. The "air grille/windscreen frame and windscreen glass" are the cause of a great number of the head injuries to adults. The windscreen frame causes the more severe injuries.

Impact Speed

One of the main problems in pedestrian accident investigation is the determination of the speed at impact. Most of the investigations use a combination of witness statements, and brake marks.

But the reliability of a witness is questionable and brake marks are not always available. In Figure 2.9 a description is given of some cumulative distributions of impact speeds. It will be clear that the distribution depends on the severity of the injuries which are considered.

The numbers in Figure 2.9 refer to the literature in which the distribution is described.

50% of all pedestrian accidents with casualties occur in the speed range:

0–16 km/h [12]
0–36 km/h [3]

While 90% of these accidents occur in the speed range:

0–44 km/h [11]
0–58 km/h [3]

Braking of the Car

While the car is braking not only the velocity of the car is decreasing but also the bumper and bonnet height. To be able to make statements about points of impact at the pedestrian, one must know whether or not the car was braking, and if so, to what extent.

According to [7] 55% of the cars were braking or skidding before the impact, 15.7% were braking or skidding after the impact, while 13.8% were braking or skidding but whether skidding commenced before or after the impact could not be established. A more recent statement from the same author [28]: "Braking at impact was considered to have occurred in 30% of all the cases."

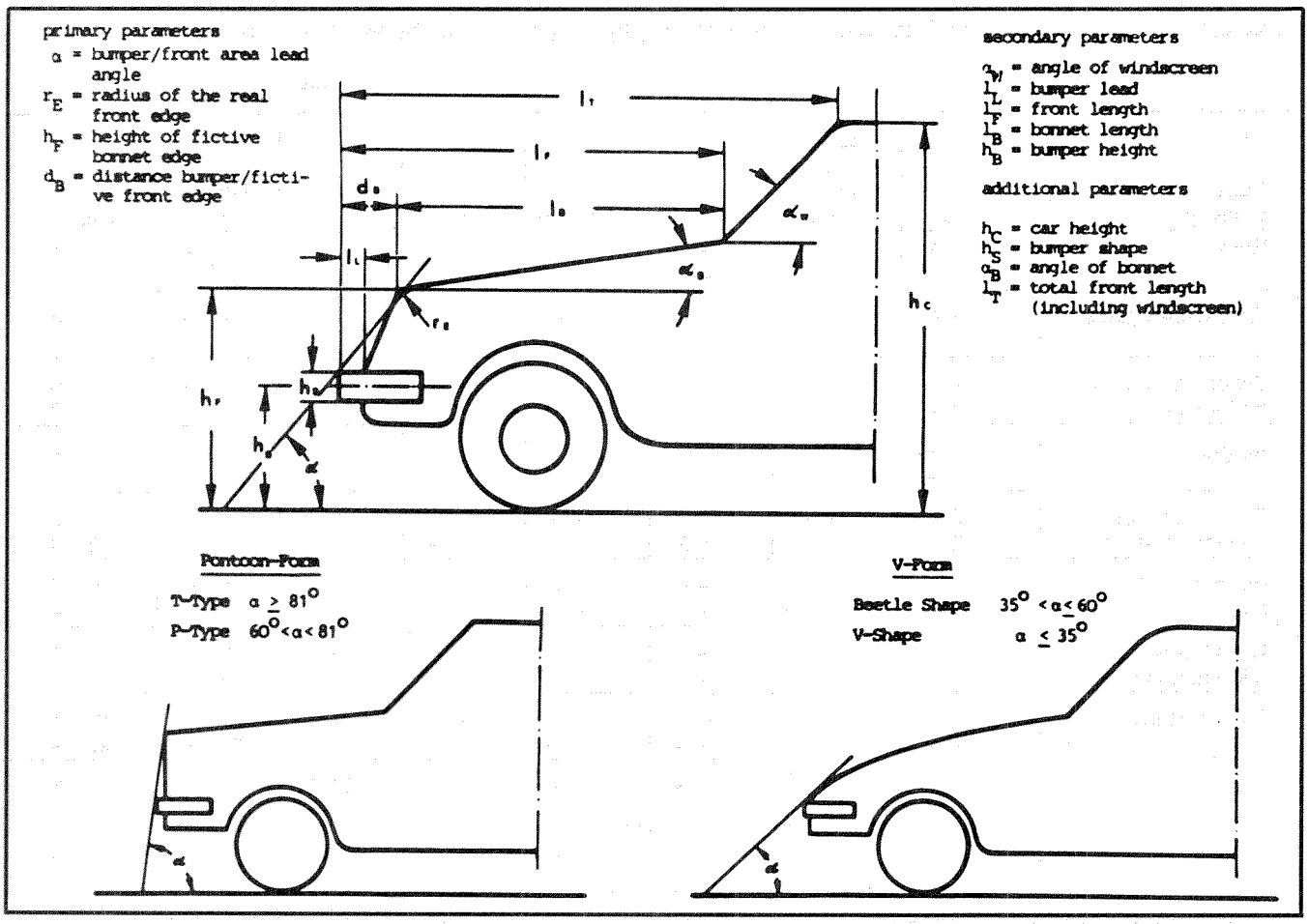


Figure 2.10. Definitions of "V-form" and "Pontoon-form", used in Figure 2.8 [15].

Table 2.5. Action of vehicle at impact by age for pedestrians struck by the front of cars and light goods vehicles [7].

Action of Vehicle	Age group							
	0–14		15–59		60+		All	
	N	Percent	N	Percent	N	Percent	N	Percent
No braking	3	3.1	9	14.3	5	9.6	17	8.1
Braking								
—Before impact	18	18.7	2	3.2	3	5.8	23	10.9
—After impact	10	10.4	4	6.3	6	11.5	20	9.5
—Time not known	10	10.4	6	9.5	5	9.6	21	10.0
Skidding								
—Before impact	44	45.8	29	46.0	20	38.5	93	44.1
—After impact	5	5.2	2	3.2	6	11.5	13	6.2
—Time not known	2	2.1	2	3.2	4	7.7	8	3.8
Other	—	—	1	1.6	1	1.9	2	0.9
Not known	4	4.2	8	12.7	2	3.8	14	6.6
	96		63		52		211	

[25] states that nearly all the drivers saw the pedestrian who was "running or darting into the street" prior to impact, and thereby reducing the impact speed.

[26] is in agreement with [7]: 54% of the vehicles were braking before impact, while [27] concludes that 62% of the drivers could reduce their speed before impact by more than 20%, and 18% did not brake at all.

REFERENCES

1. B. Aldman, L. Thorngren, O. Bunketorp, B. Romanus. "An Experimental Modes Systems for the Study of Lower Leg and Knee Injuries in Car Pedestrian Accidents". 8th ESV Conference, Wolfsburg, October 1980.
2. H. Appel, G. Stürtz, L. Gotzen. "Influence of Impact Speed and Vehicle Parameter on Injuries of Children and Adults in Pedestrian Accidents". Institute of Automotive Engineerig, T.U. Berlin, Medical University Hannover.
3. H. Appel, A. Kuehnel, G. Stürtz, H. Gloeckner. "Pedestrian Safety Vehicle—Design Elements—Results of the In-depth Accident Analyses and Simulation". Institute of Automotive Engineering, T.U. Berlin.
4. S. J. Ashton, H. R. M. Hayes, G. M. Mackay. "Child Pedestrian Injuries". Accident Research Unit, University of Birmingham.
5. S. J. Ashton. "The Cause and Nature of Head Injuries Sustained by Pedestrians". Accident Research Unit, University of Birmingham. IRCOBI, September 1975, Birmingham.
6. S. J. Ashton, J. B. Pedder, G. M. Mackay. "Pedestrian Injuries and the Car Exterior". Accident Research Unit, University of Birmingham. SAE, International Automotive Engineering Congress and Exposition, Feb.-March 1977, Detroit.
7. S. J. Ashton. "Cause, nature and severity of the injuries sustained by Pedestrians struck by the fronts of cars or light goods vehicles". Thesis University of Birmingham, 1978.
8. S. J. Ashton, J. B. Pedder, G. M. Mackay. "Pedestrian Head Injuries". Accident Research Unit, University of Birmingham. 22nd AAAM conf. and 7th IAATM conf. July 1978, Ann Arbor, Michigan.
9. S. J. Ashton, G. M. Mackay. "A Review of Real World Studies of Pedestrian Injury". Accident Research Unit, University of Birmingham. The German Association for Traffic Medicine, March 1979, Keulen.
10. S. J. Ashton, G. M. Mackay. "Car Design for Pedestrian Injury Minimisation". Accident Research Unit, University of Birmingham. 7th Internat. Techn. Conf. on Experimental Safety Vehicles, June 1979, Paris.
11. S. J. Ashton, G. M. Mackay. "Some Characteristics of the population who suffer Trauma as Pedestrians when hit by Cars and some resulting Implications". Accident Research Unit, University of Birmingham. IRCOBI, September 1979, Gothenburg.
12. M. Danner, K. Langwieder, W. Wachter, "Injuries to Pedestrians in Real Accidents and their Relation to Collision and Car Characteristics". Department of Automotive Engineering Association of Automobile Insurers (HUK Verband). 23rd Stapp Car Crash Conference, Oct. 1979, San Diego.
13. R. Haar, E. Luccini, R. Weissner. "Automobile and Pedestrian—the Accident Situation". Volkswagenwerk AG. Int. Conf. on Pedestrian Safety, December 1976, Haifa.
14. M. Kramer. "4-4 Berechnung der Unfallschwere in Experimentellen Fussgänger-Fahrzeug-Unfällen". T.U. Berlin. Proceedings of the 16th international FISITA Congress, May 1976, Tokyo.
15. K. Langwieder, M. Danner, W. Wachter, Th. Hummel. "Patterns of Multi-Traumatisation in Pedestrian Accidents in Relation to Injury Combinations and Car Shape". HUK Verband. 8th ESV Conference Wolfsburg, October 1980.
16. Stiching Medische Registratie 1978.
17. G. Stürtz, E. Suren, L. Gotzen, K. Richter. "Analyse von Bewegungsablauf, Verletzungsursache,—schwere und—Folge bei Fussgängerunfällen mit Kindern durch Unfallforschung am Unfallort". T.U. Berlin, medizinischen Hochschule Hannover; Krankenhaus Nordstadt Hannover. IRCOBI, September 1974, Lyon.
18. G. Stürtz, E. G. Suren. "Kinematic of Real Pedestrian and Two-wheel Rider Accidents and Special Aspects of the Pedestrian Accident". Institute on Automotive Engineering T.U. Berlin, Accident Surgery Medical Highschool Hannover. IRCOBI, September 1976, Amsterdam.
19. SWOV. "Factors Which Influence The Severity Of Injuries Sustained by Pedestrians, Cyclists, Moped Riders and Motorcyclists in Accidents" Preliminary Report, Unpublished.
20. K. J. Tharp, N. G. Tsongos. "Injury Severity Factors—Traffic Pedestrian Collisions". University of Houston, Texas, U.S. Department of Transportation. IRCOBI, September 1976, Amsterdam.
21. R. G. Vauhan. "A Study of Measures to Reduce Injuries to Pedestrians". Traffic Accident Research Unit, Department of Motor Transport. N.S.W. National Road Safety Symposium, Canberra, March 1972.
22. H. Weinreich. "Der Verkehrsunfall des Fussgängers". (Ergebnisse einder analyse von 2000 Unfällen). Unfallchirurgische Klinik, Städtisches Krankenhaus, Braunschweig. Unter mitarbeit: Abteilung Forschung Fahrzeugtechnik, Volkswagen A.G.
23. Centraal Bureau Voor De Statistiek. Netherlands. Conflicttabellen 1979.

24. "Abschlussbericht, Erhebungen am Unfallort" Forschungsprojecten 7263/7506, BAST. Unfallchirurgische Klinik, Medizinische Hochschule Hannover. Institut für Fahrzeugtechnik, Technische Universität Berlin.
25. K. J. Tharp, N. G. Tsongos. "Factors in Urban Vehicle Pedestrian Collisions". University of Houston, National Highway Traffic Safety Administration. Third International Congress on Automotive Safety, July 1974, San Francisco.
26. C. Thomas, G. Stcherbatcheff, P. Duclos, C. Tarrière, J. Y. Foret-Bruno. "A Synthesis of Data from a Multi-Purpose Survey on Pedestrian Accidents". Laboratoire de Physiologie et de Biomécanique de l'Association Peugeot-Renault. IRCOBI 1976, Amsterdam.
27. E. M. Geagauf, E. Niggli, A. Wehren. "Das Fussgängerunfallgeschelen in der Stadt Zürich 1978/79". Zürich, June 1981.
28. S. J. Ashton. "Factors associated with pelvis and knee injuries in pedestrians struck by the fronts of cars". 25th Stapp Car Crash Conference, September 1981, San Francisco.

CHAPTER 3. CURRENT KNOWLEDGE IN INJURY MECHANISMS AND HUMAN TOLERANCES

Kinematics

The kinematics of an adult pedestrian hit by a car can be described as follows:

A) First part of the kinematics (in general) [21].
   1) Contact between the leg(s) and the car bumper.
   2) Bending of the body, and contact of the pelvis to the front edge of the bonnet.
   3) Contact of the arm(s) and/or the thorax on the bonnet.
   4) Contact of the head on the bonnet or on the windscreen area.

B) Second part of the kinematics.
   The second part of the kinematics is more linked to chance and depends mainly from the pedestrian height, the car shape, the car behaviour. . . . For a child pedestrian it is normally not very different, but the impact point depends from the pedestrian height.

Injury Mechanisms

The injury mechanisms of the first part of the pedestrian motion are clear:

1) The contact between the leg(s) and the bumper makes leg fractures mainly in the area of the knee and/or knee ligamentum rupture for an adult pedestrian, and femur fracture for a child pedestrian. Figure 3.1 shows the location of the bumper impact on the lower limbs, for a child and for an adult. The normal bumper height is approximately 500 mm for a non-braking situation and 420 mm in a panic braking. The adult height is 1.64 m which is the average height value of pedestrians involved in a traffic accident in France [1].
   Even if leg injuries are not very severe, in terms of fatal risk, they have often important long-term consequences.
2) The shape of the car front end has a great influence on the pelvis impact but the pedestrians sustain few pelvic and/or abdominal injuries. Nevertheless the front shape of the car (and especially the front edge) is important in influencing the subsequent kinematics.
3) Thoracic impact—the shape of the car also has a great influence on the thoracic impact, but the arm position can also change the occurring of thoracic injuries, depending if the arm is placed between the thorax and the bonnet or not.
4) Head impact—the severity of head impact has to be related to two main parameters: firstly the stiffness of the specific car area contacted by the head, secondly the normal head velocity during the impact

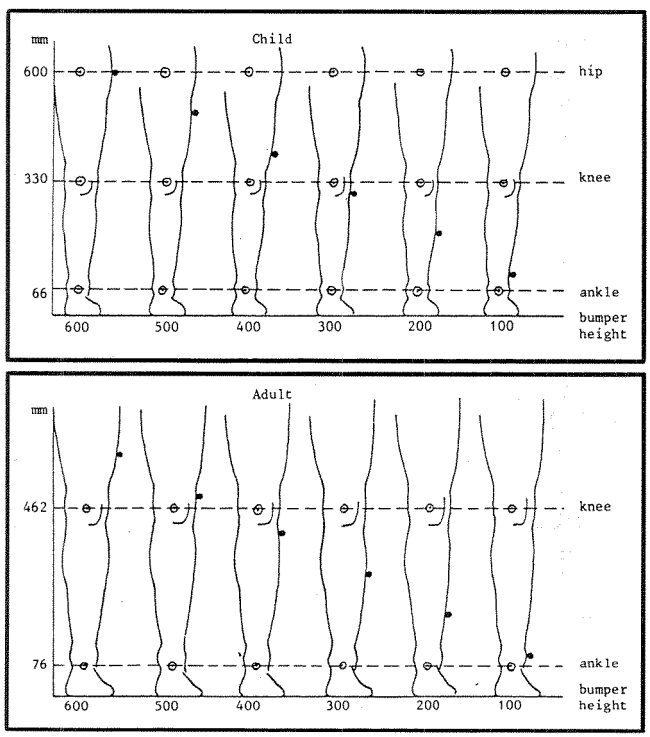


Figure 3.1. Location of bumper impact on the leg as a function of bumper height.

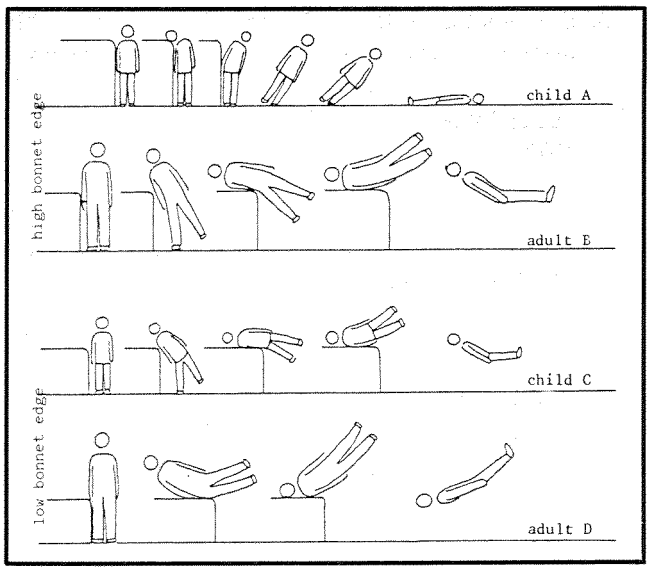


Figure 3.2. Child and adult pedestrian kinematics for two bonnets edge heights.

on the car, which depends on the whole body kinematic.

During the second part of the pedestrian kinematic, the level of the bonnet edge related to pedestrian height seems to have a great influence [2] as summarized on Figure 3.2.

The second part of the kinematics (between car impact and ground impact) influences the pedestrian position at ground impact. The happening of injuries during ground impact depends mainly from which body area hit the ground first and at which speed. The body impact speed to the ground seems less dependent on the car speed at the impact than the head impact speed on the car.

Current Knowledge in Human Tolerance

Head Tolerance

Concerning head tolerance, it is necessary to investigate separately cranial and/or facial head injuries and brain head injuries.

Bone injuries

The tolerance of skull to fracture depends mainly from the dimensions of the impacting structure. The main values published by the literature are reported in Table 3.1.

Table 3.1. Tolerance of skull to fracture in KN

Impacted area	Small		Large	
frontal	5	[4]	7	[5]
temporal	1.8	[6]	8.3	[7]
parietal	3.4	[4]	8.5	[5]
occipital	?		9.6	[7]

The tolerance of the face is lower than the tolerance of the skull. Table 3.2 summarizes the main results found in the literature.

It is not possible to measure head forces (or head pressures) on actual dummy heads; nevertheless these values could be taken in consideration when determining the criteria for a component test.

For small impacted areas the tolerance is lower than the values indicated in Table 3.2.

Brain tolerance to impact

The brain tolerance is not well established, and brain injuries have no evident correlation with skull fractures. Tolerance of head as a function of pulse duration has been established by Lissner [10] and is called "Wayne State Curve". The corresponding parameter to this curve is the GSI (Gadd Severity Index) which is defined by:

$$GSI = \int_o^t a^{2.5} dt$$

in which a is head accel. In g's and the value of 1000 is considered as the tolerable limit.

A new index called HIC has been developed more recently and is used for car occupants frontal impacts. The HIC is defined by the maximum value of:

$$\left[\frac{1}{t2 - t1}\int_{t1}^{t2} a\,dt\right]^{2.5} (t2 - t1)$$

The proposed limit of tolerance for HIC is 1000 or 1500, but recent studies have shown that this criterion is not very pertinent to predict head injuries. Some other criteria have been proposed but none were widely accepted. However in the absence of a more pertinent criterion, the HIC can be accepted in dummy tests.

Thorax Tolerance

To summarise for frontal impacts tolerable force levels range from 1500 N to 6000 N and tolerable deflection from 4 to 9 cm. Normalized chest deflection which indicates the percentage of reduction of thorax depth is tolerable in the range of 0.25—0.45 [11, 12, 13, 14].

Only one experiment deals with side impact tests, it shows levels well in the ranges of frontal tolerance (force = 2500 to 4900 N, deflection = 5.8 to 6.1 cm) [15].

Table 3.2. Tolerance of facial bones to fracture in N

	Tolerance force	
zygoma	800 to 1800	[8]
maxilla	650 to 1000	[7/8]
mandible	800 to 3000*	[8]
nose	1300N	[9]

* depending on impact direction.

Loading of a single rib with a small impactor indicates a force tolerance between 580 and 850 N with a deflection of about 5 cm. The force values seem more usable in component tests; on dummies the most frequent thoracic criteria are based on thoracic accelerations; but new side impact dummies include thoracic deflection and this parameter seems more realistic.

Pelvis Tolerance

There are no data available concerning the tolerance of the pelvis under direct loading; but research is conducted within the frame of the EEC biomechanical research program [20] to determine the tolerance of the pelvis in side impact. The results of this research will be helpful.

There is a previous proposal for a pelvic criterion (100 g's 3 ms) [16] but a force value, which is directly related to the tolerance seems more realistic, and some side impact dummies are designed to measure transverse pelvic forces.

Fibula and Tibia Tolerance

Fibula is a weak bone, but it is generally not directly exposed to impact and it has a certain degree of freedom, so the lower leg tolerance depends mainly on the tibia tolerance.

Tibia tolerance to horizontal loading seems to be between 3000 N and 9800 N depending on the impacted area with an average value of 5000 N [17]. However a recent study conducted in Sweden [18] has found a much lower value of lower limb tolerance. The value of the momentum corresponding to the fracture is about 200 Nm [3]. However these values are related to a small surface impact and the tolerance in a bumper-like impact is probably higher.

Overall Remarks

The tolerance limits are greatly affected by the age: a younger person has much higher tolerance to impact than an older one, and the values chosen should correspond to the population at risk.

REFERENCES

1. G. Stcherbatcheff, C. Tarrière, P. Duclos, A. Fayon. "Simulation of collisions between pedestrians and vehicles using adult and child dummies". 19th Stapp Car Crash Conference, Paper 751167, 1975.
2. H. Appel, G. Stürz, S. Behrens. "Influences of front and design of passenger cars on injuries of pedestrians in car-to-pedestrian collisions". Proc. of the Meeting on Biomechanics of Injury to Pedestrians, Cyclists and Motorcyclists, IRCOBI, 1976.
3. S. J. Ashton, J. B. Pedder and G. M. Mackay. "Pedestrian injuries and the car exterior". Society of Automotive Engineers Transactions—Paper 770092. Society of Automotive Engineers, Warrendale, USA, 1977.
4. J. W. Melvin, P. M. Fuller, R. P. Daniel, G. M. Pavliscak. "Human head and knee tolerance to localized impacts". SAE 690477, 1969, Mid. Year Meeting, Chicago IL, May.
5. G. E. Voigt, V. R. Hodgson, L. M. Thomas. "Breaking strength of the human skull vs. impact surface curvature". Contract n° DOT HS 146.2.230 Final Report, 1973.
6. O. Messerer. "Elasticity and strength of human bones". Verlag d.j.G. Gott's schow Buchhandlung, Stuttgart, 1980.
7. R. L. Stalnaker, J. W. Melvin, G. S. Nusholtz, N. M. Alem, J. B. Benson. "Head impact response". Proc. of 21st Stapp Car Crash Conference, Paper 770921, 1977.
8. V. R. Hodgson, W. A. Lange, R. K. Talwalker. "Injury of the facial bone". 9th Stapp Car Crash Conference, 1965.
9. D. C. Schneider, A. M. Nahum. "Impact studies of facial bones and skull". 16th Stapp Car Crash Conference, Paper 720965, 1972.
10. J. J. Swearingen. "Tolerance of the human face to crash impact". Federal Aviation Agency, Office of Aviation Medicine, 1965, Rept AM. 65.20.
11. H. R. Lissner, M. J. Lebow, F. G. Evans. "Experimental Studies on the relation between acceleration and intra-cranial pressure changes in man". Surg. Gyn. Obst., 1960, Vol. III, pp. 329-338.
12. A. M. Nahum, C. W. Gadd, D. C. Schneider, C. K. Kroell. "The biomechanical basis for chest impact protection: I force deflection characteristics of the thorax". J. Trauma, 1971, Volume 2, n° 10.
13. A. M. Nahum, C. W. Gadd, D. C. Schneider, C. K. Kroell. "Deflection of the human thorax under sternal impact". International Auto. Safety Conference compendium, SAE Editor, Paper 700400, 1970.
14. C. K. Kroell, D. C. Schneider, A. M. Nahum. "Impact tolerance and response of the human thorax". Proc. of 15th Stapp Car Crash Conference, Paper 710851, 1971.
15. H. R. Bierman, V. R. Larsen. "Distribution of impact forces on the human through restraining devices". Naval. Med. Res. Inst. Project X.630, Report n° 4, Feb. 1946.
16. R. L. Stalnaker, V. L. Roberts, J. H. McElhaney. "Side impact tolerance to blunt trauma". 17th Stapp Car Crash Conference, Paper 730979, 1973.
17. "Joint biomechanical project". KOB, Unfall- und Sicherheitsforchung im Strassenverkehr, Heft 34, Köln, 1982.
18. J. W. Young. "Applied forces of lower leg impact,

1966" reported by R. G. Snyder, Human impact tolerances. 1970 International Auto. Safety Conference compendium.
19. O. Bunketorp, B. Aldman, R. Jonson, B. Romanus, B. Roos, L. Thorngren. "Experimental studies on leg injuries in car pedestrian accidents". 6th IRCOBI, 1981.
20. D. Cesari, M. Ramet. "Pelvic tolerance and protection criteria in side impact". To be presented at the 26th Stapp Car Crash Conference, 1982.
21. V. Montanari. Fiat Technical Presentation, 5th ESV Conference, London, 1974.

CHAPTER 4. INCREASING OF PEDESTRIAN SAFETY BY IMPROVEMENT OF VEHICLE DESIGN

Results of experimental simulations of car-to-pedestrian accidents, as well as the results from on-the-scene analyses of accidents show the influence of the shape and design of cars on the injuries of pedestrians involved in accidents. The main problem is the design of a car front end, which should be less aggressive to the speed range of up to 40 km/h [1, 3, 5].

Two aspects in car design have to be considered:

—*The overall shape* of the car and its influence on the kinematics of the impacted pedestrian due to the primary impact on the car structure and also due to the secondary impact on the road surface.
—*The local dynamic stiffnesses* of sections of cars that are impacted by pedestrians.

In most accidents analyses the shape of the car involved has been classified in three to five main groups, mainly because of the small number of analysed cases per car type.

Figure 2.10 shows the definition of car shapes from the literature [5]. The main data for the classification of shapes are:

—bumper lead and radius of the front edge [20, 21]

—bumper/front lead angle = arctan

$$\frac{\text{bonnet height} - \text{bumper height}}{\text{bumper lead}} \quad [5, 12, 21].$$

Although the shape of the front structure of a car can be described in this general way, difficulties arise in considering the effects of the pedestrian's height.

In order to eliminate the effects of pedestrian height, bumper height and bonnet height can be expressed in the following way [12], (see also Figure 3.2 in chapter 3):

$$\text{Relative Bumper Height} = \frac{\text{Absolute Bumper Height}}{\text{Pedestrian Height}}$$

$$\text{Relative Bonnet Height} = \frac{\text{Absolute Bonnet Height}}{\text{Pedestrian Height}}$$

The data of the car geometry in the above mentioned studies were taken from undamaged cars although depending on the stiffness of the impacted car area, the car shape is altered during impact. The Group feels that there is a need for a uniform and more realistic definition of undeformed car shapes taking into account the ability to deform and to absorb energy.

An examination of the relationship between injury severity and the car shape showed that the overall pedestrian injury severity was about in the same range for "pontoon" and "V-form" cars, but the patterns of injuries were different.

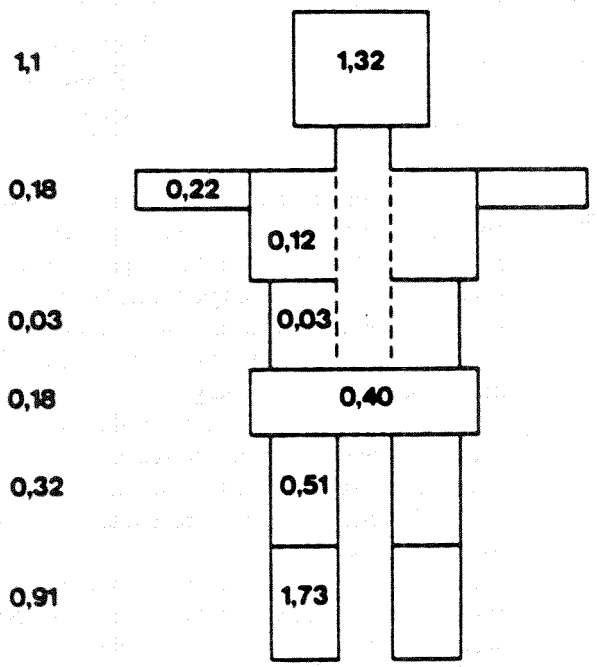
Serious head injuries in conjunction with serious lower leg injuries are typical for the V-form. The pontoon-form was found to have a higher incidence of serious head injuries in conjunction with injuries to the pelvis and femur [4, 5]. In the case of children, the trapezoidal form (T-Typ), as a subgroup of the pontoon-form, causes injuries of the thorax or the abdomen, depending on the height of the children. Box-form cars show the highest degree of traumatisation (product of injury severity and injury frequency) for children as well as for elderly persons and therefore the box-form is the most aggressive car shape. It should be remembered that the traumatisation scale only considers injury severity and injury frequency; it will give no indication of the long term consequences, for example healing time or disability which may be an important feature, for pedestrians who are frequently elderly. Figures 4.1., 4.2. and 4.3. show the injury severity and injury frequency for children and elderly persons for different car shapes resulting from at-the-scene accident investigations [3].

From the demand for a controlled impact force, minimum rebound velocity and long contact time between the pedestrian and the striking car, three requirements for the car front structure can be given:

—sufficient deformation to give low impact force
—high energy absorption
—collapsing structure does not bottom out on to a rigid internal structure.

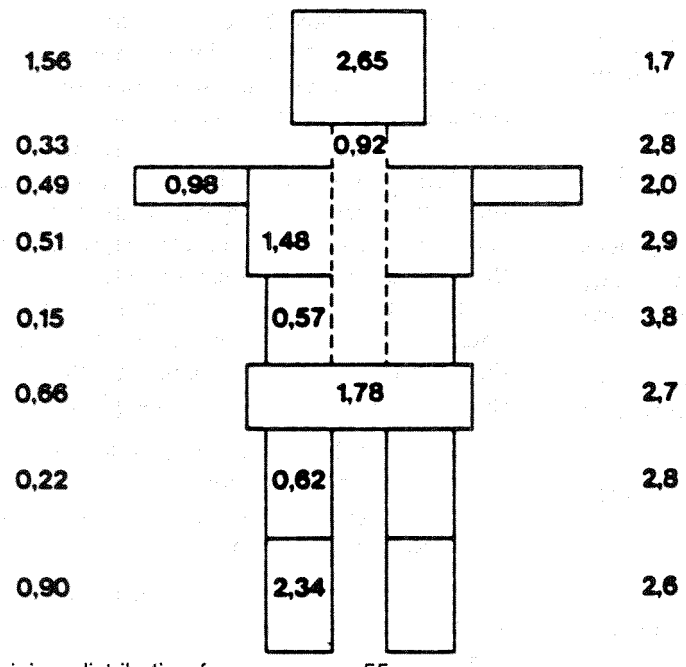
The stiffness of every part of the front structure should be based upon the established biomechanical tolerance levels of the body areas impacted. As seen in chapter 2, the bumper, the bonnet edge and the windshield frame, including the A-posts, are the most dangerous parts of the front-end of cars.

Many proposals have been made for increasing pedestrian safety by the improvement of vehicle design; some



OAIS	Number of cases
0	5
1	6
2	15
3	7
4	2
5	1
6	

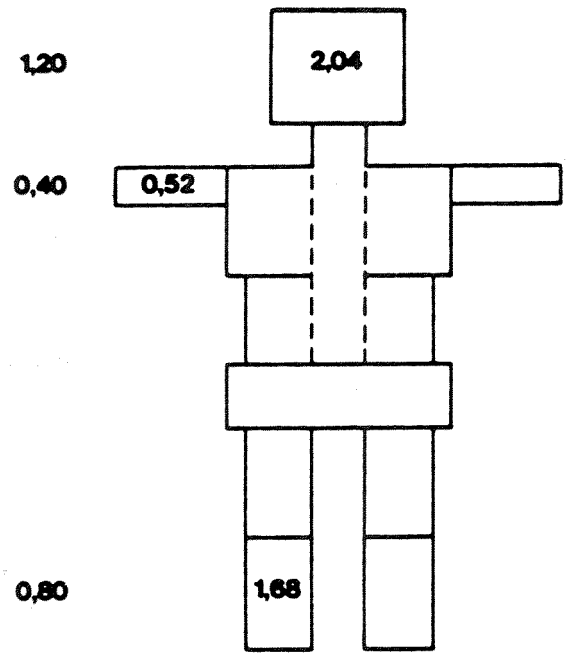
injury distribution for children 7-14 years
collision with Pontoon-form vehicle; n = 36
average age = 10 years
total degree of traumatisation = 4,33



OAIS	Number of cases
1	2
2	8
3	19
4	12
5	12
6	2

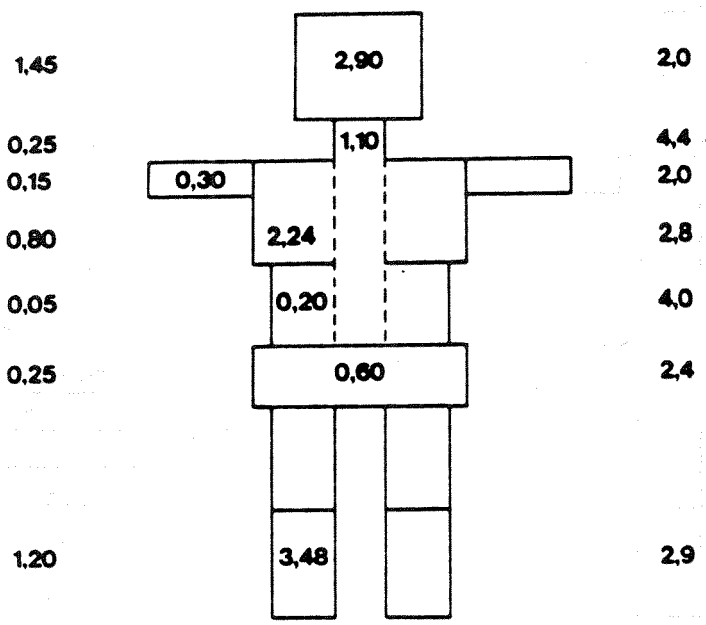
injury distribution for persons > 55 years
collision with Pontoon-form vehicle; n = 55
average age = 74 years
total degree of traumatisation = 11,37

Figure 4.1. Injury distribution "Pontoon-form" [3].



OAIS	Number of cases
0	1
1	3
2	4
3	3
4	1
5	
6	

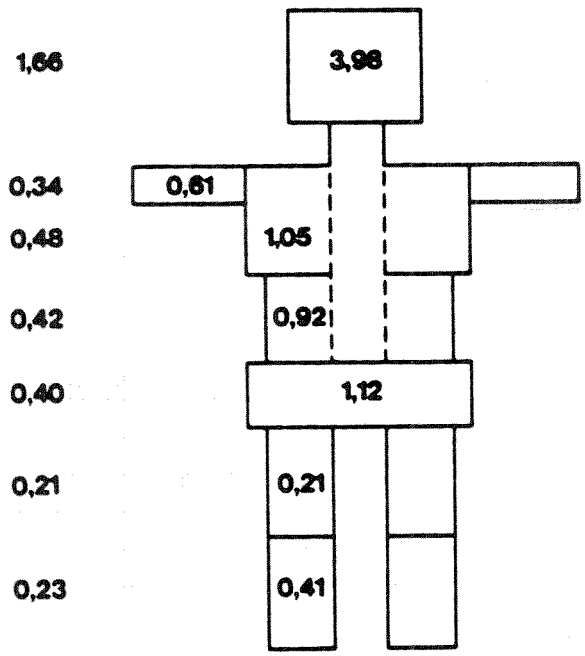
injury distribution for children 7-14 years
collision with V-form vehicle; n = 12
average age = 10 years
total degree of traumatisation = 4,24



OAIS	Number of cases
1	
2	2
3	6
4	6
5	4
6	2

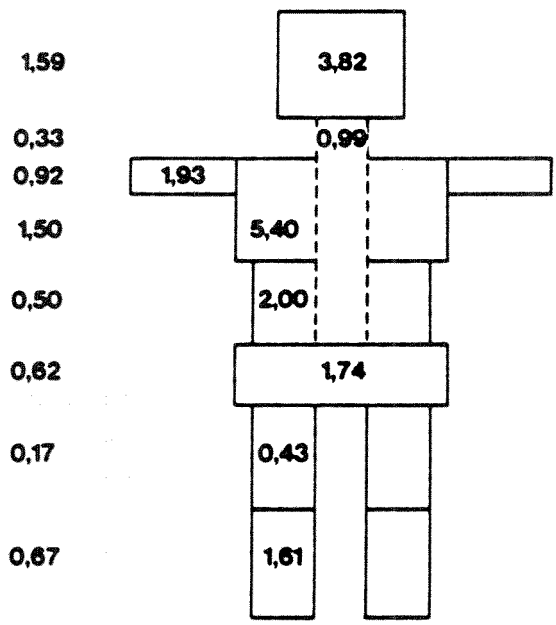
injury distribution for persons > 55 years
collision with V-form vehicle; n = 20
average age = 71 years
total degree of traumatisation = 10,82

Figure 4.2. Injury distribution "V-form" [3].



OAIS	Number of cases
0	
1	1
2	1
3	4
4	5
5	3
6	

injury distribution for children 8-14 years
collision with box-form vehicle; n = 14
average age = 8 years
total degree of traumatisation = 8,30



OAIS	Number of cases
1	
2	
3	2
4	3
5	4
6	3

injury distribution for persons > 55 years
collision with box-form vehicle; n = 12
average age = 73 years
total degree of traumatisation = 17,92

Figure 4.3. Injury distribution "Box-form" [3].

are listed below, others can also be found in [25]. The data for car geometry or deformation characteristics have been taken from the literature:

—the bumpers of passenger cars have an average static height of 450 mm which drops to between 320 mm and 390 mm in the braking position [11].

This height is very unfavourable. A lower static height of 300 up to 330 mm could prevent complicated knee injuries with possible long-time consequences to adult pedestrians [6, 11].

This is almost in agreement with the required bumper level of 340 mm in [22]. Lowering the bumper to the level of the doorstep is also required for better side impact protection. In a mathematical simulation, which also includes the aspect of head impacts, an optimum bumper height for children as well as for adults was found by a height of 500 mm [7].

The influence of bumper height on the amount and kind of head impact, which is also depending on the height and shape of the bonnet edge, is still under discussion. Further research is needed. Other authors call for a second (soft) bumper system, mounted below an existing (high) front bumper [8, 9, 15].

—*The front face of the car* should have a lead angle of less than 80° in [22] a lead angle of even less than 60° is required. Dummy tests and theoretical calculations suggested that for an impact of 40 km/h and a tolerance level of 4 kN for the hip make it necessary to have a crush depth of 200 mm for the front face when the car strikes a pedestrian [15].

—*The bonnet front edge* should be compliant and curvatured. A radius of 150 mm can help to avoid pelvis injuries to adult pedestrians and abdomen or thorax injuries to children [7]. Proposals for a bonnet height between 670 and 730 mm have been made to avoid head impacts of small children on the hood edge [10, 11].

—The "*soft face conception*" with a compliant front structure, made, for instance, of polyurethane (PU) or PU-foam and extended over the whole front face of the vehicle, is beneficial in the case of pedestrian accidents. It can also protect the vehicle from damages in low-speed car-to-car accidents [12]. All research vehicles with soft faces, built for better pedestrian protection, showed better results than common cars in the experimental tests conducted [2, 13, 14, 17].

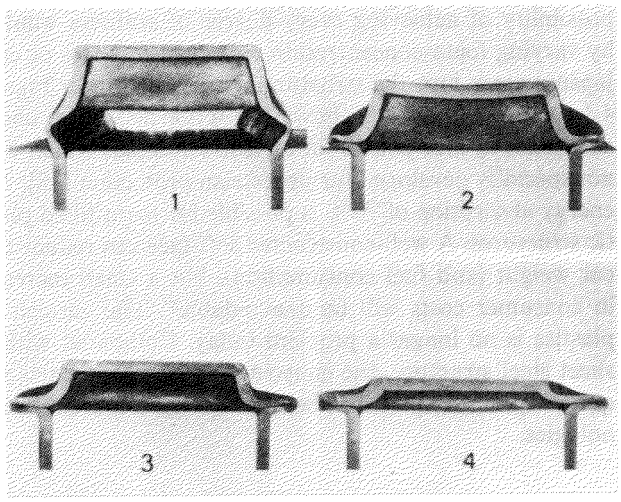
—The *bonnet* should be as long as possible to avoid head impacts on the windscreen or the windscreen frame. For a head impact on the soft hood area a length of 1200-1400 mm from hood edge with a bonnet height of 700 mm is necessary [7, 10, 11]. This length cannot be attained in the case of small cars.

An elimination of local rigid areas on the top surface of the hood, for instance, the joints of the bonnet and wings, will reduce the risk of serious head injuries. In [10] a deformation of 80 mm is required for the hood, when struck by the head of a pedestrian*. Hard parts of the engine at a distance of less than 100 mm under the hood should be avoided.

—For the *windscreen* the question whether laminated or tempered glass might be the better solution has not been answered yet. A thick cushioning of the windscreen surrounding would provide a somewhat greater extent of deformation [24].

—Masking of the stiff lower edge of the windscreen frame by means of a compliant structure, perhaps by extending the rear edge of the bonnet farther back over the frame and fitting compliant material over the A-posts, would provide a reduction in the severity of head impacts [12]. Air bags for the hood, especially

* The head impact velocity is in the range of 80-120% of the impact velocity of the car and is dependent on the car shape, found in full scale tests [23].



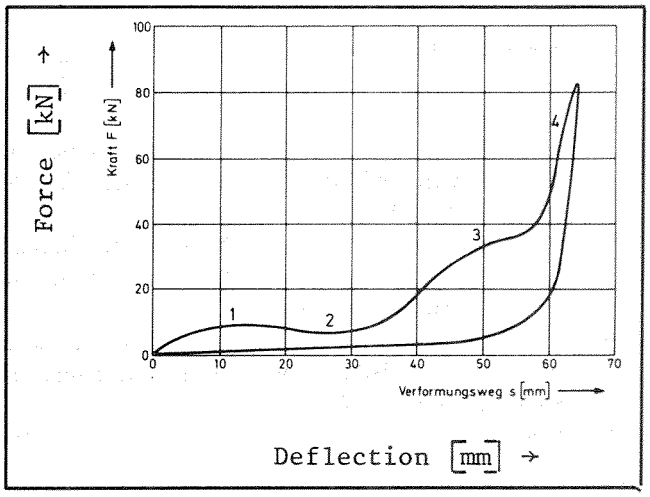


Figure 4.4. Force characteristic of a PU-bumper versus deflection.

for the windscreen frame area have been proposed too [19].

—*Headlamps* should be recessed and *windscreen wipers* and—*shafts* should be concealed.

—*Air dams* and any other device for better aerodynamic behaviour mounted on the car front should take the safety of pedestrians into account and should therefore be constructed by flexible materials and should give also a widely distributed loading to the impacted body parts with no sharp edge contacts.

Although still open problems exist and technical questions still are under discussion and although still no standardized test methodology for pedestrian accidents exists, it can be said, that also a step-to-step approach by legislation for testing car front components can be done for better pedestrian protection.

Due to the applied materials for the car front structure, for the bonnet and the wings, sheet steel has the best deformation characteristics. A covering with soft plastic material is possible [24]. An energy-absorbing soft-face for cars can be made of soft sheet steel or Polyurethane (PU) and/or PU-foam. The plastic material provides the possibility of achieving every degree of stiffness wanted by varying foam-concentration and including ribs or collapsing areas into the structure. This is shown in Figure 4.4 as an example. I1 shows the force deflection characteristics in four phases for a plastic bumper, which was not specially developed for pedestrian protection [18]. An energy absorption of 70% is possible for foam-filled plastic structures. A well-constructed soft-face can reduce the car weight (and fuel consumption), but a small increase in consumer costs will be unavoidable*. The varnish of plastics is no longer a problem today. Compared with a sheet steel structure, the construction of plastic parts requires special experience because of the different technologies.

REFERENCES

1. Luccini E., Weissner R.: Results from Experimental Simulations of Car-to-Pedestrian Collisions with VW-Production Cars, 7th ESV-Conf., Paris 1979.
2. Glaeser K. P.: Results of simulated Car-to-Pedestrian Collisions with the Minicars Research Safety Vehicle, 8th ESV-Conf., Wolfsburg 1980.
3. Tscherne, Appel H.: Abschlussbericht "Erhebungen am Unfallort" im Auftrage der Bundesanstalt für Strassenwesen, unpublished 1980.
4. Danner M., Langwieder K.: Collision Characteristics and Injuries to Pedestrians in Real Accidents, 7th ESV-Conf., Paris 1979.
5. Langwieder K. et al.: Patterns of Multi-Traumatisation in Pedestrian Accidents in Relation to Injury Combinations and Car Shape, 8th ESV-Conf., Wolfsburg 1980.
6. Stürtz G. et al.: Analyse von Bewegungsablauf, Verletzungsursache, Verletzungschwere, Verletzungsfolge bei Fussgängerunfällen mit Kindern durch Unfallforschung am Unfallort, Der Verkehrsunfall, Heft 2, Februar 1975.
7. Appel H., Glöckner H.: Fubgängerschutz am Pkw—Ergebnisse mathematischer Simulation, Berlin 1981.
8. Harris J.: Safer Cars for the Pedestrian, 1980.
9. Matthes D.: Sicherheit im Strassenverkehr—der Beitrag der Fahrzeugtechnik, unpublished.
10. Neilson I.: The Protection of Pedestrians and Pedal Cyclists by the Improved Design of Road Vehicles, OECD Symposium on Safety of Pedestrians and Cyclists 1979.
11. Stürtz G.: Das Kind im Verkehrsunfall: Biomechanik, Anforderungen an die äussere und innere Sicherheit von Kraftwagen, Fortschr.—Ber. VID-Z Reihe 17, Nr. 8, Düsseldorf 1981.
12. Ashton S. J., Mackay G. M.: Car Design for Pedestrian Injury Minimization, 7th ESV-Conf., Paris 1979.
13. Luccini E., Weissner R.: Experimental Simulations of Car-to-Pedestrian Collisions with the Calspan RSV, 7th ESV-Conf., Paris 1979.
14. Kühnel A., Appel H.: First Step to a Pedestrian Safety Car, 22nd Stapp Conf. 1978.
15. Harris J., Radley C. P.: Safer Cars for Pedestrians, 7th ESV-Conf., Paris 1979.
16. McLean R. F., Eckel C.: Cost Evaluation for Four Federal Motor Vehicle Standards. Task 7: Cost Review of Pedestrian Safety Modifications, Final Report, Troy 1979.
17. Pritz H. B.: Vehicle Design for Pedestrian Protection, 7th ESV-Conf., Paris 1979.
18. Hoffman J.: Über die Durchführung von Aufprallversuchen mit Stossfängern aus Chemiewerkstoffen für Kraftfahrzeuge, Hrsg.: HBM, Messtechnische Briefe 14 (1978), Heft 2.
19. Appel H., Kühnel A., Rau H.: Sicherheitsauto für Fussgänger und Insassen, ein Widerspruch? VDI-Tagung 11, 1976 in Berlin.
20. Appel H. et al.: Pedestrian Safety Vehicle—Design Elements—Results of In-Depth Accident Analyses and Simulation, 23.AAAM, 1978.
21. Bez U., Hoefs R., Stahl H.-W.: The V-Shaped Vehicle Front—Its Influence on Injury Severity in Pedestrian Accidents and Side Collisions, 7th ESV-Conf., Paris 1979.
22. Bunketorp O., Aldman B., Jonson R., Romanus B., Roos B., Thorngren L.: Experimental Studies on Leg Injuries in Car-Pedestrian Accidents. 6th IRCOBI, 1981.
23. Cesari D., Färber E., Glaeser K.-P., von Wijk J.,

* By modifying a 1978 Pontiac with a soft face, a reduction in weight of 130 N and an increase in costs of 12 DM was found [16].

Wismans J.: Proposed Standardized Pedestrian Test Methodology, EEC Biomechanics Programme Project G 6, 1981.
24. Appel H., et al.: Das Sicherheitskonzept des Forschungs-PKW UNI-CAR, VDI-Berichte 418, 1981.
25. Appel H. et al.: Biomechanik des Fussgängerunfalls, Schriftenreihe der Forschungsvereinigung Automobiltechnik e.v., Heft Nr. 7, Frankfurt 1978.

CHAPTER 5.
TEST AND ASSESSMENT METHODS

Comparison of Test Methods

When a pedestrian is struck by a vehicle the severity of the resulting injury is mainly dependent upon the kinematics of the pedestrian and the crush characteristics of the particular locations on the vehicle struck by the pedestrian.

Pedestrian kinematics are dependent upon all of the following factors: shape and stiffness at the front of a car, the impact velocity, the size of the pedestrian and his standing position. The important crush characteristics are stiffness, crush depth and energy absorption.

When reviewing test methods for assessing these characteristics, the impact sequence has been considered as essentially a two-dimensional problem with a three-dimensional aspect introduced in situations which cause the pedestrian to rotate about the vertical axis of its spine. The Group suggest that the relevance of the third-dimension is examined in order to determine if the problem may be adequately assessed by only a two-dimensional analysis.

The methods currently used to assess the effectiveness of these characteristics in a vehicle structure may be broadly divided into the following three main groupings:

i) full-scale tests in which a vehicle or simulated vehicle impacts a dummy or cadaver;
ii) body segment impact tests, in which an impactor representing a segment of a dummy strikes an appropriate component of a vehicle;
iii) mathematical model which gives a theoretical presentation of a vehicle striking a pedestrian.

Full-scale Testing

These tests give the most comprehensive data on the interaction of vehicles and pedestrians in an accident. They test the performance of the vehicle structures at the points of impact, but because the structural stiffness characteristics are often constantly changing with respect to location, the results obtained in such a test may not be applicable to impacts at any other location on the vehicle. The tests are complex, requiring extensive facilities and suffer from poor repeatability, making the result of small changes in vehicle design difficult to detect. They will, therefore, be difficult to use as a standard test but are an indispensable basic research tool for determining criteria for rig testing and for validating mathematical models.

Body Segment Impact Tests

These tests are generally simple, give good repeatability and are suited to assessing the stiffness and energy-absorbing capability of discrete structures for both standards and development testing. The tests give no assessment of the overall shape of a car, or an analysis of the kinematics of a pedestrian. In the past they have sometimes given poor agreement with results of full-scale tests because of the difficulty of determining a representative mass of the impactor.

Mathematical Models

An inherently repeatable process, which when fully validated to a satisfactory standard, will probably be the most precise method available for analysing and comparing the performance of the profile, stiffness and design features of a vehicle for pedestrian protection.

The advantages of this method are:

i) It is repeatable, giving a complete picture of the event and is, therefore, suitable for studying the influence of changes to single components.
ii) It is able to predict the responses for different sizes of pedestrians.
iii) In many circumstances it can calculate quantities which are difficult to measure experimentally.
iv) It enables a simulated vehicle or component to be assessed before it is actually produced.

The main disadvantages are:

i) All of the characteristics of the pedestrian model have to be determined.
ii) The sections of the vehicle structure that influence the response of the pedestrian model to impact have to be identified and appropriate characteristics determined.
iii) Features that may influence a pedestrian's response in an impact but are overlooked when setting up the model, may pass unnoticed.
iv) When assessing vehicles or components that are still in the design stage an estimate must be made of the appropriate crush characteristics.

Full-Scale Vehicle Test Procedures

Introduction

For this test a vehicle or simulated vehicle is accelerated to a selected speed to strike a standing dummy placed in its path. The vehicle is then decelerated by a braking system during the impact. The resulting response of the dummy is monitored by appropriate instrumentation and photographic recordings.

Impact Vehicle

The impacting vehicle may take the form of either a complete car running on its own road wheels [1, 2, 3, 4] or the front section of a car mounted on a test trolley [5]. Simple changes in design may be represented by mounting simulated body panels on to a trolley fitted with a variable geometry mounting frame [6, 7, 8].

Greatest accuracy of acceleration, guidance and braking of the vehicle or trolley is obtained by mechanical or electrical control, but driver controlled car tests have been successfully conducted [9]. Impact speeds have ranged from 10 to 60 km/h, with particular attention given to the 25 to 45 km/h region. Vehicle braking decelerations corresponding to emergency brake levels are at 0.6 to 0.7 g and in some instances decelerations of 0.5 g have been used in tests.

Tests have shown that the speed and height of a vehicle at the moment of impact are important parameters in determining the charcteristics of the impact to the dummy. During brake application the height of the car may change appreciably (brake dive). Accident data [10] suggest that both the 'brake dive' and the normal running height conditions occur at pedestrian impact and tests to represent both vehicle settings should be considered.

When tested, complete cars running on road wheels usually have their suspension free to operate and they therefore reproduce 'brake dive'. Trolley mounted body shells are generally set at a fixed height to reproduce either the normal running height or the brake dive condition.

In order to achieve comparable test conditions, it is important that vehicle speed and ride height at the moment of impact should be both predictable and repeatable. This may be easier to achieve if the brakes are applied just after the instant of impact. Dummy leg to bumper contact time has been reported as only 100 ms [11].

With braking prior to striking the dummy, the velocity [2], and on cars with active suspensions, the ride height will also be rapidly changing at the instant of impact, thus making a specified ride height and impact velocity difficult to achieve.

On a vehicle with an active suspension system, there may be a risk that a descending bumper will hold an impacted leg to the ground. With brake application at or after impact, this possibility will be minimised because the leg will leave contact with the bumper before brake dive commences.

On standard cars the fully dived condition at impact may be achieved with more assurance of repeatability by pre-clamping the suspension system in the dive attitude.

Pedestrian Dummy

The two dummy sizes normally utilised represent a six-year-old child and a fiftieth percentile adult male, modified as necessary at the pelvis and shoulder/neck joint to allow a standing posture.

Some road accident data claim that the fiftieth percentile height of a pedestrian victim is 1.60-1.65 m compared to the 1.75 m of the dummies commonly used [1, 2, 12].

The use of the taller dummy is however probably acceptable since its head is more likely to strike in the region of the windscreen or its surround which are a frequent source of serious head injuries [11, 12].

Claims are frequently made that it is difficult to obtain repeatable results from existing dummies and also that they require improving in order to give a more accurate representation of a human pedestrian in an accident.

The neck, torso and pelvis of the child dummies are considered to be too inflexible. The adult dummies currently in use have been criticised for the following reasons [3,4,9,13,14].

1. The lumbar joint, torso and neck are too inflexible. The spine should be flexible over its total length and also have vertical compliance and elasticity.
2. The shoulders are too stiff in lateral compression.
3. The knee joint requires lateral compliance.
4. Leg adduction is insufficient.
5. The ankle joint requires lateral rotation.

A two-dimensional pedestrian dummy has been proposed and in view of the predominately two-dimensional characteristics of a pedestrian accident, the Group believe that this possibility should be examined to determine if such a device may simply, successfully and repeatably reproduce all of the necessary features of a pedestrian accident.

Dummy Stance

The dummy may be positioned at any location in front of the car to test the different stiffnesses of the front structure and bonnet top with the location, stance and joint conditions closely controlled so that tests may be repeated as accurately as possible.

The dummy is normally positioned so that it is totally in the path of the car; difficulty may be experienced in obtaining repeatability from corner impacts in which the car strikes only a portion of the dummy.

Dummies are normally supported from the head and released electrically just before impact. With this arrangement the joints are torqued to approximately the 1g level

but greater flexibility may be obtained by reducing this value to 0.5g or less.

Some tests have been conducted with free standing dummies and in these instances, there was no joint friction and weak shear pins were fitted at the adult hip and knee and the child knee [8,15]. The free standing arrangement is more difficult to set up. The weight of the dummy is usually equally distributed between both feet but on some occasions 90 percent of the load was on the impacted leg which was considered to reproduce the most severe leg impact condition [7].

Impacts have usually been to the side of the dummy with a small number to the front and rear, thus reflecting the directional frequency in the real world accident situation.

The impact tests to the side of a dummy may give the most severe leg impact condition [7].

Impact of the shoulder or elbow to the bonnet top frequently occurs and because on current dummies these components are far more rigid than on a person, they give to the dummy an unrealistically high degree of protection to the head [5,9]. In some instances this has been overcome by standing the dummy essentially at right angles to the impacting car but rotated towards the bonnet by 30 degrees and with the impacted leg rearwards. This is claimed to give a representative loading to the lower limbs and also imparts sufficient rotation to the dummy during the impact to ensure the headform strikes the bonnet without shoulder contact [14]. It has been noted, however, that with this stance a dummy has virtually no residual adduction at the leg.

The arms have, where necessary, been lightly taped to the torso to ensure that they do not interfere with head or thorax to bonnet impact. There may be an advantage in removing the arms from the dummy if it can be shown that their omission does not cause a significant change in the subsequent trajectory of the dummy. It would be appropriate to partially ballast the torso to compensate to some degree for the arms being removed.

Instrumentation

High-speed cameras and instrumentation for recording accelerations and forces are necessary for a comprehensive assessment of the impact.

Photography

Cameras running at up to 500 frames per second can give a clear close-up of the initial impact and an overall view can also be taken from a distant position at right angles to the impact location. This second camera must be duplicated if an accurate assessment is required of the dummy kinematics up to subsequent impact with the ground. If accuracy is required only for the dummy-to-car impact period of the test, then a panned camera may be sufficient to give the overall scene.

Additional cameras positioned over the point of impact and mounted on the vehicle to view the dummy from the roof and from the side have also proved to be useful.

Accelerometers and load cells

Triaxial accelerometers are fitted to the head, upper thorax and pelvis of both the adult and child dummies, with additional accelerometers at the knee and ankle of the adult.

Rotational acceleration of the head is a cause for concern, but there is no acceptable current measurement.

Bending moments have been measured on both the upper and lower leg segments as well as loads on hip joint and occasionally loads on neck and the leg in compression [8,16].

On the impacting vehicle, bumper loads and bonnet fore and aft and vertical loads have been recorded.

Assessment

Precise assessment of an impact is usually conducted for all stages up to the headform striking the bonnet or windscreen area. Subsequent impact with the ground is often considered only in general terms because the response of the dummy is unlikely to accurately reproduce the actions of a pedestrian for kinematics of such duration and complexity.

The main purpose of the test is to assess the kinematics of the dummy, the velocity of the different body regions when striking the car and the exact location on the car of each particular impact.

Acceleration and force measurements are primarily of value for comparison with other tests, using an identical dummy to show if there are significant changes in the severity of impact.

Severity of leg impact may be assessed by consideration of the bending moments in the long bone and the bending moments and shear force in the knee joint. Knowledge of these parameters is particularly necessary when multiple impacts to the leg occur.

In conditions where the leg is struck only by the bumper, and the shape and position of the bumper is unchanged, then some indication of the relative severity of the leg impact may be obtained from consideration of the knee or ankle acceleration or the bumper load. Correlation of knee acceleration against injury has been reported in one series of cadaver tests [17], but generally researchers have not been able to show any correlation of leg accelerometer measurements to injury.

Comparison of impact severity at other body regions may be related to the following measurements:

Pelvis—Impact load on hip joint or pelvic acceleration
Thorax—Thoracic acceleration
Head—Head acceleration

For tests into all types of structures, impact location

and impact velocity of the different body segments are important. Accelerations are only meaningful if the structure impacted is a section of a real car or is suitably designed to represent an appropriate automobile structure.

Additional factors may help to assess the risk of severe head injury from ground impact. These are, the extent of rotation of the dummy on to the bonnet and then to the ground, the throw height and throw distance and the contact time of the dummy on the vehicle.

Rig Component Tests

Introduction

This form of tests consists of an impact between a section of a vehicle and a body segment of a dummy or cadaver. The impacting device may be either a pendulum, or a form fired from an air or hydraulic gun or mounted on a small trolley.

Head Impact Tests

In this test an impactor representing a headform is propelled into a test structure at an appropriate speed and direction that has been determined either from full-scale tests described in paragraph 5.2 or from a mathematical model.

A firmly mounted air or hydraulic gun is probably the most suitable device to accelerate the headform, allowing for impact at nearly any angle, but free fall or pendulum system are also satisfactory in many situations.

Establishing the effective mass of a headform has proved to be difficult and values ranging from 4.3 kg to 7.12 kg have been used [18,19].

When the headform and torso of a dummy simultaneously strike a flat panel, such as a bonnet top, there is probably only a small loading transmitted through the neck and the effective mass of the headform corresponds approximately to its own weight. If this dummy were to dive head-first into the same panel, the effective mass of the headform would be increased by a proportion of the torso mass and the magnitude of this increase would be influenced by the angle and stiffness of the neck.

Several researchers have experienced difficulty in reproducing on the component test rig the headform accelerations measured in full-scale tests, and this difference has been attributed to unrepresentative or constantly changing effective masses. It is possible that the choice of effective mass of the headform may vary depending upon the location on the car of the component under test.

Leg Impact Tests

Rig tests relating to legs, fall into two main groups. The simpler tests consist of an impactor representing a legform, striking a car bumper. In the alternative and more complex test method a trolley mounted bumper or car front is propelled into a sophisticated dummy leg attached either to a complete dummy or to a mechanical system representing this.

Moving legform tests

The impactors shaped to represent the knee or shinform are propelled by a gun or pendulum device at speeds up to 40 km/h into the front face of a rigidly mounted bumper. The effective mass of the legform will partly depend on the height of the bumper and, therefore, the region of the leg that is struck and partly on the lateral compliance at the knee.

Full-scale tests using dummies having no lateral compliance at the knee have shown that the effective mass may range from 5.5. kg with a bumper height of 180 mm to 18 kg with a bumper height of 400 mm [8].

Tests with cadavers, which have a lateral compliance at the knee approximating to that of real pedestrians, indicate that the effective mass used by a bumper mounted at 500 mm is approximately 3.2 kg [17].

The most realistic value of effective mass is probably best derived from knee acceleration and bumper forces measured on full-scale cadaver tests with the magnitude of the impact in the tests chosen to give a closely defined severity of knee, or knee ligament injury.

The method used to assess the moving leg test is by consideration of the magnitude of the acceleration of the impactor. This may be satisfactory over a limited range of impactor shapes and stiffness, but it is unlikely that the performance of a wide range of car frontal shapes can be accurately assessed.

Moving bumper test

A bumper or car front face is mounted on a small test trolley (300 kg has been used) and propelled into a sophisticated legform fitted with a knee joint having a small measure of lateral compliance. A mass representing the torso is pin-jointed to the top of the upper leg [20].

Performance of the impacting device may be assessed by considering either the angle of flexure at the knee or the bending moment across the knee or the forces acting on the ligaments if these are fitted. An analysis of shear forces across the knee may also prove to be necessary.

When fully developed this procedure is potentially more suitable for assessing the performance of a much wider range of shapes than the first method considered.

Bonnet Leading Edge Tests

The bonnet leading edge is for many cars the component which gives the major force of impact to the pedestrian. It strikes either the pelvis or femur of an adult, or the thorax of a six-year-old child. Tests to assess the performance of this important component take account

of the effective mass of the adult pelvis which is probably the heaviest of these segments and will, therefore, require the greatest crush depth and also the child thorax, which is the lightest and requires the least stiffness. The effective mass is, however, influenced by the shape of the front of a car and consequently full-scale tests measuring bonnet leading edge fore and aft loads and equivalent adult pelvis and child thoracic accelerations are necessary to determine a range of realistic values [21].

A gun or pendulum device is suitable for projecting the impactor horizontally into the car component at velocities up to 40 km/h. Performance of the component is assessed by analysis of the acceleration/time history of the impactor measured by an accelerometer mounted at its centre of gravity.

Mathematical Model

Introduction

A mathematical model is a process which utilises a computer program to predict the kinematics and the impact forces on a pedestrian struck by a vehicle. A computer run of the program is closely equivalent to an experimental test with a car and a dummy pedestrian.

Similarly to the Full-Scale Vehicle Test, its main purpose is to show the kinematics of the dummy, the velocity of the various body regions when striking the car, and the location of the respective impacts to the car.

When used as a research tool, it may also provide time histories of the forces and accelerations acting at the knee, pelvis, thorax and head of the pedestrian dummy when striking the car. The kinematics when thrown from the bonnet to the ground are only of general interest, to show the probable orientation of the thorax and head at impact with the ground.

General Description

The model may be either two or three dimensional.

The three-dimensional version is much more expensive to run and also requires a larger computer. Nevertheless when the relatively expensive development of the computer programme is complete, it can be used for many tests at costs which are considerably cheaper than those of a full-scale dummy test. It should furthermore be capable of giving accurate results for most configurations of vehicle frontal and corner design and pedestrian stance [22,23,24].

The two-dimensional model is most suited to impacts with symmetrical loadings which do not induce lateral displacement or rotation apart from pitching. A limited number of studies using a two-dimensional model have been conducted in which some measure of asymmetric loading was present and good agreement with the results of full-scale tests was noted. A large number of validation tests would be necessary, however, to demonstrate the limits to which this process may be used with acceptable accuracy [14].

Pedestrian Model

The specification of the pedestrian model is based on the characteristics of a dummy, that is, a series of rigid elements connected by joints. Cadavers and real people have semi-flexible elements which are much more difficult to represent.

For two-dimensional models, 7 or 8 segments are normally used and 14 or 15 for the three-dimensional model.

Each segment is defined by:

i. Mass.
ii. Location of joints.
iii. Location of centre of gravity.
iv. Moments of inertia in x, y, and z directions.
v. Dimensions of the semi-axis of ellipsoids of contact.

Joints generate two sets of forces: constraint forces, that keep the segments together and spring forces.

The constraint forces are composed of tension compression, shear and the components of torque not caused by friction.

The spring forces are generated by a movement between two adjacent segments. These are composed of elastic and viscous torques and coulomb friction using polynomial joint stops where appropriate. The joints are further defined by the positions of the centres of rotation and of the joint stops.

Vehicle Model

The vehicle is described by up to twenty deformable panels each with an appropriate stiffness. Stiffness values at certain locations will be applicable to many models of car.

The ground is represented by one of the vehicle panels. If the panel is depicted as stationary relative to the standing dummy, then foot friction may be reproduced. In the instances where the panel moves with the vehicles, zero foot friction is assumed so that the pedestrian does not move before impact.

Full-scale tests have shown that foot friction has a significant influence on the kinematics of a dummy and also on the impact forces to the leg.

Operating Model

Realistic contact forces have been represented by the model in the following situations:

i. Narrow sections—When a narrow section of a vehicle (eg., a bumper) struck a long segment of a pedestrian, (eg., a leg) then a reactive force was always generated.

ii. Soft panels—When a segment penetrated a soft panel, (eg., a bonnet top) then the reactive force was maintained.
iii. Adjacent panels—When a segment strikes two adjacent panels, then the development force took account of the loading to the adjacent panel.
iv. Reactive force—Calculations of reactive force differentiated between recoverable planes, in which energy is stored and fractured planes (eg., windscreens) in which impact energy is destroyed.

To simplify operation of the model it has proved helpful for the integration method to have a variable step size.

The step time interval is set to be short for the period that the pedestrian is in contact with the vehicle and longer during the 'in flight' condition.

Validation

Models are validated by comparing the output with the result of full-scale tests to show the measure of agreement achieved over the required range of variations of vehicle/dummy shape, size, stiffness, impact location and speed. Currently models are compared to test results which are based on a wide range of dummies which have known, even if unsatisfactory, characteristics.

In order that mathematical model performances can be standardized it may be helpful if an agreed set of pedestrian surrogate impact responses to given impact situations were compiled and made universally available for the validation of new or modified models.

The characteristics of the pedestrian surrogate should be developed to depict as closely as possible, those of a human being rather than of current dummies. In accident reproduction tests, dummies have proved to be more rigid than the pedestrian and cadavers more flaccid.

REFERENCES

1. A. Küehnel, H. Appel. First step to a pedestrian safety car. Proc. 22nd Stapp Car Crash Conference, Ann Arbor, USA, October 1978.
2. G. Stcherbatcheff, C. Tarrière, P. Duclos, A. Fayon, C. Got, A. Patel. "Simulation of collisions between pedestrians and vehicles using adult and child dummies". Proc. 19th Stapp Car Crash Conference, San Diego, USA, November 1975.
3. E. Luccini, R. Weissner. "Results from experimental simulations of car to pedestrian collisions with VW production cars". Proc. 7th Conference on Experimental Safety Vehicles, Paris, France, June 1979.
4. P. Billault, M. Berthommier, J. Gambarelli, J. Farisse, G. Seriat-Gautier, N. Daou, P. Bourret, C. Cavallero, D. Cesari, M. Ramet. "Pedestrian safety improvement research". Proc. 8th Int. Tech. Conference on Experimental Safety Vehicles, Wolfsburg, Germany, October 1980.
5. H. B. Pritz. "Comparison of the dynamic responses of anthropomorphic test devices and human anatomic specimens in experimental pedestrian impacts". Proc. 22nd Stapp Car Crash Conference, Ann Arbor, USA, October 1978.
6. M. Kramer. "Pedestrian vehicle accident simulation through dummy tests". Proc. 19th Stapp Car Crash Conference, San Diego, USA, November 1975.
7. H. B. Pritz, C. R. Hassler, J. T. Herridge, E. B. Weis. "Experimental study of pedestrian injury minimization through vehicle design". Proc. 19th Stapp Car Crash Conference, San Diego, USA, November 1975.
8. D. G. C. Bacon, M. R Wilson. "Bumper characteristics for improved pedestrian safety". Proc. 20th Stapp Car Crash Conference, Dearborn, USA, October 1976.
9. J. Harris, C. P. Radley. "Safer cars for pedestrians". Proc. 7th Int. Tech. Conference on Experimental Safety Vehicles, Paris, France, June 1979.
10. S. J. Ashton. "Pedestrian injuries and the car exterior. Chapter 6: Cause nature and severity of the injuries sustained by the fronts of cars or light goods vehicles". PhD Thesis, University of Birmingham, Birmingham, 1978.
11. F. Brun, D. Lestrelin, F. Castan, A. Fayon, C. Tarrière. "A synthesis of available data for improvement of pedestrian protection". Proc. 7th Int. Tech. Conference on Experimental Safety Vehicles, Paris, France, June 1979.
12. S. J. Ashton, J. B. Pedder, G. M. Mackay. "Pedestrian injuries and the car exterior". Society of Automotive Engineers Transactions, Paper 770092. Society of Automotive Engineers, Warrendale, USA, 1977.
13. K. W. Kreiger, A. J. Padgaonkar, A. I. King. "Full-scale simulation of pedestrian-vehicle impacts". Proc. 20th Stapp Car Crash Conference, Dearborn, USA, October 1976.
14. D. Lestrelin, F. Brun-Cassan, A. Fayon, C. Tarrière, F. Castan. " 'Prakimod' Mathematical simulation of accident victims. Validation and application to car-pedestrian collisions". Proc. 8th Int. Tech. Conference on Experimental Safety Vehicles, Wolfsburg, Germany, October 1980.
15. V. J. Jehu, L. C. Pearson. "The trajectories of pedestrian dummies struck by cars". Dept. of the Environment, TRRL Report LR 718, Crowthorne 1976. Transport and Road Research Laboratory.
16. G. Stürtz. "Repetition of real-child pedestrian accidents using a high instrumented dummy". Proc. 3rd Int. Meeting on the Simulation and Reconstruction of Impacts in Collisions, IRCOBI, Lyon, France, September 1978.

17. R. H. Eppinger, H. B. Pritz. "Development of a simplified vehicle performance requirement for pedestrian injury mitigation". Proc. 7th Int. Tech. Conference on Experimental Safety Vehicles, Paris, France, June 1979.
18. M. Kramer. "Improved pedestrian protection by reducing the severity of head impact on to the bonnet". Proc. 7th Int. Tech. Conference on Experimental Safety Vehicles, Paris, France, June 1979.
19. G. Stcherbatcheff, P. Duclos, C. Tarrière, A. Fayon, G. Walfisch. "Simulations and reconstructions of pedestrians and two-wheel riders head-to-car impacts". Proc. 3rd Int. Conference on Impact Trauma, IRCOBI, Berlin, Germany, September 1977.
20. B. Aldman, L. Thorngren, O. Bunketorp, B. Romanus. "An experimental model for the study of lower leg and knee injuries in car-pedestrian impacts". Proc. 5th Int. Conference on the Biomechanics of Impacts, IRCOBI, Birmingham, England, September 1980.
21. S. Daniel, R. H. Eppinger, D. Cohen. "Considerations in the development of a pedestrian safety standard". Proc. 7th Int. Tech. Conference on Experimental Safety Vehicles, Paris, France, June 1979.
22. J. Maltha, J. Wismans. "Madymo-Crash victim simulation. A computerised research and design tool". Proc. 5th Int. Conference on the Biomechanics of Impacts, IRCOBI, Birmingham, England, September 1980.
23. J. P. Cotte, M. Laurent, M. Berthommier. "Improvement of a mathematical model to study pedestrian safety". Proc. 5th Int. Conference on the Biomechanics of Impacts, IRCOBI, Birmingham, England, September 1980.
24. J. E. Fowler, R. K. Axford, K. R. Butterfield. "Computer simulation of the pedestrian impact. Development of the contact model". Proc. 6th Int. Tech. Conference on Experimental Safety Vehicles, Washington, USA, October 1976.

Sources of Head Injuries and the Reconstruction of Vehicle Head Contacts in Pedestrian Accidents

S. J. ASHTON
T. A. GREETHAM
The Ohio State University, Columbus, Ohio
H. B. PRITZ
National Highway Traffic Safety Administration
M. PEREIRA
Transportation Research Center of Ohio

ABSTRACT

The relative importance of head injuries in pedestrian accidents and the influence of head impact location on the severity of head injuries is examined by reference to the PICS data file.

The results of an experimental program, in which the relative stiffnesses of different locations on the hood fender top surface were determined are described and compared to the accident data analysis.

The initial findings of a program to reconstruct pedestrian head to vehicle contacts is reported and problems relating to the reconstruction of head impacts discussed.

INTRODUCTION

Pedestrian accidents currently result in approximately 8000 people dying, and approximately 150,000 people sustaining non-fatal injuries, in the United States of America each year. A recent study by Wolfe and O'Day (1) showed that over 75% of U.S. pedestrian accidents occur in urban areas and that in about 80% of the accidents, the pedestrian is struck by a car. Data from the Pedestrian Injury Causation Study (PICS), a NHTSA-sponsored in-depth study of urban pedestrian accidents involving cars and light trucks, indicate that roughly two-thirds of the pedestrians struck by a car or car derivative receive a direct blow from the front of the vehicle (2). Combining these results indicates that in over one half of all U.S. pedestrian accidents, the involved pedestrian is struck by the front of a car or car derivative.

Head and leg injuries have been identified as the injuries most often sustained by pedestrians struck by the fronts of cars; head injuries being particularly important as they are the injuries most frequently responsible for death (2, 3). In this paper, the sources of head injury in U.S. pedestrian accidents are described. The factors influencing the severity of vehicle contact head injuries are examined.

An experimental test program examining the properties of the vehicle structures contacted by pedestrian's heads is described and the effectiveness in reproducing real world head impacts is commented upon.

PEDESTRIAN HEAD INJURIES

The Data

The results presented in this section were obtained from analysis of the final Pedestrian Injury Causation Study (PICS) data file. In the PICS study, data on a total of 1997 accidents involving 2021 vehicles and 2068 pedestrians were obtained by investigations conducted in various cities in the United States between 1977 and 1980 by five accident investigation teams. Each team investigated a stratified sample of accidents involving cars, car derivatives or light trucks such as pickups or vans. To allow for combination of the data, weighting factors based on each team's sampling plans were computed for each case. Weighting the data in the data file produced an effective data base of 5152 accidents involving 5317 pedestrians and 5280 vehicles.

Restricting the analyses to only those cases where a single pedestrian was struck by the front of a car or car derivative, and details of the pedestrian's age and injuries were known, reduced the effective data base to 2686 cases.

The Injuries

Head injuries (including injuries to the face) were sustained by 62% of the pedestrians struck by the front of a car or car derivative. Just over half (52%) of those with a head injury were noted as having received just one such injury; while 20% received three or more head injuries and 3% received 5 or more head injuries. However, many of these injuries resulted from a single cause. For instance, a person who received a blow to the head which resulted in a scalp laceration, a skull fracture and a period of unconsciousness would be recorded as having three injuries. The majority (87%) of the head injuries were attributed to a single cause or contact (Table 1).

Further analysis of the source of the head injuries indicated that almost twice as many head injuries were caused by contact with the ground than by contact with the vehicle (Figure 1).

Table 1. General source of head and face injuries by number of distinct injury sources for pedestrians struck by the fronts of cars or car derivatives—weighted PICS data.

General source of Injury	Number of distinct injury sources			
	1	2	3	All
Vehicle only	423	16		439
Ground only	940	6		946
Vehicle and ground		168	19	187
Not known	80	2		82
	1443	192	19	1654

Relative Importance of Vehicle Contact and Ground Contact Injuries

Although contact with the ground was the main source of head injury, a high proportion of the injuries resulting from ground contact were relatively minor injuries; 84% of the ground contact injuries being minor or moderate (AIS 1-2) injuries compared to 64% of the vehicle contact injuries (Table 2). It was found that the importance of the vehicle as a source of injury increased as the severity of the head injuries increased (Table 3). While contact with the vehicle was responsible for 34 to 39% of all head injuries, it was responsible for 55–58% of the AIS 4-6 head injuries. Malliaris, Hitchcock and Hedlund (4) reported that 62% of the harm to pedestrians' heads resulted from contact with the vehicle: harm being a concept in which the importance of a particular injury or injury source is assessed using injury cost data to weight the AIS ratings.

Contact with the vehicle is thus currently an important source of pedestrian head injury and is more important than contact with the ground.

General Location of Vehicle Head Contacts

The top surface of the hood and fenders was the area most frequently struck by pedestrians' heads, approximately 60% of all head contacts with the vehicle being to this area. Contact with the windshield or windshield surround accounted for about 22% while contact with the front structure of the vehicle, i.e., the leading edges of hood and fenders and the radiator grill, accounted for 13%. As would be expected, age had a strong effect on the location of the contacts. The proportion of vehicle head contacts that were to the top surface of the hood or fenders rising from about 30% for the very young child (<5 years old) to about 80% for the older child, and then declining to about 35% for adults aged 30-44 years but increasing to about 75% for elderly adults (>60 years) (Figure 2). These differences with age in the proportion of vehicle head contacts to the hood and fender top surface can be explained by consideration of the variation in height of pedestrians with age and in variation in impact circumstances with age.

Specific Vehicle Location and Severity of Vehicle Head Contacts

The relative importance of the various structures contacted by the head is related to the frequency of contact and the injury severity if there is a contact. An analysis on the relative importance of vehicle components was

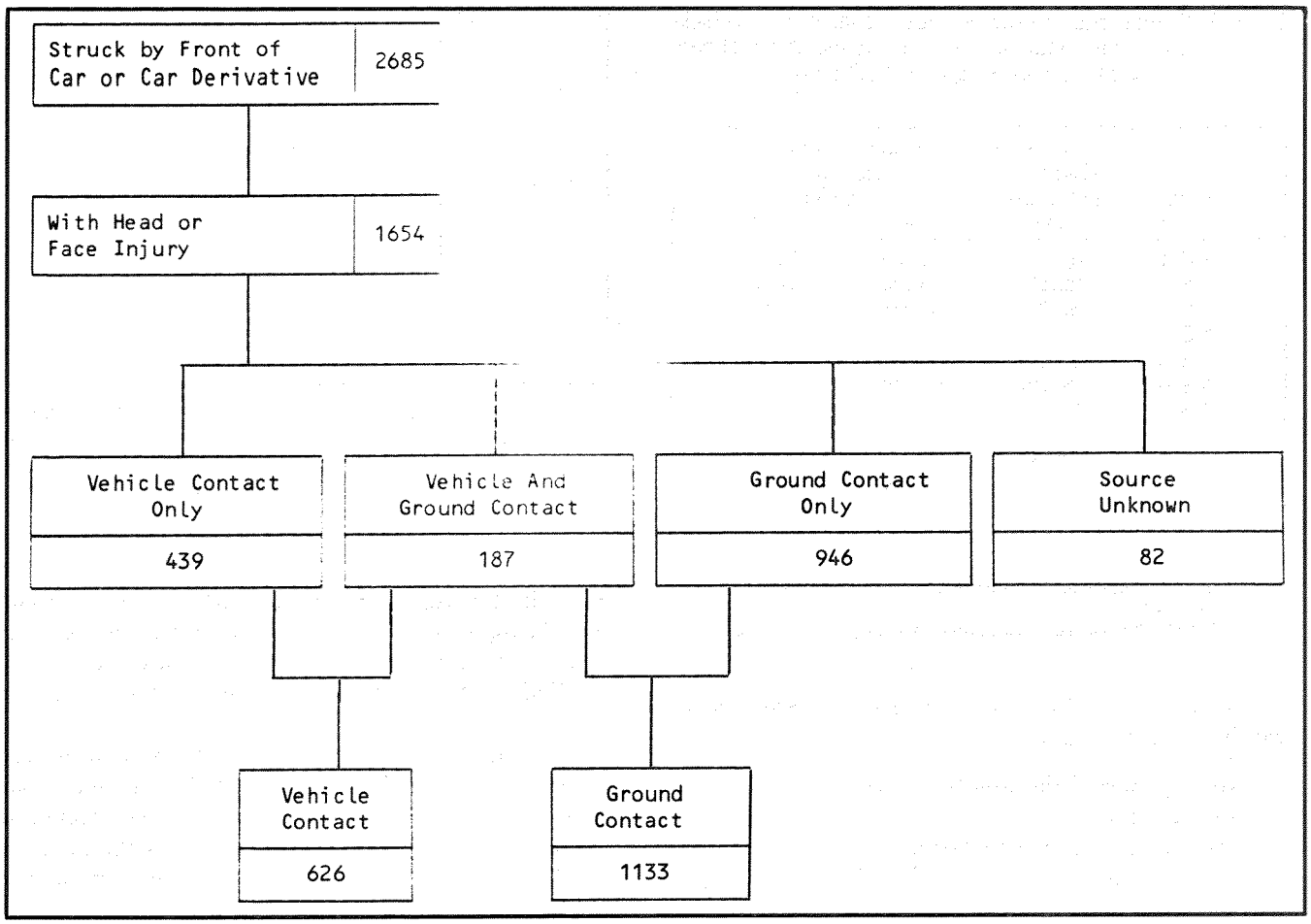


Figure 1. General source of head injury for pedestrians struck by the fronts of cars or car derivative.

performed taking into account both of these concepts. In conducting this analysis, all distinct sources of injury were considered.

The main structures contacted, in order of decreasing frequency of contact, were:

—the top surface of the hood
—the top surface of the fenders
—the front structure of the vehicle
—the lower edge of the windshield frame/cowl
—the windshield glass
—the "A" pillars
—the top edge of the windshield frame

Contact with the top surface of the hood occurred about 4 times as often as contact with the next most frequently contacted structure, and was the cause of just under 50 percent of the vehicle contact head injuries.

In terms of injury severity, however, contacts with the top surface of the hood, front face of the vehicle, and the windshield were found to be less likely to result in AIS 4-6 injuries than contacts with other structures (Figure 4). Contact with the top edge of the windshield frame was the most hazardous; 60% of such contacts resulting in AIS 4-6 injuries. This reflects the high speed necessary to reach these structures. Ranking the structures in order of decreasing hazard, hazard being related to the risk of

Table 2. Severity of head injuries by general source of injury for pedestrians struck by the fronts of cars or car derivatives—weighted PICS data.

General source of injury	AIS						
	1	2	3	4	5	6	All
Vehicle contact	334	86	118	53	40	23	654
Ground contact	718	239	102	43	34	10	1146
Not known	43	24	11	5	1		84
	1095	349	231	101	75	33	1884

Table 3. Percentage of head injuries resulting from vehicle contact for pedestrians struck by the fronts of cars or car derivatives weighted PICS data.

Injury severity group	Percentage vehicle contact Excluding unknowns (1)	Including unknowns (2)		(3)
AIS 1	31.6%	30.3%	–	34.2%
AIS 2	26.5%	24.5%	–	31.5%
AIS 3	53.6%	51.1%	–	55.8%
AIS 4	55.2%	53.5%	–	57.4%
AIS 5	54.1%	53.3%	–	54.7%
AIS 6	69.7%	69.7%	–	69.7%
AIS 1-6	36.2%	34.6%	–	39.1%
AIS 2-6	42.8%	40.6%	–	45.8%
AIS 3-6	55.3%	53.2%	–	57.0%
AIS 4-6	57.1%	55.5%	–	58.4%
AIS 5-6	58.9%	58.3%	–	59.3%

Note: If "V" is the number of vehicle contact injuries, then (1) = 100.V/(V+G).
If "G" is the number of ground contact injuries, (2) = 100.V/(V+G+N).
If "N" is the number of unknown contact injuries, (3) = 100(V+N)/(V+G+N).

sustaining an AIS 4-6 head injury from a head contact with the structure, gave:

—the top edge of the windshield frame
—the "A" pillars
—the top surface of the fenders
—the lower edge of the windshield frame/cowl
—the top surface of the hood
—the front structure of the vehicle
—the windshield glass

The relative importance of the different structures is a function of the frequency of contact and the severity of the injuries sustained. On the basis of frequency of contact, the top edge of windshield frame ranked seventh and the top surface of the hood ranked first, while on the basis of the severity of the injuries sustained, the top edge of windshield frame ranked first and the top of the hood fifth.

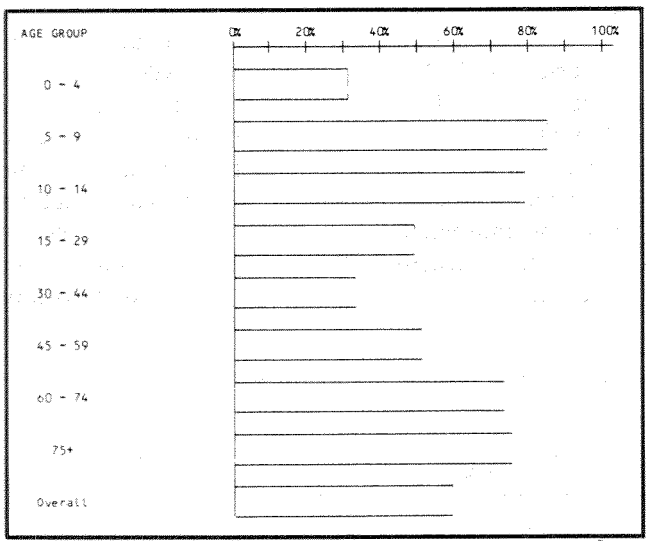


Figure 2. Influence of age on the proportion of vehicle head contacts that are to the top of the hood or fenders for pedestrians struck by the fronts of cars or car derivatives—weighted PICS data—.

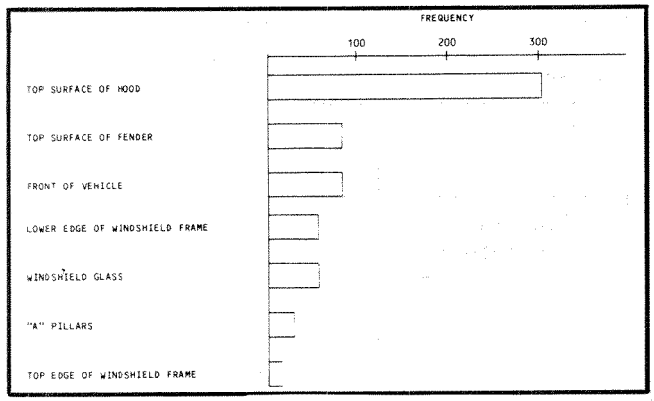


Figure 3. Frequency of contact for various vehicle structures as the source of the most severe head injury sustained by pedestrians struck by the fronts of cars or car derivatives—weighted PICS data.

The concept of harm used by Malliaris, et al. (4) provides a method of taking into account both frequency and severity. Figure 5 shows a comparison of the percent total harm for each vehicle component. Ranking the structures on the basis of the percent total harm gives, in order of decreasing harm:

—the top surface of the hood
—the top surface of the fender
—the lower edge of the windshield frame/cowl
—the "A" pillars
—the top edge of the windshield frame
—the front face of the vehicle
—the windshield glass

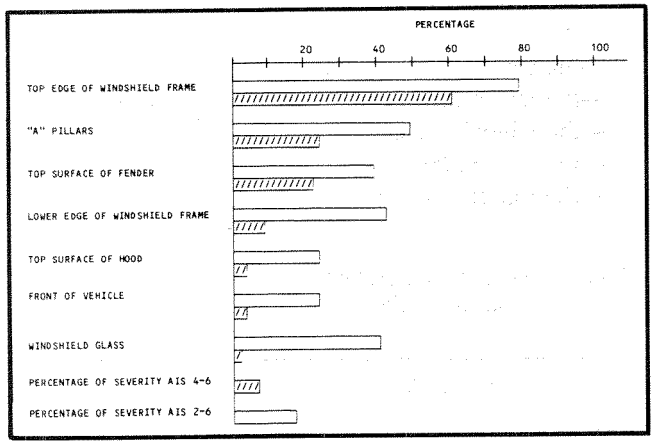


Figure 4. Risk of receiving a serious head injury by vehicle structure contacted for pedestrians struck by the fronts of cars or car derivatives—weighted PICS data.

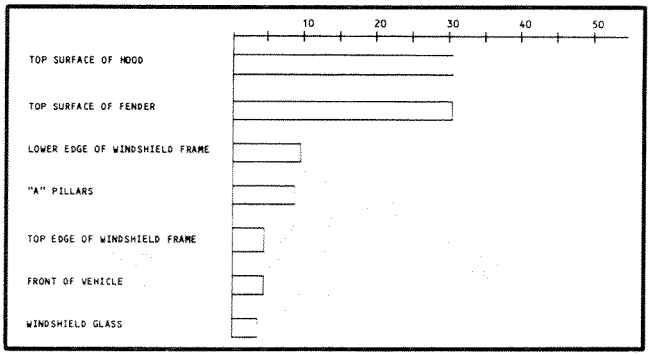


Figure 5. Percent total harm associated with head contacts on various vehicle structures struck by the heads of pedestrians struck by the fronts of cars or car derivatives—weighted PICS data.

From these results it is concluded that although the hood is one of the least hazardous structures contacted, it is the most important structure due to the frequency with which it is contacted. The fenders, although contacted with a frequency only 1/4 of that of the hood, are nearly as important as the hood due to increased risk of injury once contacted. Contact with the top edge of windshield frame, the most hazardous type of contact, fortunately was relatively infrequent. Overall, contact with the hood, top surface of fender, the cowl and lower edge of the windshield frame accounted for 70% of the harm to pedestrians' heads as a result of vehicle contact.

EXPERIMENTAL INVESTIGATION OF HOOD AND FENDER CHARACTERISTICS

The analysis of the first 450 PICS cases indicated that contact with the top surface of the hood was the leading cause of non-minor vehicle contact head injuries for adults and the second most frequent cause of non-minor vehicle contact head injuries for children (5). An experimental program was initiated to examine the properties of current vehicle hoods. The objectives of the initial program were to determine (a) baseline properties of current vehicle hoods and fenders, and (b) the viability of using a headform impactor in simulating the head impact of a pedestrian with the hood or fender.

The use of a headform impactor permits precise positioning of the impact on the vehicle surface. The experimental technique is straightforward and permits tests to be conducted at a minimal cost.

The experimental test setup is shown in the photograph of Figure 6 and in schematic in Figure 7. A headform positioned above the vehicle hood surface is propelled downward into the hood by an impactor. The impactor is cantilevered over the vehicle front. Both the vertical position of the headform and the angle of impact are adjustable (Figure 7). The horizontal positioning of the headform is accomplished by moving the vehicle.

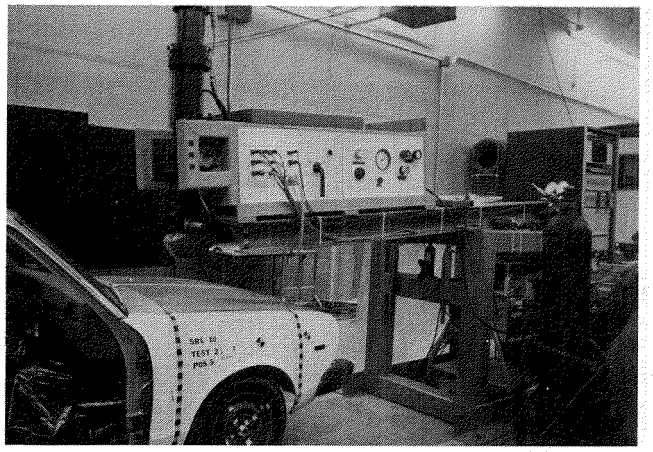


Figure 6. Experimental test setup.

The impactor is similar to the impactor developed to simulate pedestrian knee/bumper impacts (6). The impactor uses pneumatic pressure to accelerate a drive piston which accelerates the impacting ram and headform. The drive piston is stopped by a snubber piston, and the impacting ram continues in free-flight until it strikes the target location on the hood. The impacting ram is a free projectile confined to uniaxial motion.

The headform is a modified Part 572 dummy head. The rear of the head has been removed and a mounting plate welded in place as shown in Figure 8. The mounting plate is oriented in such a way that the direction of motion is the same as the impact direction used in the calibration procedure for the Part 572 dummy head. The weight of the entire headform projectile is similar to that of the original dummy head, and including the modified headform and skin, attaching bolts, and tubular impact ram,weighs 9.81 pounds. The headform is instrumented to independently measure acceleration, velocity, and displacement in the direction of impact and to provide an impact event marker.

A review of the first set of PICS cases was done to identify principal locations on the hood where head impacts are likely to occur. This review produced 47 cases in which a head impact was clearly identified on the vehicle and was also clearly dimensioned. Of the 47 cases, 24 involved children, 13 involved adults, and 10 involved elderly persons.

To compare the impact locations of the head on the hood for the various vehicles, a calculation was made of the distance from the ground around the profile to the center of the head impact location. This measurement, termed the wraparound distance, is a parameter that should be somewhat independent of the various vehicle frontal profiles for defining the head impact location.

Figure 9 illustrates for the 47 cases of clear head contact the percent of the cases with a given wraparound distance. Two distinct areas of interest are indicated. A significant percentage of impacts occur at a wraparound distance of

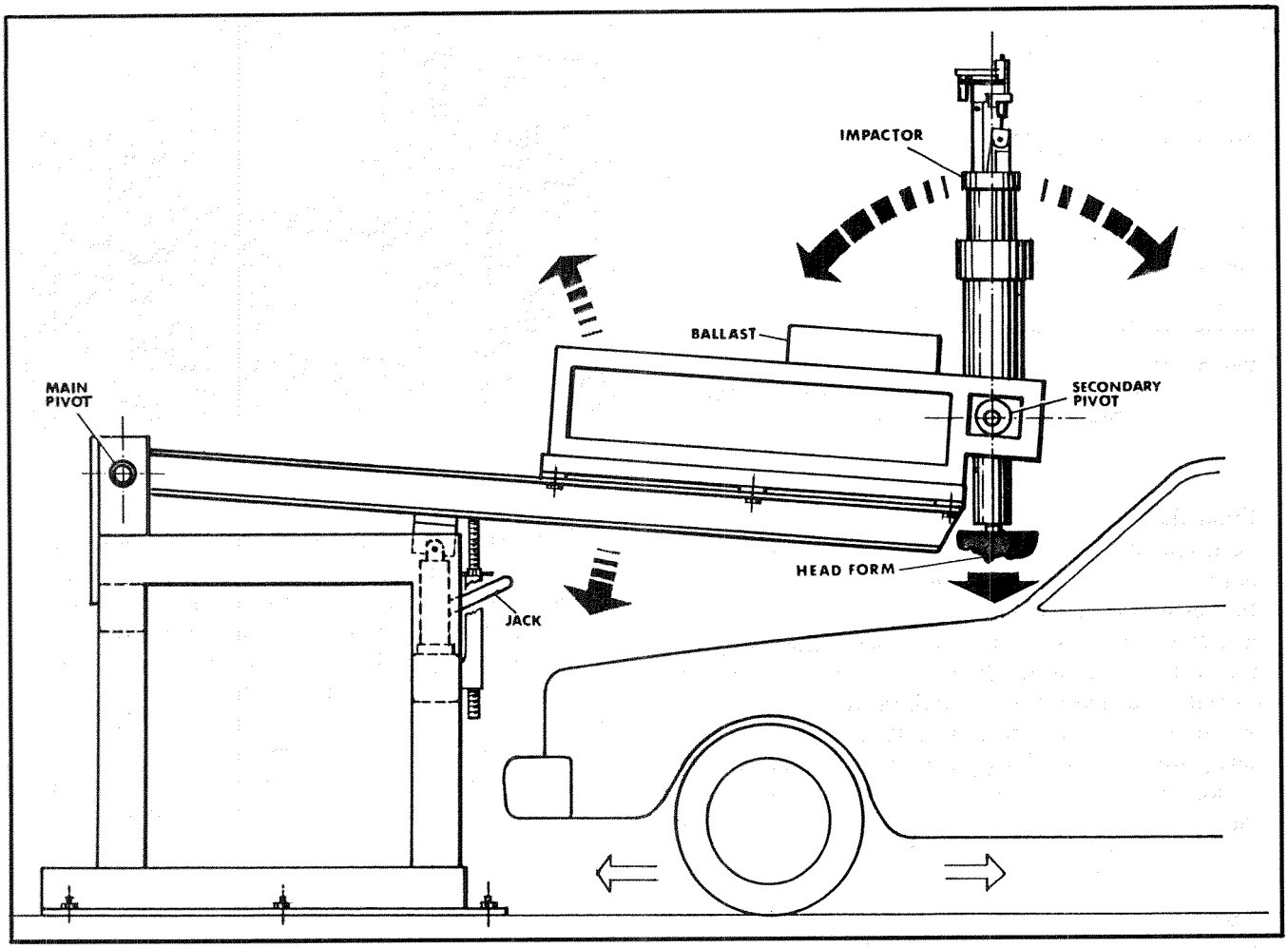


Figure 7. VRTC pedestrian head impact simulator.

64 inches which is consistent with an average adult temporal height. A second large percentage of cases are seen having a wraparound distance of approximately 40 inches which represent the child injury cases. Half of the 47 cases involve children. Although these findings are not based on a very large or statistically proven sample, the indications of these two principal impact zones suggest that it may be possible to focus attention on particular areas of the hood and fender rather than the entire surface.

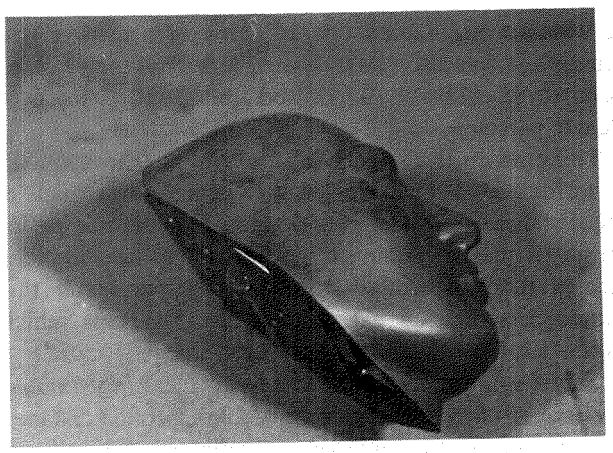


Figure 8. Test headform.

Using these findings to determine the probable head contact locations a test matrix was developed that would allow the relative injury potential of a number of different production vehicle hoods to be established. Specifically, the test matrix was structured to examine variables in dynamic response resulting from such factors as (1) changes in impact location, (2) differences in bottoming distances to various engine components, (3) side-to-side symmetry, and (4) basic test reproducibility and repeatability.

The test matrix consists of 7 impacts as shown in Figure 10. Seven impact locations were specified on the right side of the hood of the vehicle. Points 1-5 were located at a wraparound distance of 64 inches and equally spaced from the hood/fender seam to the center of the vehicle. Points 6 and 7 were forward of axial points 2 and 4 and at a wraparound distance of 58 inches. All seven impacts were conducted at an impact velocity of 25 mph.

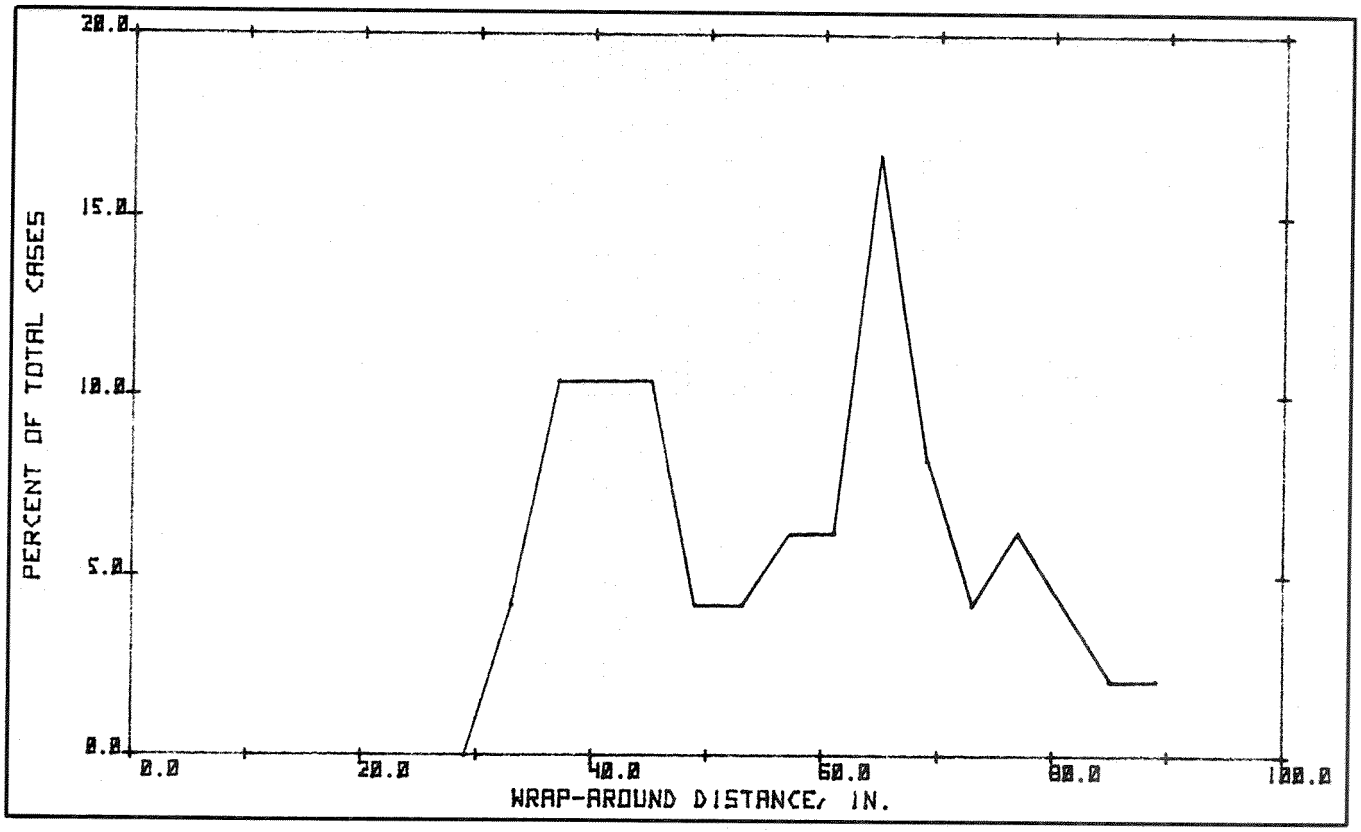


Figure 9. Frequency distribution of wrap distance—48 cases.

The experimental test matrix was conducted on eight distinct vehicles selected to span the range of production hood designs and vehicle types. Vehicle sizes range from sub-compact to full size and include an "X" body and two intermediate sizes. An Oldsmobile Cutlass was included to examine differences between hood materials, and a BMW was used to investigate a different hood design.

Figure 11 shows the principal results of these experimental baseline impacts. Plotted are the HIC values for the seven impact locations. Position 1 is the hood/fender seam and position 5 is the center of the hood. All tests are at 25 mph.

The HIC values for Position 1, the hood/fender seam, range from 3600-6200 and are considerably greater than the remainder of the surface. The majority of impact positions have HICs from 1000-2000. The HICs for the hood/fender seam are approximately 3 times that of the hood. It is to be noted that a similar ratio was obtained from the analysis of the PICS data in determining the hazard of an impact on the hood or fender. It was found that a contact with the fender was about 4 times as hazardous as contact with the hood. This suggests in a general way that there is probably a relation between structural properties as measured by a head impact simulator and actual head injury severity.

Referring again to Figure 11, it is evident that the HIC values are also largely independent of vehicle size and vehicle type. HIC values are the same at some point for both the subcompact Datsun and the fullsize Catalina.

Further analysis of these experiments indicate a strong relation between HIC and dynamic displacement. The dynamic displacement is very dependent on the clearance

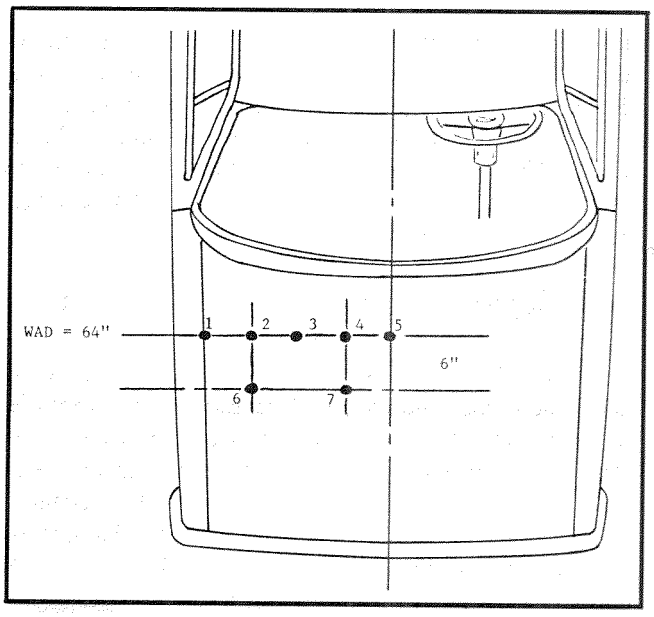


Figure 10. Experimental test matrix—injury severity mapping.

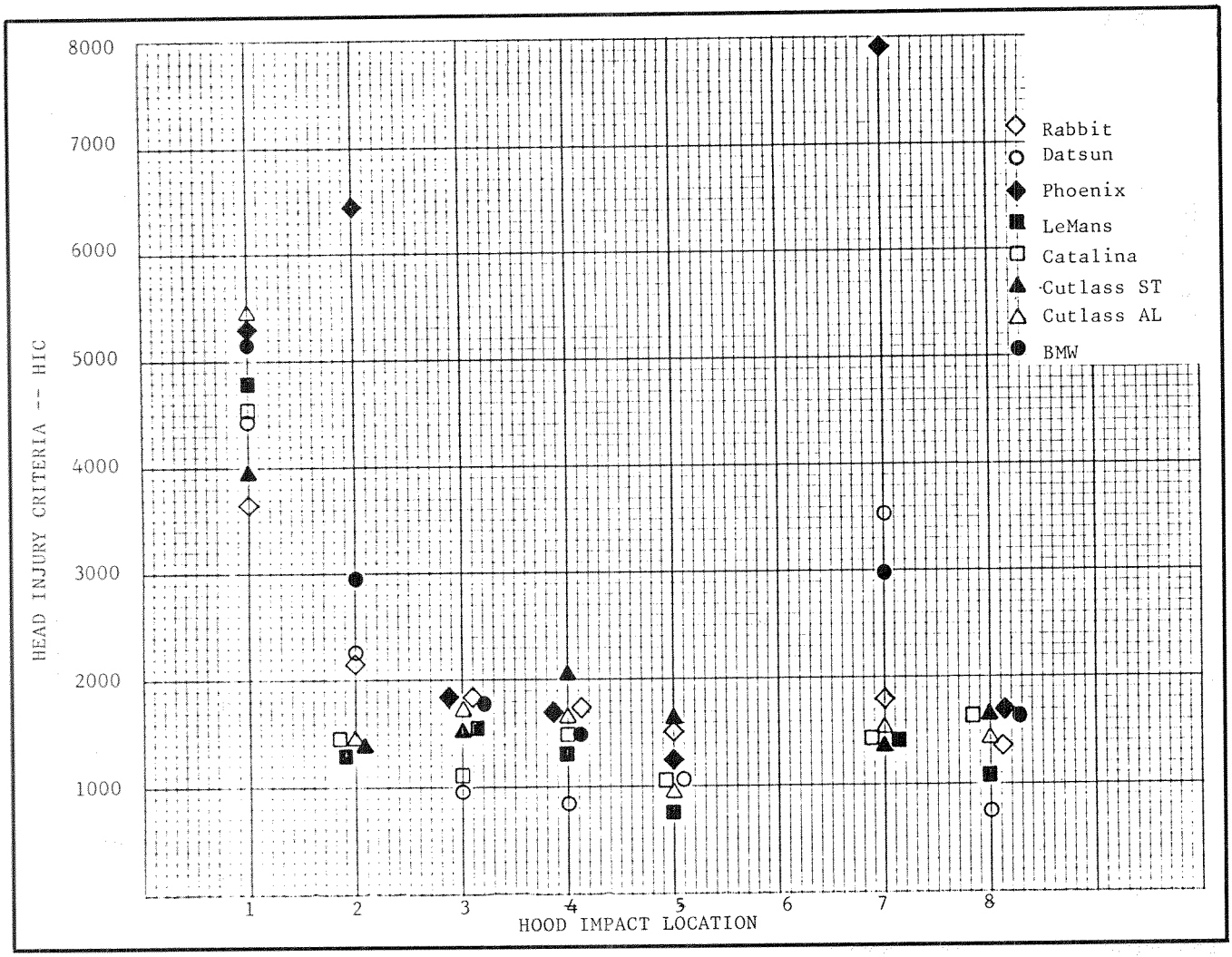


Figure 11. HIC versus hood impact location—25 mph baseline tests.

distance between the hood and engine structure components. For example, a 1 inch clearance as in areas near shock towers produced a HIC of 4000-6000 whereas a 2-1/2–3 inch clearance produced a minimum HIC of about 1000. Thus it is likely that pedestrian head injury severity could be reduced by simply permitting a larger stroke distance in key areas on the hood.

RECONSTRUCTION OF HEAD IMPACTS

The PICS study, and other accident studies, have enabled the nature and causes of pedestrians' head injuries to be documented. These studies have shown that the structure contacted by the head has a large influence on the severity of the head injury sustained. Experimental testing just described has shown that the dynamic response of the various structures that pedestrians' heads contact, as measured by an impactor device, does appear to relate to the severity of the head injuries sustained in real world accidents. The purpose of the research described in this section is to further define and establish this relation between injury and head impact dynamics.

Accident investigation provides details of the injuries sustained and the residual damage to the vehicle; it does not, and cannot, provide any information about the actual forces applied to the head or the vehicle. The damage to the vehicle, however, provides a record of the impact dynamics of the actual accident.

Reproducing the damage to the vehicle in the laboratory should make it possible to determine the forces acting at impact and, by reproducing sufficient cases, to obtain information about the relationship between impact dynamics and resultant injuries (Figure 12).

A pedestrian accident reconstruction program has, therefore, been initiated by NHTSA and has as its objectives:

—The determination of the complexity required of impactors in reproducing accident damage.
—An examination of the relationships between impact dynamics and resultant injury.

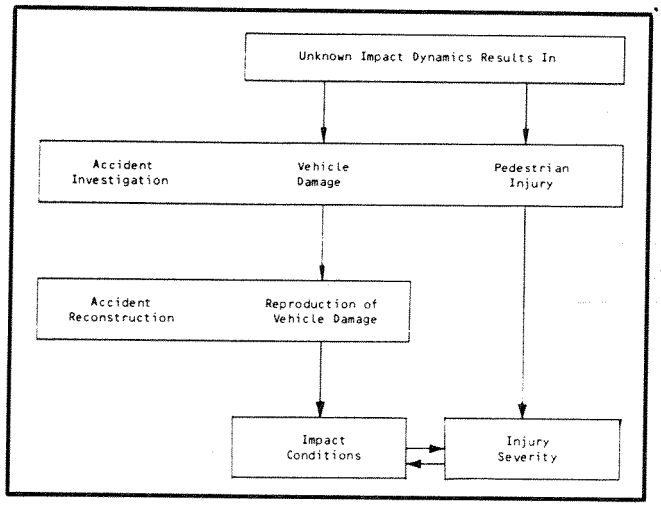


Figure 12. Rationale for reconstruction of impact damage.

This program developed out of the test program reported in an earlier section of this paper, which examined the properties of hoods.

Selection of Cases for Reconstruction

At the start of the program, the only cases available were those investigated as part of the PICS study. The PICS data file was interrogated and those cases identified, in which a pedestrian had been struck by the front of a car or light commercial vehicle and had a head injury attributed to contact with the vehicle. The original case files were then examined. It was found that in the majority of the cases there was a lack of detailed information on the damage to the vehicle. The PICS study was structured to provide an overall description of the pedestrian accidents and to document the structures contacted by pedestrians and the resultant injuries. It did not require detailed documentation of the vehicle damage, the damage being described only in gross terms of type and extent. Many of the cases did, however, have fairly good photographic coverage of the dent.

An accident investigation study was initiated to provide cases in which there was documentation of the vehicle damage in sufficient detail to enable the damage to be more clearly reproduced experimentally. This study, the Pedestrian Accident Investigation Data Support (PAIDS) study, is being performed for NHTSA by Traffic Safety Research (TSR) in Palo Alto, California. In the study, 100 accidents in which a pedestrian is struck by the front of a car or car derivative and sustains a head contact with the vehicle are to be investigated. If there is damage to the vehicle as a result of the pedestrian's contact with the vehicle, the investigating team has been instructed to obtain the damaged sheet metal whenever possible. If this is not possible, the damage is to be documented using a standardized recording procedure.

Laboratory Reproduction of Accident Dents

The impactor used in the investigation of the impact response of hoods was used for the reconstruction tests. This is a modified Part 572 headform weighing 9.81 lb. The impactor was aligned such that at impact the forehead of the dummy head struck, normally, to the same structure that had been contacted by the pedestrian's head in the accident. Tests were conducted over a range of impact velocities such that the dents produced in the experimental tests banded the accident dent.

It was found that when the accident dent was located on a relatively flat panel there were few problems in producing similar dents in the laboratory. However, when the impact occurred on a curved panel it was more difficult to obtain a satisfactory reproduction of the dent. The procedures used and some of the difficulties are illustrated in the following example.

Example Case 81-08-211

A 7-year-old girl, height 44.5 inches, weight 40 lb., was struck by the front of the vehicle at an impact speed of about 20 mph. The vehicle was braking at impact. Her head contacted the top surface of the hood on the feature line on the right side of the hood, resulting in a small dent. There was a contusion on the back of the head caused by contact with the hood. This injury is coded as an AIS 1. The damaged hood was obtained after the accident.

Twelve impactor tests were conducted before it was considered that a satisfactory reproduction of the accident dent has been obtained. As the deformation was very localized, tests were carried out at the location of the accident dent and also at the mirror image location. This reduced the total number of undamaged hoods that had to be purchased.

Figure 13 compares the accident cross section and the experimental test cross sections for the tests; these cross sections were taken at right angles to the longitudinal axis of the vehicle through the point of maximum deformation. On these cross sections, the arrow indicates the general location of the impact and the direction of travel of the impactor.

The initial tests were conducted with the impactor in a vertical position striking the hood inboard from the top of the feature line curve. It was found from these tests that the damge was located on the top surface of the hood rather than on the curved section of the feature line. The impactor was then tilted and a further series of tests run. It was found that small variations in impact angle and position influenced the nature of the dent; for example, the deformations produced in runs SRL39-111 and SRL 39-112 were different in profile even though both runs were at the same angle and impact speed. These two runs were at a slightly different position.

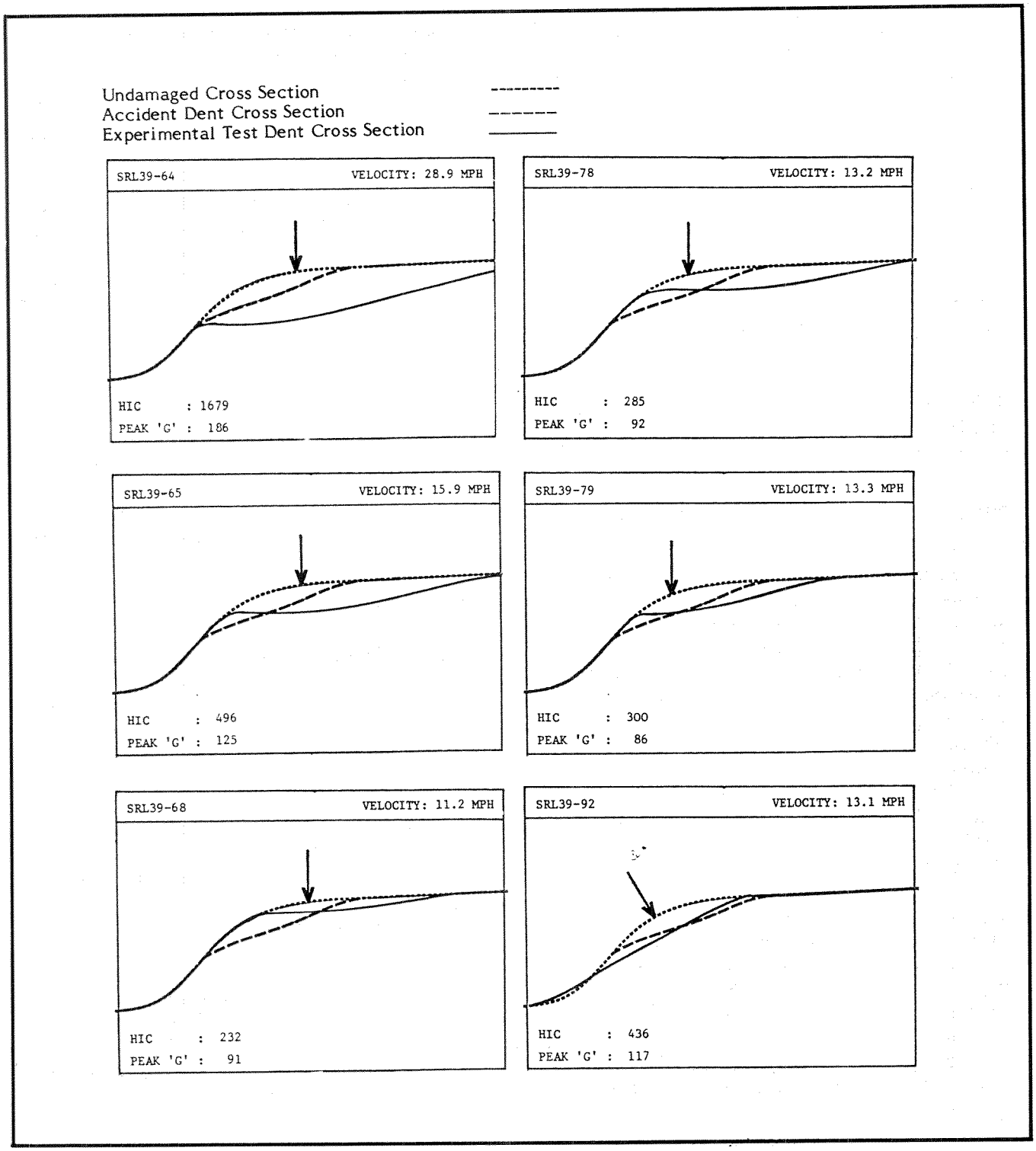


Figure 13. Comparison of accident and experimental test dents.

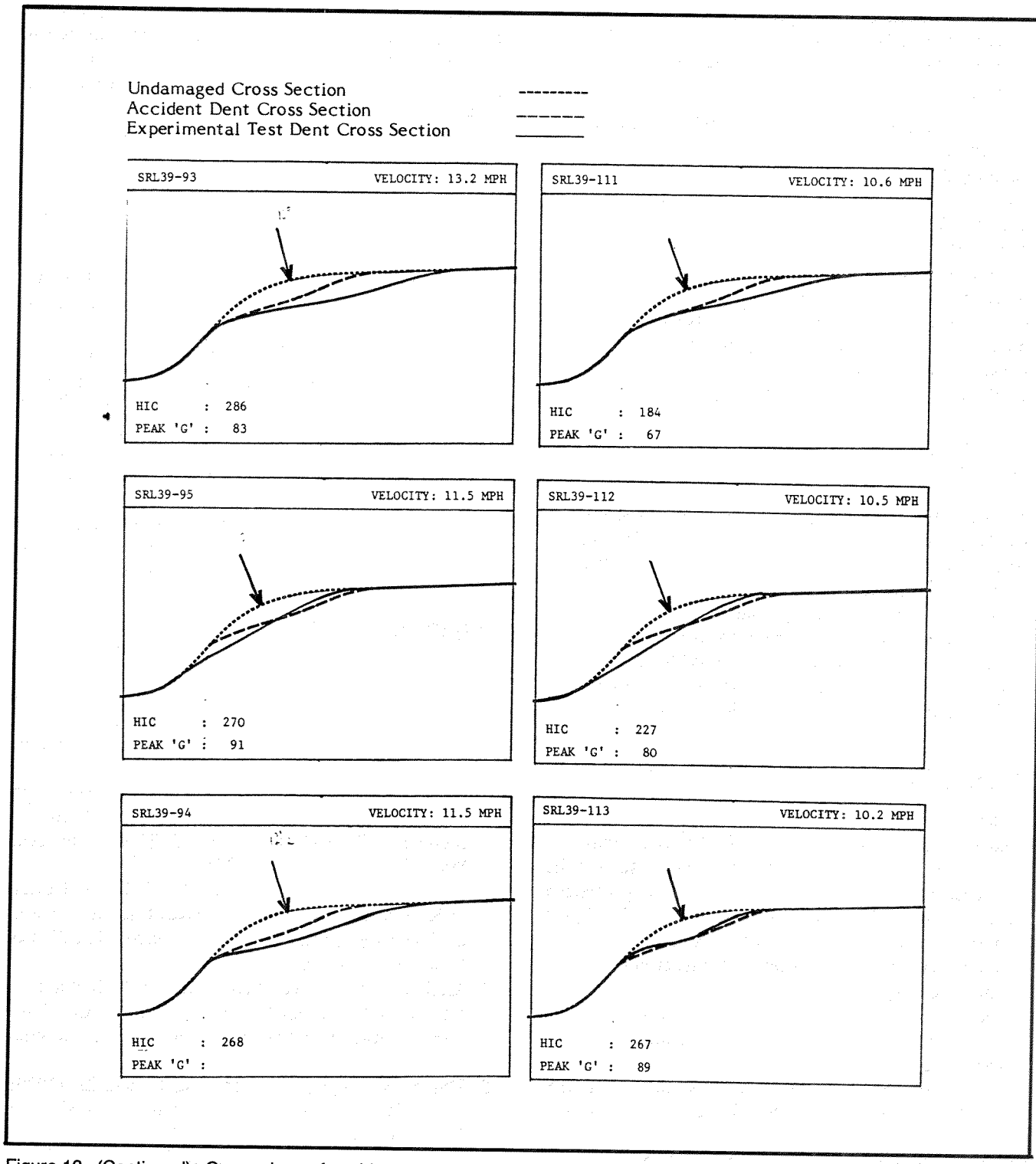


Figure 13. (Continued). Comparison of accident and experimental test dents.

Test SRL39-113 was judged to be a good reproduction of the accident dent, the test dent and accident dent being in the same location and of similar shape. It can be seen in the figures that the HIC levels for the three closest reproduction tests are in the order of 200.

Head impact reconstruction tests have been conducted on a total of 27 real world accidents, these accidents spanning the range of head injury severity from minor (AIS 1) to untreatable (AIS 6) head injuries. Documentation on the accidents ranged from a general description of the head contact on the vehicle to detailed recording of the cross section of the dents and including, in some cases, the actual damaged sheet metal. In the early part of the project, the cases available for reconstruction were those investigated in the PICS program. While it was possible to produce dents which were similar to the description of the dent in the accident file, the lack of detailed documentation on the accident dent meant that there was some uncertainty as to which experimental test most closely reproduced the accident dent. This was especially the case where the head contact had been to a relatively stiff structure such as the fender where there was only a small change in dent depth with impact velocity. The later cases, investigated as part of the PAIDS program, had detailed documentation of the dents and it was found that in these cases it was possible to reproduce the dent to a good degree of similarity using the impactor.

These tests have shown that it is possible to reproduce quite closely with an impactor the vehicle damage resulting from an actual pedestrian head contact.

Development of Injury Tolerance Data

The major purpose of reconstructing pedestrian head impacts is to establish a relationship between a dynamic measurement and actual injury. Preliminary results of the 27 pedestrian accidents suggests a relationship between measurements such as HIC and the injury severity. These reconstructions were all done with a constant mass headform and the velocity, position, and impact angle varied to reproduce the vehicle damage.

Concurrent tests were run to examine the sensitivity of HIC measurements to impact velocity and impactor mass. It was found that the residual or permanent deformation is directly related to impact energy, which, of course, involves both mass and velocity. Large changes in HIC or peak g's could be produced by changing mass and velocity with very similar resulting vehicle dents.

Research efforts are now under way to determine the resulting head effective mass and velocity in a given accident. Several mathematical computer models are now being exercised and validated. Actual vehicle characteristics at the various impact locations are being determined using the impactor and these are used as input into the computer models. The complete accident sequence from initial bumper contact to hip impact with the hood edge to head and upper body impacts will be examined and reconstructed in the laboratory to more completely simulate a particular accident. The results of this effort should produce significant data on pedestrian impact injury tolerances.

CONCLUSIONS

The following conclusions can be stated from this research effort to date.

1. Analysis of the PICS data has shown that most severe head injuries are a result of contact with the vehicle.
2. Based on the concept of total harm, the hood and fenders are the most important vehicle components.
3. A headform impact simulator can be used to examine differences in vehicle structures.
4. It is possible to reconstruct the vehicle deformation resulting in pedestrian head impact using a headform impact simulator.
5. Further research is needed to incorporate the effect of head effective mass into the relationship between dynamic impacts measurements and injury severity.

REFERENCES

1. Wolfe, A. C. and O'Day, J. (1982), "Pedestrian Accidents in the U.S." *HSRI Research Review, March-April 1982.* Highway Safety Research Institute, Ann Arbor, Michigan, pp. 1-16.
2. Greetham, Thomas A., "An Analysis of Head Injury in Real World Pedestrian Accidents and Their Experimental Reproduction." M.S.C. Thesis, The Ohio State University, August 1982.
3. Ashton, S. J. and Mackay, G. M. (1979), "A Review of Real World Studies of Pedestrian Injuries." *Unfall-und-Sicherheitsforchung Strassenverkehr,* Heft 21, Cologne, pp. 119-139.
4. Malliaris, A. C., Hitchcock, R., and Hedlund, J. (1982), "A Search for Priorities in Crash Protection." Paper 820242, Society of Automotive Engineers, Warrendale, Pennsylvania.
5. Daniel, S., Eppinger, R. H., and Cohen, D. (1979), "Considerations in the Development of a Pedestrian Safety Standard." *Proceedings of the Seventh International Technical Conference on Experimental Safety Vehicles,* DOT, Washington, D.C., 1979. pp. 724-738.
6. Eppinger, R. H. and Pritz, H. B., "Development of a Simplified Vehicle Performance Requirement for Pedestrian Injury Mitigation." *Proceedings of the Seventh International Technical Conference on Experimental Safety Vehicles,* U.S. DOT, Washington, D.C., 1979.

Some Principles of Large-Scale Accident Studies Related to "Active Safety"—The Need for Providing Adjusted Accident Material and the Limits of Current Conclusions

M. DANNER; K. LANGWIEDER
HUK-Verband
Automobile Engineering Department
German Association of Third Party, Accident, Motor Vehicle and Legal Protection Insurers

INTRODUCTION

The need for accident studies regarding "active safety"

Following a phase of car safety research in which questions of passive safety and of biomechanics were of dominant importance, in recent years the number of works dealing with active safety have increased. This development started from the discussion on

—the extent to which the improvement in active safety, which was doubtless achieved, influences accident prevention
—where typical behavioural defects in the complex driver-vehicle control loop are to be found and
—whether or how far the additional technical safety is cancelled out by the driver's behaviour or by the change in traffic flow.

The discussions in various countries about imposing regulations on car behaviour give rise to the need to define typical critical situations in real-life traffic. Only with a reliable knowledge of accident occurrence in real life is there adequate justification for discussing regulations with regard to safety. But knowledge of the correlation of active safety and accident prevention is still inadequate.

There is an urgent need to take stock of the situation in the area of accident research as well. The different criteria for selecting accidents with regard to "active safety" lead to a different structure of the accident material, and this inevitably results in different distributions of the accident parameters; but it is still not known to what extent the recording criteria influence or partially anticipate the results.

AIM OF THIS WORK

On the basis of the HUK research with independent studies related to "active safety", this paper attempts to take stock in a critical way of

—the results achieved so far and the extent to which they can be compared
—criteria for selecting accidents (homogeneous accident material) and presenting the results in keeping with the complexity of the problem
—eliminating from the material inadmissible factors which cover and interfere with the normal behaviour pattern of the driver-vehicle control loop
—the necessary number of accidents for standard parameter distributions which can be reproduced by independent material with the same methodology.

Finally a systematisation of "critical accident situations" is proposed. The experience gained in previous studies with regard to methods to be adapted and presentation of the findings must now be combined and put into a comprehensive research concept. This work should contribute to this aim.

THE OBJECTIVES OF STUDIES INTO "ACTIVE SAFETY"

The ideal objective of such studies is naturally to record the effect of technical improvements on the driver's behaviour and thus on accident prevention, and if at all possible to make it quantifiable. This would apply not only to global car concepts, it would certainly be attractive to derive, in particular, findings on specific car models or even individual technical elements from real-life accidents. But in view of experience hitherto it must be clearly stated: If the objective set out above were the only aim of these accident studies it would be completely justifiable to stop these analyses of "active safety". Findings typical of one particular design relating to driving behaviour—even if this appears plausible—still have to be relegated to the realm of speculation, and this will certainly be the case for the foreseeable future, too.

The principal objectives of studies into "active safety" are, however, first to be found in other fields, whose each area of validity has to be strictly distinguished individually:

—A clearly defined description of the current accident occurrence and of accident frequencies with *unweighted reflection of the facts* not interpreted for the purpose of supposed causes. It is decisive not only to state the frequency of accidents occurring, but also to describe as accurately as possible the individual circumstances, for example, environmental influences, characteristics of the road, critical situations.
—Ascertaining driver and vehicle characteristics as the effect of the complex control loop in defined critical

situations. This task has to be largely detached from the technical aspects of active safety, and it chiefly contains the description of defects in driver behaviour. One of the main problems here is the fact that the driver characteristics which can be objectively ascertained and thus described reproduce only *a small sector* of the personal characteristics responsible for the driver's behaviour or the occurrence of an accident.

—The fundamental basis for recognising the change in *accident frequencies*—both by technical measures and driver characteristics. New technologies and electronic systems enable new solutions to be found in the field of "active safety". An assessment of the accident frequencies possibly influenced by technical innovation and their effect on accident prevention is only possible when the previous state of the accident occurrence was already largely known.

Thus, independently of the above-mentioned ideal intention of car-related conclusions, it is one of the primary tasks of present-day studies to aid decision-taking for the need and priorities of safety measures in the complex field of "driver-vehicle-environment" by showing defined accident frequencies and to provide at least starting points for before/after analyses.

Used correctly in this way, studies into "active safety" can offer a certain help in continued risk determination and safety improvement.

COMPARISON OF CURRENT RESULTS

The following comments are restricted to studies in Germany (1-12), so as to exclude unknown influences of accident characteristics in foreign countries. In the future, however, it will be necessary to intensify international comparisons.

Figure 1 includes accident characteristics of different origin and structure; they cover the period of the last decade and, partly, contain varying accident groups, for example car-to-car or single car accidents. This leads to the problem that for comparative purposes it is difficult to mark off a defined accident selection of similar characteristics. In view of the currently considerable change in the technical design of cars, e.g., front wheel drive, car weight (11, 13, 14), it is extremely difficult to filter out the influence of modern vehicle technology when a fairly long period of time is covered by accident sampling.

This does not mean that the value of these studies is questioned, but this major problem of all studies into active safety must be faced.

But in spite of the differing sampling of accidents, it is possible to draw conclusions on some individual factors which may already be regarded as generally valid for "single car accidents". Problems arise mainly when these individual findings are to be connected with other factors.

recent studies into "active safety"		number of cases	selection criteria	sampling period
HUK	(2)	63,000	c, ▣	69
Zomotor	(4)	3,000	c, ▣	-
HUK	(3)	5,000	b, ▲	74-77
Engels	(8)	1,400	a, d	77(a), 74(d)
HUK	(1)	7,700	a, ▲	69
MHH	(5)	230	a	73-81
HUK	(7)	4,500	a, ▣	75
HUK	(6)	1,200	a, ▲	74-79
DB/Dekra	(9)	9,375 (c), 737 (a)	a, c, ▣	76-81
HUK	(10)	1,500	a, ▣	79-81
HUK	(11)	1,500	a, ▣	79-80
HUK	(12)	3,000	a, ▣	79-81

explanation of signs
a = single-car accidents
b = car/vehicle collisions
c = all groups of road users
d = car/pedestrian accidents
▲ = with personal injury only
▣ = with/without personal injury

Figure 1. Examples of studies on the subject of "active safety" in Germany.

General agreement was found on the special risks incurred by adolescent drivers, who are far more frequently involved in accidents in which the vehicle leaves the road in bends than any other age group. Single car accidents are caused mainly (4, 6) by young drivers up to the age of 25. Moreover, the latter are involved in accidents more frequently than other age groups under the influence of alcohol (11). Women drive more defensively than men (9) and cause fewer accidents (1, 2, 15). Accidents on straight roads account for 30-40%, and are thus considerably less frequent (3, 7, 9) than accidents in bends. Two HUK studies of single car accidents (6, 11), however, showed a far higher proportion of accidents on straight roads, between 50 and 60%—although each of these studies covered some 1,000 to 1,500 cases. This reveals how difficult it is to ascertain the influence of the different criteria on the results depending on the sampling method.

Generally the limits of car handling properties are not reached (12),—the accidents are chiefly due to the inappropriate reaction of the driver, uncontrollably intensified by accident stress. This means that considerable importance attaches to dynamic driving processes with their effect on the *average* driver in the transition stage from normal to critical driving behaviour (12, 19).

With some deviations, depending on the selection of accidents, fundamental patterns of car dynamics and behaviour, however, do emerge:

—Rear block (rear engine and drive) cars are involved in accidents in bends more frequently than cars with front block or of conventional concept (front engine/rear drive) (4, 8, 16). This tendency increases on wet roads (3, 6, 11).

—Skidding by sports cars which yaw are found above average according to (4, 6, 9); but apart from technical factors, for example, the momentum of inertia, the fact had to be taken into consideration that these

accidents occur at far higher speeds than accidents of other cars, and that a different behaviour and response characteristic of this group of drivers exists.

—Four groups of driver populations can be observed (3, 6) which influence the accident characteristics of the categories of cars they use (3). Besides technical factors, the purchase price of the vehicle represents a dominant criterion for the distribution of the driver population for particular car models.

—The more frequent skidding of small cars (4) seems to be strongly influenced by their driver population apart from technical criteria, for example, low inertia momentum and the effect of a small wheelbase (16).

In almost all the studies the distribution of cars' ages is recorded, but this effect is usually not separated in the results any more for the purpose of "adjusted material" (11). This leads to an uncontrollable inclusion of "obsolete technical concepts" and gives additional problems to the classification by "car concepts" (according to the position of drive and engine) which is rather unsatisfactory anyway.

But the review has shown that

—pragmatic values regarding driver/vehicle interaction from previous studies emerge, even if comparison is difficult because of the differing structure of the accident material and sampling criteria.

—Quite often different accident groups (for example, single car accidents or car-vehicle collisions) or different types of accidents, (for example, a rear-end collision or accidents on crossings) are lumped together, although their basic characteristics are totally different. Doing this is bound to result in an inadmissible distortion of the relations.

—It is typical of all studies hitherto that methods and possible ways of selecting the necessary accident material have been sought for. Generally valid reference qualities to relativise the results obtained have not yet been found.

It is still quite unpredictable, into which fields of "active safety" it will be possible to penetrate. On the one hand, it is a fact that improved technical safety has an effect in real-life traffic. On the other hand, it is a problem to find appropriate accident material and a way of presenting the results which reflects the complexity of the parameters (17, 18) and their interaction.

Another problem: even if accident causes could be reliably categorised and analysed in certain partial areas, one must nevertheless realise that it is a long way from recognising the causes to countermeasures of accident prevention. In spite of this, there must be no slackening in our efforts, for these analyses represent the only access known today to quantitative data of accident occurrence (19).

NEW STUDY OF SINGLE CAR ACCIDENTS

Structure of the Material

Over and beyond the hitherto available HUK studies evaluated according to the same criteria (3, 6, 11), for this study 3,000 single car accidents have been evaluated by HUK' engineers over a period of three years.

This accident material (Fig. 2) comprises accidents involving considerable damage (comparable to the tow-away criterion) to the car with and without injuries to persons. The accidents are from the years 1979-81; they cover the whole area of West Germany, all road categories and a normal monthly distribution. The accident characteristics in general agree with the National German Accident Statistics (20), with some over-representation of fatal accidents in our material.

A random sample of 578 accidents (particularly well documented cases, most of them with reconstructions and details of the critical situation) was taken from this basic material which corresponds to the characteristics of the total material. In addition to the criteria applied hitherto (3, 6, 11), a new criterion, the "onset/end characteristic" (12) during the disturbance (Fig. 3), was used instead of the unsatisfactory description of the scene of the accident according only to a bend or straight road. This "onset/end characteristics" (AEC) describes the entire course of the road between the onset and end of the disturbance and the intended driving line and thus the necessary driv-

overall injury severity (OAIS)	HUK-research material 3000 single-car accidents	
occupants	No.	%
uninjured	1,746	37.2
minor	1,156	24.6
moderate	871	18.5
serious	336	7.1
critical	129	2.8
fatal	460	9.8*
total	4,698	100.0

		single-car accidents HUK 1979-1981		national statistics [20] 1980	
		No.	%	No.	%
area of accident	urban	903	30.1	45,814	38.4
	rural	2,097	69.9	73,341	61.6
	total	3,000	100.0	119,155	100.0

Figure 2. Accident material of this study on single-car accident.

ing manoeuvre. This avoids the problem existing today that only the spot of the final position of the car is described, which cannot indicate the course of the road during the full length of the disturbance. AEC 3—bend/straight road—indicates that a disturbance, for example, skidding, started in the bend and ended in final uncontrollability in the section "straight road" that followed. On the other hand, AEC 1—"straight road"—indicates that both the onset and end of the disturbance occurred within a straight section of the road. The application of AEC causes problems in only a few cases in which the "onset-area" of the disturbance is difficult to ascertain (12).

Beyond detailed registration of the car model, the classification according to "car concepts" was used. This quite unsatisfactory classification is used in the absence of any better alternatives and it should be kept in mind that with the car concept automatically a large number of other parameters change—therefore, all results below may not be regarded as the influence of "car concept" only. On the other hand it is hopeless and, because of the extremely large number of combinations, even dangerous to try to form an overall criterion for car behaviour (19). The only technically correct method of inquiry according to individual car models will not work because of the problem of sufficient accident material and adjustment criteria.

Finally, the random sample of 578 cases was checked individually to show the necessary "adjustment criteria" and the possibility of an elimination of inadmissable interference factors.

Possibility of Standard Parameter Distributions in the Accident Material and the Number of Cases Required

One of the decisive questions in accident studies on "active safety" is from what size of accident material constant, reproducible standard distributions of the parameters can be expected when using the same sampling criteria and the same method of evaluation. Figure 4 shows the distribution of the influences "road section" and "road conditions" for the various car concepts. Of the 3,000 single car accidents 50.1% occurred on straight roads and 49.9% in bends.

This result agrees with earlier findings—but there are deviations from other material (6) of 1,200 single car accidents in which accidents in bends accounted for about 60-70%.

This difference can be partly explained by the earlier sampling period, from 1974 to 77, and a far higher proportion of rear block cars than in the present material from 1979 to 81 (11); furthermore, the former study (6) covered single car accidents with injury to persons only. A comparison of different accident material can only be carried out with extreme caution even when the same definitions are used, and it calls for a precise knowledge

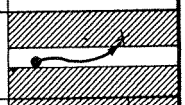
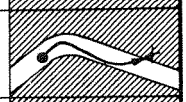
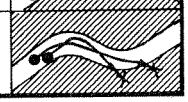
course of road during disturbance	AEC category	symbol
onset ⟶ end	No.	
straight road only	1	
bend only	2	
bend ⟶ straight road	3	
straight road ⟶ bend	4/5	
straight road ⟶ bend ⟶ straight road		
bend ⟶ straight road ⟶ bend	6/7	
s-bend		

Figure 3. Proposal for a new criterion of "onset/end characteristics" during the disturbance to the driver-vehicle control loop.

of the internal structure of the accident material. Moreover, the change in the frequency of types of car registered may result in not inconsiderable differences when the accidents are recorded in different periods.

The nature of the road conditions within the car concepts shows deviations, which cannot yet be finally assessed. In the case of snow or ice the value for cars of conventional concept is relatively high, but, conversely, the accident frequency of front and rear block cars on dry roads is far higher. In the absence of any general reference quantity it is impossible to assess which risk is over- and which under-represented. In Figure 4, for example, it cannot be ruled out that all risks of accidents on icy roads would be the same in reality, while a certain proportion of the single car accidents with conventional drive or front block that could theoretically be expected on dry roads, does not occur. The age distribution of the drivers with their different accident characteristics (6) may also play a dominant role here.

Figure 4 therefore should only be understood as reflecting facts in the accident material; at this point any further interpretations are inadmissible. It is a fundamental danger when discussing "active safety" in the light of real-life accidents that distributions in the accident material have to be published which can be misused to come to premature conclusions, without the structure of the material providing adequate support.

A comparison with the first set of 1,500 accidents (Fig. 5) indicates that the parameter distributions have not changed in general, and the partial sample shows very good agreement especially with the overall relation of the final material, surprisingly even in the parameter "road conditions" broken-down into the car concepts (Fig. 4, 5).

car concept			front block No	front block %	conventional No	conventional %	rear block No	rear block %	total No	total %
road section	straight road		433	**45.9**	1,018	**52.6**	52	**42.6**	1,503	**50.1**
	bend	left	306	59.9	554	60.5	36	51.4	896	59.9
		right	205	40.1	362	39.5	34	48.6	601	40.1
		subtotal	511	**54.1**	916	**47.4**	70	**57.4**	1,497	**49.9**
	total		944	100.0	1,934	100.0	122	100.0	3,000	100.0
road condition	dry		476	50.4	202	41.8	64	52.5	1,348	45.0
	moist		40	4.2	47	2.4	7	5.8	94	3.1
	wet		143	15.1	299	15.5	25	20.5	467	15.6
	pools of water		15	1.6	30	1.5	1	0.8	46	1.5
	snow		47	5.0	102	5.3	5	4.1	154	5.1
	ice		184	19.5	598	30.9	16	13.1	798	26.6
	sticky		31	3.3	31	1.6	2	1.6	64	2.1
	loose gravel		8	0.9	19	1.0	2	1.6	29	1.0
	total		944	100.0	1,934	100.0	122	100.0	3,000	100.0

Figure 4. Distribution of the parameters "road section" and "road condition" according to car concept in the accident material (3000 single car accidents).

car concept			front block pilot sample	front block total sample	conventional pilot sample	conventional total sample	rear block pilot sample	rear block total sample	total pilot sample	total total sample
road section	straight road		**49.9**	**45.9**	**58.0**	**52.6**	**46.1**	**42.6**	**54.7**	**50.1**
	bend	left	60.0	59.9	60.1	60.5	43.5	51.4	59.0	59.9
		right	40.0	40.1	39.9	39.5	56.5	48.6	41.0	40.1
		subtotal	**50.5**	**54.1**	**42.0**	**47.4**	**53.9**	**57.4**	**45.3**	**49.9**
total number of cars			-	-	-	-	-	-	1500	3000
road condition	dry		49.7	50.4	40.9	41.8	52.7	52.5	44.3	45.0
	moist		4.0	4.2	2.6	2.4	9.2	5.8	3.3	3.1
	wet		16.6	15.1	14.8	15.5	18.4	20.5	15.6	15.6
	pools of water		1.5	1.6	1.6	1.5	1.3	0.8	1.5	1.5
	snow		5.2	5.0	6.0	5.3	2.6	4.1	5.6	5.1
	ice		19.7	19.5	31.5	30.9	11.9	13.1	26.8	26.6
	sticky		2.9	3.3	1.5	1.6	2.6	1.6	2.0	2.1
	loose gravel		0.4	0.9	1.1	1.0	1.3	1.6	0.9	1.0
	total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Figure 5. Comparison of part of the material of 1,500 accidents with the total material (3,000 accidents).

Only in the parameter "road section" are there deviations amounting to around 5% (for example, straight roads with 54.7 and 50.1%).

Apparently the number of about 1,500 cases thus marks a limit from which reliable parameter distributions and standard results in independent material are to be expected. Even when the results are broken down into some frequent car models, a good constant parameter distribution could be observed in the first set of 1,500 as compared with 3,000 accidents.

Accident material covering about 1,500 cases of a homogeneous accident group, for example, single car accidents, evaluated with defined criteria, can thus give a largely constant representation of accident characteristics of which accident frequencies and trend analysis of the effect of the driver/vehicle control loop in total may be based. But problems arise as soon as parameter combinations are formed, which is necessary for the analysis of driver- or car-related parameters.

Conclusions from a Random Sample with the Refined Criterion of the "Onset/End Characteristic" of the Disturbance

Figure 6 shows the distribution of the "accident area" in the random sample (578 cases) on which the onset/

	AEC No	car concept: front block	conventional	rear block	total
specific onset/end characteristic (AEC)	1	32.7	42.3	24.7	**36.7**
	3	6.4	7.7	11.8	8.0
	5	4.1	1.3	3.5	2.5
total AEC with * final accident area "straight road"	1|3|5	43.2	51.3	40.0	**47.2**
global criterion * accident area "straight road" (Fig.4)		45.9	52.6	42.6	**50.1**
specific onset/end characteristic (AEC)	2	52.1	44.8	54.1	**48.4**
	4	2.3	1.3	3.5	1.9
	6|7	2.4	2.6	2.4	2.5
total AEC with * final accident area "bend"	2|4 6|7	56.8	48.7	60.0	**52.8**
global criterion * accident area "bend" (Fig.4)		54.1	47.4	57.4	**49.9**

★ random sample 578 cases * total sample 3,000 cases

Figure 6. Improved description of the crisis situation using the new "onset/end characteristic" (AEC) compared with the global criterion of "bend", "straight road".

end characteristic was tested for the first time. While the proportion of cases with "onset and end of the disturbance inside *one* bend" (48,4%) corresponds very accurately to the figure of 49.9% in the total material, it is clearly shown that the global criterion of the "accident area straight road" does not adequately reflect reality. While the global criterion classifies 50.1% as "straight road accidents", only in 36.7% did the onset and end of the disturbance occur within *one* straight road section (AEC 1). In 8.0% the disturbance had already begun in the bend and only on the straight road following the bend did the car get out of control, i.e., did the accident occur. The refined definition "AEC" thus results in a considerable improvement in the possibility of assessing dynamic driving processes.

This also becomes clear in the distribution within the car concepts. To make the comparison easier, in addition to the individual breakdown, the AEC 1,3,5 and AEC 2,4,6,7 were combined, each corresponding to the global criterion of the "final accident area straight road" or "bend". By combining in this way there was good comparability in the case of front-block cars (43.2% compared with 45.9% in the sample with global criterion) and of conventional drive cars (51.3% compared with 52.6%).

The distribution of the AEC with car concepts showed considerable variations in the frequencies of the dynamic driving processes during the course of disturbance which led to the accident. With cars with front block and conventional cars the onset and end of the disturbance was predominantly found inside *one* bend or *one* straight section of road. With rear-block cars, however, the proportion of combined road sections is higher. But it must be pointed out once again that these values indicate only the internal relation in this material and cannot determine the risk in absolute terms. Thus it might be conceivable that with all car concepts the accidents of one AEC type per 100,000 registered cars had the same risk, but other disturbance characteristics, for example, when driving in a bend, come through so dominantly that the relations observed here within the car concepts emerge. This absence of any point of reference and thus of an absolute risk determination has always to be pointed out.

Accident Characteristics of Driver Groups

The distribution of the accident characteristics largely depends on driver influences. Young drivers in possession of a driving licence for up to three years have a completely different accident cause distribution (6) than experienced drivers; as a licence is acquired at usually 18-19 years of age the lack of driving experience is covered up by the young drivers' attitude to risk exposure.

The AEC distribution of the different age groups shows typical differences (Fig. 7). Adolescent drivers have a far greater frequency of accidents in bends: the first three years after acquiring a licence are particularly critical, but only after seven years is the distribution typical of beginners reduced and in the subsequent age groups these relations become blurred. But Figure 7, too, reflects the problem of a generally valid risk determination: the percentages given are *only valid within* the reference groups and should not be misinterpreted as a risk comparison (for example, per 100,000 licence holders) in the different age groups. This would, for example, lead to the false conclusion that older drivers had an accident frequency inside straight sections of road almost 1.7 times higher than beginners.

Figure 8, however, shows a possibility of generally determining risks—although presupposing, which is not strictly the case, that the distribution in Figure 7 for single car accidents per age group reliably indicates the distribution of all single car accidents.

The age distribution of car drivers who did not cause the accident is known from the HUK studies (15), and experience in the past shows that this can be roughly equated with the normal distribution of drivers using the roads.

Making the above presupposition, the AEC distribution according to Figure 7 can now be related to the estimated average driver population, and this produces a relative risk (Fig. 8). Because of the uncertainties mentioned, the risk factors were deliberately not indicated quantitatively—but it becomes clear that young people who begin

AEC / age groups	1		2		3		4/5		6/7		total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
18 - 20	51	30.3	89	53.0	16	9.5	7	4.2	5	3.0	168	100.0
21 - 25	58	36.9	76	48.4	12	7.7	7	4.5	4	2.5	157	100.0
26 - 30	23	34.8	31	47.0	6	9.1	4	6.1	2	3.0	66	100.0
31 - 40	39	42.4	42	45.6	7	7.6	1	1.1	3	3.3	92	100.0
41 - 50	18	50.0	13	36.1	2	5.6	3	8.3	-	-	36	100.0
51 - 60	16	53.4	13	43.3	-	-	1	3.3	-	-	30	100.0
over 60	5	45.4	4	36.4	-	-	1	9.1	1	9.1	11	100.0
total	210	37.5	268	47.9	43	7.7	24	4.2	15	2.7	560	100.0

• = onset of disturbance x = final position of car/accident spot

Figure 7. Involvement of drivers in single-car accidents according to age groups—course of the road (AEC) during the disturbance (random sample without adjustment).

to drive have a generally increased accident risk, which on straight roads is about three times and in bends as much as about ten times higher than for car drivers aged 30 or above.

These features typical of drivers are completely transferred to the driver-vehicle control loop and, because of the varying driver populations for car models, result in differences in accident frequency. Attempts to estimate this influence are still in their early stages. It may well be possible that—also by using preciser definitions such as AEC—a far better basis for assessment can be expected in the future when the new, refined study material is available.

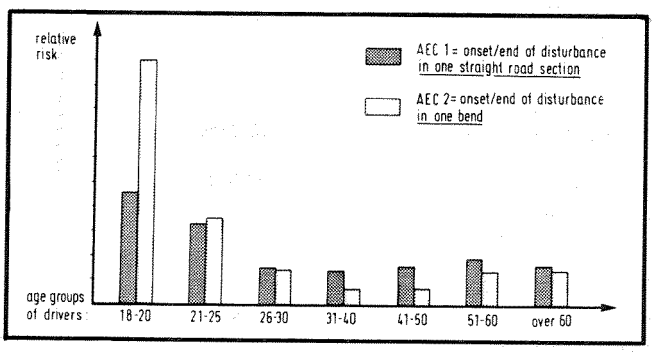


Figure 8. Estimate of a relative risk distribution of drivers' age groups in single-car accidents.

THE BASIS OF "ADJUSTED ACCIDENT MATERIAL"

Defining Terms

It is absolutely essential to adjust the accident material if conclusions are made which extend beyond reflecting the occurrence of real-life accidents and which aim at assessing the influence of the driver-vehicle control loop or even the vehicles' technical concept. This adjustment entails eliminating from the accident material inadmissible interference factors and dominant factors (such as the drivers' ages) which may cover up all the other influences of less significance. In this paper the term "adjusting the accident material" is, moreover, to be understood in a much broader sense:

"Theoretically adjustment must result in homogeneous accident material in such a way that only the relationships relevant to the investigation should have an effect and all other interference factors are eliminated or neutralised or the extent of their effect can be assessed."

Considerations with regard to "adjusted accident material" must therefore begin even when formulating the criteria for selecting the accidents, and they differ according to the aims of the study.

Desirable Adjustment Criteria

Figure 9 shows some adjustment criteria recognisable at present with an assessment of the possibility of re-

groups of parameters	adjustment criteria	examples	possibilities of recording *
structure of accident material	- defined selection	- road category/area	●●●●
	- homogeneous accident group	- car-to-car accidents/ single-car accidents	●●●●
	- accident consequences	- accidents with/without injury	●●●●
	- identical type of accident	- rear-end collisions/ collisions at crossings	●●●●
driver	- age/sex		●●●●
	- possession of driving licence	- young drivers	●●●●
	- driving experience		●●
	- acute/chronic behavioural defects	- alcohol	●●●
		- drugs	●
		- illness/impaired sight /heart attack	●● ●
	- temporary influences on driver behaviour	- familiarity with the car	●●
		- adaption to the car	●
		- social behaviour	●
		- attitude to risk	●
	- momentary disposition	- blackout/overfatigue	●●
		- sudden distraction (environment/occupants)	●
		- psychical stress situation	●
car	- car age - mileage		●●●● ●●●●
	- present condition	- maintenance	●●●
		- mechanical defects	●●
		- loading	●●
environment	- traffic flow/density	- traffic jam	●●●
	- influence of other party	- driving manoeuvre/ insisting on right of way	●●
	- road characteristics	- signs/information	●●●
		- road under construction	●●●
		- defect of road structure	●●
	- specific weather conditions	- snow	●●●●
		- ice	●●
		- aquaplaning	●●

* — easily possible ●●●● — normally possible ●●● — possible with limitations ●● — not possible or very difficult ●

Figure 9. Catalogue of requirements for hitherto recognizable adjustment criteria of the accident material in studies of the driver-vehicle control loop.

cording them. It can be seen at once that the precondition of completely "adjusted accident material" cannot be fulfilled because of the number and complexity of the influencing factors. But it should be ensured that at least the main features of a body of accident material are adjusted to such an extent that conclusions of defined validity can be drawn. Other, in general nearly unascertainable, criteria—such as the drivers' attitude to driving, social behaviour patterns, personal disposition at the time of the accident or even familiarity with the car—have to be compensated as far as possible by a sufficient number of cases and brought to a standard distribution. How many cases are required to do this, however, has not yet been established analytically.

Practical Possibilities

The effect of interference factors and thus the importance of adjustment criteria for the result depend to a great extent on how the accident material is recorded and structured. Single car accidents thus have to be treated quite differently from car-to-car collisions or car-pedestrian accidents.

Taking the catalogue of requirements according to Figure 9, a check has to be made in each case to be analysed as to

—which interference factors dominate to such an extent that they have to be eliminated from the material or
—which criteria require only the relative frequency of occurrence to be given.

This procedure was applied to the random sample of 578 single car accidents. Usually it is assumed that in the case of single car accidents the best correlation is to be found between driver/car interaction and the accident type (especially since there is no influence of another party) and that this accident group is therefore particularly suitable for analysing "active safety". This idea has to be largely revised.

Single-car accidents are influenced so much by special factors such as, for example,

—driver group distribution typical of beginners
—car fleet with a high proportion of older vehicles
—an extremely high proportion of night and alcohol accidents

that the results must by no means be generalised in an unadjusted state to produce conclusions as to the requirements of "active safety" with regard to vehicles in *all* traffic conditions or regarding the *normal* behaviour pattern of driver/vehicle interaction.

Out of the random sample of 578 single-car accidents

—212 occurred under the influence of alcohol	36.7%
—through black out, overfatigue	0.9%
—4 through some other serious distraction of the occupants or acute or chronic health defects (heart attack, impaired sight)	0.7%
—6 through mechanical defects (tyres, lighting, brakes) mostly resulting from inadequate maintenance	1.0%
	39.3%

In 4 out of 10 single car accidents recorded the normal behaviour pattern of the driver-vehicle control loop was possibly largely reduced by an interference factor. In this proportion, environmental hazards caused by sudden hindrances on the road, unexpected icy patches, snow or aquaplaning—altogether about 14.5% of the cases—are not yet taken into account.

These cases have to be included when discussing environmental influences or accident distributions, but there are other specific analyses, for example, driving dynamics or braking behaviour where these cases have to be partly eliminated from the investigation material.

Thus single car accidents in unadjusted distribution do not result in the high direct correlation to "active safety" which is presumed to exist, at least results found there cannot be transferred to the whole traffic requirements without considerable restrictions.

The Effects of Adjusting the Material

In the case of single car accidents it is essential to adjust at least the "alcohol" factor, which has a different significance in relation to driver groups or sex or the distribution of accident characteristics.

Figure 10 indicates the AEC distribution of the accidents involving alcohol. While alcohol played a part in about one-third of the accidents on straight roads, this figure is well over 40% for single car accidents in bends. As the AEC 4/5 with 53.8% of cases of alcohol show, it is especially difficult for inebriated drivers to estimate the appropriate speed and to react with controlled steering input. Accident material which has not been adjusted at least according to this parameter is bound to lead to distorted conclusions when assessing the driver-vehicle control loop. The proportion of adolescent drivers involved in single car accidents under the influence of alcohol is extremely high (Fig. 11): Out of the 212 single-car accidents with the influence of alcohol, young drivers of up to 25 were involved in as many as 124 cases (58.5%). About 40% of the young people in single-car accidents were found to be driving under the influence of alcohol.

A study of the cases involving alcohol confirmed that this completely covered up the typical driving characteristics resulting from age and experience.

In conclusion, Figures 12 and 13 show the characteristics of driver groups and vehicle concepts based on adjusted accident material when the influence of alcohol is eliminated:

course of road during disturbance onset ⟶ end	AEC No.	single-car accident total No.	total %	with alcohol influence No.	with alcohol influence %
straight road only	1	212	36.7	59	27.8
bend only	2	278	48.1	115	41.4
bend ⟶ straight road	3	45	7.8	17	37.8
straight road ⟶ bend straight road ⟶ bend ⟶ straight road	4/5	26	4.5	14	53.8
bend ⟶ straight road ⟶ bend s-bend	6/7	17	2.9	7	41.2
	Σ	578	100.0	212	36.7

significance of alcohol-influenced single-car accidents according to [9]
- on straight roads 39.4 %
- in bends 44.2 %

Figure 10. The necessity of adjustment of the material illustrated by the example of the interference factor "alcohol influence".

driver age groups	number ①	of these under influence of alcohol number ②	%	alcohol exposure ②/①(%)
18-20	168	66	31.1	39.3
21-25	157	58	27.3	36.9
26-30	66	26	12.3	39.4
31-40	92	44	20.8	47.8
41-50	36	12	5.7	33.3
51-60	30	6	2.8	20.0
over 60	11	–	–	–
total	560	212	100.0	–

Figure 11. The frequency of occurrence of the adjustment criterion "alcohol" in single-car accidents in the drivers' age groups.

AEC / age groups	1 No.	1 %	2 No.	2 %	3 No.	3 %	4/5 No.	4/5 %	6/7 No.	6/7 %	total No.	total %
18 - 20	31	29.5	61	58.1	8	7.6	4	3.8	1	1.0	105	100.0
21 - 25	43	44.3	43	44.3	7	7.2	2	2.1	2	2.1	97	100.0
26 - 30	18	46.1	15	38.5	3	7.7	1	2.6	2	5.1	39	100.0
31 - 40	25	52.1	15	31.2	6	12.5	1	2.1	1	2.1	48	100.0
41 - 50	16	61.6	7	26.9	2	7.7	-	-	1	3.8	26	100.0
51 - 60	14	63.6	7	31.8	-	-	1	4.6	-	-	22	100.0
over 60	5	45.4	4	36.4	-	-	1	9.1	1	9.1	11	100.0
total	152	43.7	152	43.7	26	7.5	10	2.9	8	2.2	348	100.0

• = onset of disturbance x = final position of car/accident spot

Figure 12. The accident characteristics of the drivers according to age groups by using adjusted material with elimination of alcohol influence.

car concept / AEC	not adjusted material [%] * front block	conventional	rear block	total	adjusted accident material [%] * front block	conventional	rear block	total
1	32.7	42.3	24.7	36.7	44.3	46.5	21.4	41.9
2	52.1	44.8	54.1	48.4	48.1	38.9	58.9	44.7
3	6.4	7.7	11.8	8.0	2.9	9.1	12.5	7.8
4/5	6.4	2.6	7.0	4.4	2.9	3.0	5.4	3.4
6/7	2.4	2.6	2.4	2.5	1.8	2.5	1.8	2.2

* random sample 578 cases according to figure 6

⋆ adjusted random sample 366 cases

Figure 13. The distribution of the "onset/end characteristic" (AEC) in the car concepts changed by the adjustment criterion "alcohol".

The defects in behaviour of "beginners" caused by a lack of experience emerge even more clearly (Fig. 12). These considerable changes in the AEC distribution by eliminating the alcohol influence from the material only have, because of the varying proportion of the driver population, a strong direct influence on the accident characteristics (Fig. 13) of any car-related sample.

It is obvious that with an analysis of a specific type or series of cars with the lower number of cases simply because of the adjustment criteria a substantial change of the parameter distributions is to be expected. This effect will have to be quantified using expanded accident material in the future.

The estimate of the requisite numbers of cases is influenced by the structure of the accident sample and the aim of the study.

Assuming a homogeneous accident group and using uniform definitions in the material compiled, basic values begin to appear in constant distribution from 600 cases and up—there being no possibility of a further breakdown into other parameters because of the limited number of cases.

For one- or two-parameter combinations of the single-car accident characteristics, relatively constant distributions can be achieved from 1,500 accidents or more according to the studies carried out (even if 40% of the cases have to be eliminated due to adjustment). If the influence of the driver is neutralised, whether with respect to age or driving experience, the number of cases increases considerably. According to Figure 8 it is advisable to form three categories of drivers (those in possession of a licence for 1-3 years, up to 7 years and over 7 years). Under these circumstances it is necessary to compile accident material from about 5,000 cases, and this will also enable the basic influences of vehicle categories to be assessed.

As far as influences of the driver-vehicle control loop or even of accident frequencies typical of drivers or vehicles are discussed, it is no longer sufficient to give isolated parameter frequencies, as this automatically results in suppressing the interaction of these parameters (12, 19).

For this aim of a study a systematic sequence of parameters is required to categorise accident situations with the equivalent external conditions.

A proposal for a comprehensive system, describing the "critical situation" (Fig. 14), has been worked out in (12). This procedure enables the whole course of the disturbance to the "driver-vehicle control loop" to be presented uniformly using objective criteria, and a defined basis for analysis results from the prescribed parameter combinations.

The system is based on two combinations of criteria which describe the "driving situation at the onset of the disturbance" and the "course of the disturbance". This system proved to be very suitable for allowing an assess-

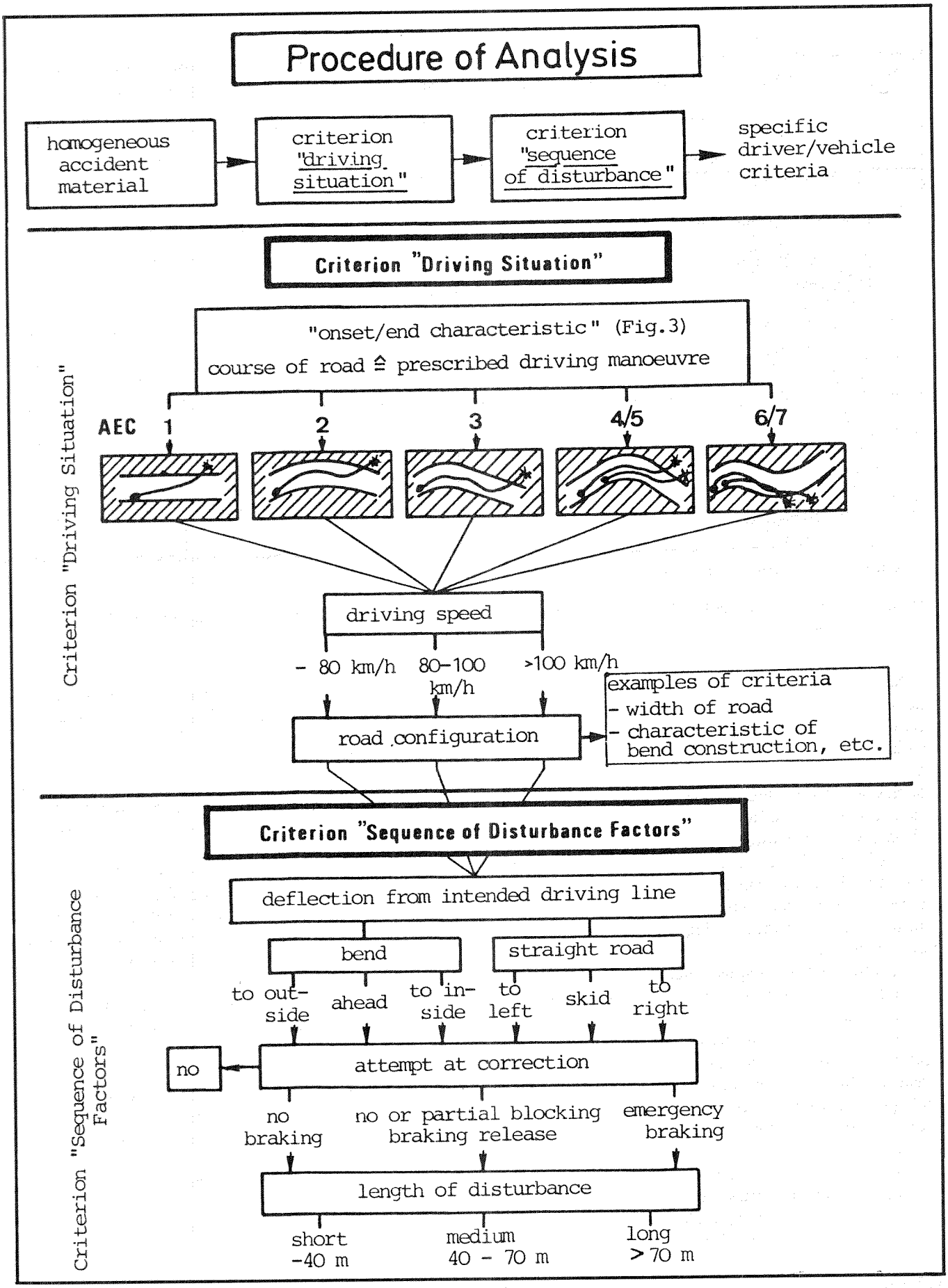


Figure 14. Proposal for a comprehensive system for describing the *"crisis situation"* using objective facts.

ment of the frequency of "dynamic driving processes" in defined typical accident situations; specific results are discussed in depth in (12). But in order to obtain reliable standard distributions of driver or vehicle influences basic material covering some 10,000 single car accidents is required. This corresponds to the limit of what seems feasible. For then, on account of the time required for the evaluation of the accident material, there is a risk that the results would no longer reflect the technological developments after the study had been completed.

For this reason it will not be possible to pass a final judgment on the possibilities and limits of assessing "active safety" until an "experimental phase" lasting several years has been concluded.

But it is already clear that

—the efforts made so far to record accidents have to be intensified to prove the results obtained up to now
—uniform definitions and methods of evaluation have to be achieved and
—the comparison of independent studies has to be encouraged.

Far more attention than hitherto will have to be paid to the necessity of adjusting the accident material. This paper has thus inevitably given rise to more questions than answers; but this critical approach is necessary to utilise the possibilities and advantages which undoubtedly exist from deriving results on "active safety" from real-life accidents.

CONCLUSIONS AND PROSPECTS

The further development of car safety and the possibility of applying new technologies make it desirable to take stock of the present situation of accident occurrence and of the influence of technical measures on accident prevention. The increasing number of accident studies in recent years from the point of view of "active safety" have already produced some experience on parameter distributions in the accident material and on trends in the driver-vehicle control loop.

Large numbers of accidents are necessary, however, if reliable findings on the driver-vehicle control loop are to become available beyond global criteria. Presupposing homogeneous accident material and a uniform method of evaluation, it is true that standard distributions of the basic parameters do begin to emerge after about 600 cases. But for analyses typical of drivers or vehicles at least 3,000 to 10,000 accidents are necessary, depending on the aim of the study.

These problems are aggravated by the evidence furnished here of a necessary "adjustment of the accident material". This "adjustment" should not only be restricted to eliminating or neutralising the interference factors, but must already result in a homogeneous distribution when the accident material is compiled. Taking a case study of 578 accidents the possibilities and limits of "material adjustment" were discussed.

For the analysis of the effects of the driver-vehicle control loop adjusting the accident material—shown in the case of single-car accidents—is of far greater importance than had been assumed up to now.

Because of the special internal structure of the single-car accidents particular caution is called for when transferring the results to overall conclusions of active safety, and the knowledge thus obtained must be supplemented by independent studies of other accident groups, for example, car-to-car accidents or car-pedestrian accidents. But in this case the influence of the other party involved in the accident arises, and this effect still has to be examined and may lead to new problems.

An expanded classification of the scene of the accident, describing the whole course of the road from the onset to the end of the disturbance to the driver-vehicle control loop, produced considerable advantages in assessing dynamic driving processes compared with the global classification used up to now. This applies in particular when the comprehensive system "crisis situation" (Fig. 14) with prescribed parameter combination of the course of the accident is used. This seems to be an important precondition for the discussion of influences typical of drivers or vehicles.

Work up to now can be described as a search for suitable recording criteria, methods and ways of presentation, which reflect the complexity of the problem. To some extent the current situation resembles the state of injury research at the beginning of the 'sixties.

The aim of this paper is to help take stock of the possibilities and limitations of investigations into "active safety" and to realistically assess the results that can be achieved. Whether in future with expanded and adjusted accident material reliable results on car-specific characteristics can be obtained is highly questionable—especially since an overall criterion of driving behaviour or a separation of individual vehicle parameters does not seem to be possible.

The principal task of current studies of active safety is, however, to work out quantitative data on the frequency, circumstances and course of accidents through reliable studies and thus to provide a chance of assessing more exactly the effect of feasible and necessary safety measures on the basis of real accident occurrence.

In spite of all the problems and restrictions that exist it is necessary to continue in a critical way the work that has been begun. The basic knowledge has greatly improved as a result of accident analyses in recent years, and the limits and problems have been recognised. This offers the chance to solve these problems or to confine the analyses to those areas in which the problems can be reliably solved. By making a critical use of the currently known instruments of the accident studies of active safety

an aid to decision-making may emerge so that "active safety" can be further improved in the future.

REFERENCES

1. HUK-Verband. "Ursachen und Begleitumstände der Verkehrsunfälle mit schwerem Personenschaden in der Bundesrepublik Deutschland, Unfalltyp E, "Abkommen von der Fahrbahn" ", Hamburg 1971.
2. HUK-Verband. "Ursachen und Begleitumstände der Verkehrsunfälle mit schwerem Personenschaden in der Bundesrepublik Deutschland, Sammelband M", Hamburg 1973.
3. Langwieder, K., Danner, M., Wrobel, M. "Ansatzpunkte zur Beurteilung des Fahrverhaltens in seiner Auswirkung auf das reale Unfallgeschehen", XVIII. FISITA-Kongress, Hamburg, Mai 1980.
4. Zomotor, A. "Untersuchungen über den Zusammenhang zwischen Aktiver Sicherheit und Unfallverhütung", XVII. FISITA-Kongress, Budapest, Juni 1978.
5. Otte, D. et al. Abschlußbericht "Erhebungen am Unfallort", Forschungsvorhaben FP 7236 und FP 7506 der Bundesanstalt für Straßenwesen, Köln, Juli 1981.
6. Danner, M., Langwieder, K., Wrobel, M. "Considerations in Appraising the Driver Vehicle Control Loop in a Study of Real-Life Accidents", 8. ESV-Conference, Wolfsburg, October 1980.
7. Pfundt, K. "Fahrunfälle in Kurven", "Der Verkehrsunfall", Heft 7/8, 1979.
8. Engels, K. "Der Einfluß der Fahrwerkskonstruktion von Pkw auf das Unfallgeschehen in Kurven", XVIII. FISITA-Kongress, Hamburg, Mai 1980.
9. Boürsig, K. "Auswertung realer Unfälle im Hinblick auf die aktive Sicherheit", Diplomarbeit (FH), Fachhochschule Offenburg/DEKRA, Stuttgart.
10. Danner, M., Langwieder, K., Schmelzing, W. "Bedeutung von Alleinunfällen für die sicherheitstechnische Auslegung von Fahrzeugen", Entwicklungslinien in Kraftfahrzeugtechnik und Straßenverkehr, Forschungsbilanz 1981, Verlag TÜV Rheinland GmbH, 1982.
11. Danner, M., Langwieder, K., Schmelzing, W. "Möglichkeiten und Probleme der Beurteilung der aktiven Fahrzeugsicherheit durch Auswertung des realen Unfallgeschehens", Jahrestagung der VDI-Gesellschaft Fahrzeugtechnik, München, Oktober 1981.
12. Langwieder, K., Danner, M. "Möglichkeiten und Grenzen des Aussagebereiches zu Fragen der Aktiven Sicherheit—Erkenntnisse aus einer Großzahluntersuchung von Pkw-Alleinunfällen", XIX. FISITA-Kongress, Melbourne, Nov. 1982.
13. Verband der Automobilindustrie e.V. "Tatsachen und Zahlen aus der Kraftverkehrswirtschaft".
14. Schweizerische Beratungsstelle für Unfallverhütung (BfU): "Jahresbericht 1978".
15. HUK-Verband: "Fakten zu Unfallgeschehen und Fahrzeugsicherheit", Büro für Kfz-Technik, München, 1977.
16. Jones, J. S. "The Role of Vehicle Handling in Accident Causation", SAE-Congress and Exposition, Detroit, Michigan, February 1975, Paper 750 115.
17. Bundesanstalt für Straßenwesen. "Fahrer/Fahrzeugverhalten in kritischen Situationen", Köln, November 1979.
18. Bergmann, W. "Correlation between Vehicle Tests and Subjective Evaluation", Entwicklungsstand der objektiven Testverfahren für das Fahrverhalten, Verlag TÜV Rheinland GmbH, 1978.
19. Enke, K. "On the Validity of Some Conclusions From Handling Properties Toward Active Safety", 8. ESV-Conference, Wolfsburg, October 1980.
20. Statistisches Bundesamt Wiesbaden, Reihe 3.3, 1980: "Straßenverkehrsunfälle".

Restraint Use and Effectiveness as Estimated from U.S. Accident Files and Observational Surveys

JOHN VAN DYKE
GLENN A. SPRINGER
National Highway Traffic Safety Administration

ABSTRACT

The paper begins with an abbreviated history of passenger car restraint regulation and use in the United States. Selected studies which estimated usage and effectiveness for the period 1963 to 1977 are referenced and corresponding estimates are given. Accident data files and observational surveys from which more recent (post-January 1, 1977) estimates can be obtained are then described. Restraint usage rates obtained from these sources are presented. Factors which influence usage such as occupant role and vehicle size are addressed and comparisons between sources are made to determine consistency. Overall estimates of usage are given. Restraint effectiveness is defined and estimates of injury and fatality reduction are given as calculated from these accident data sources.

Overall estimates are given for injury and fatality reducing effectiveness. Finally, the benefits of wearing belts are quantified in terms of lives saved and injuries prevented.

INTRODUCTION

In 1966 the Congress of the United States enacted the National Traffic and Motor Vehicle Safety Act. This Act gave the Secretary of Transportation the authority to issue Federal Motor Vehicle Safety Standards (FMVSS) directed at reducing motor vehicle accidents and the deaths and injuries resulting from them. The National Highway Traffic Safety Administration (NHTSA) was given the responsibility to develop, implement and evaluate safety standards.

One of the first standards was FMVSS 208-Occupant Crash Protection. This standard became effective January 1, 1968. It required lap and shoulder seat belt assemblies at the front outboard seating positions and lap belt assemblies at all other designated seating positions in all passenger cars, except convertibles, manufactured on or after January 1, 1968.

Occupant use of seat belts in significant numbers began about a decade before Standard 208 became effective. At first the entire lap belt assembly was optional equipment. Then in the early 1960s manufacturers began installing the lap belt anchors, thus making it possible for car owners to complete the installation by simply adding the belts. Prior to 1964 several states passed laws requiring lap belt installations. By 1964 lap belt assemblies were standard equipment in the front outboard positions of passenger cars. Gradually lap belts were provided for the rear seat outboard positions also. By 1968 almost all cars of model year 1964 and newer had lap belts in outboard seating positions, front and rear.

In the early 1960s many cars with seat belts were so equipped by choice of the owner. Seat belt use rates for those belt-equipped cars were thus relatively high. In a review of the literature on use of restraint systems, Grimm (1) shows that restraint use rates from most studies conducted during 1963-67 were above 30 percent. These estimates were for belt-equipped cars only and were based exclusively on interviews and questionnaires used to survey belt usage in particular states or roadways. One study conducted nationwide in 1967, with an interview sample size of 701,882, reported a 55 percent use rate on long trips and a 38 percent rate for in-town driving (2).

In the ten years following the effective date of Standard 208 (1968-1977), many surveys for determining restraint use rates were conducted. Most of these surveys were confined to specific states or cities and many were directed at cars of particular model years, makes or sizes, or to certain categories of occupants (1). These surveys do not provide results that can be considered representative of the Nation. They do, however, when taken all together, give a qualitative picture of usage trends. In general, as seat belts became standard equipment for a larger percentage of the passenger cars each successive year, the percentage of occupants using these belts became smaller. If one focuses on restraint use in accident reports or as observed on the roads and includes all model years, one observes that usage rates of greater than 30 percent in 1968 were down to below 20 percent in 1977. This decline was interrupted in 1972-75 when first the buzzer/light warning system (January 1, 1972) and then the ignition interlock (1974 models) was required. The interlock requirement lasted for about a year, until the Congress overruled the NHTSA and abolished the requirement. Usage rates in this period, 1972-75, rose again above 30 percent only to drop below 20 percent in several years.

The effectiveness of lap and lap/shoulder belts in real world accidents has been of interest since belts were first installed. Estimates of this effectiveness have varied widely, as is well documented in Griffin's 1973 review of the literature on the benefits of certain safety devices (3). He reports fatality and injury reductions due to belts ranging from 35 to 65 percent. Reinfurt et al. (4) in a later study of 1973-1975 model cars involved in towaway crashes report reductions in serious injuries of 53% (lap belts) and 62% (lap/shoulder belts). In an attempt to explain the wide variation in published estimates of belt effectiveness, Campbell and Reinfurt (5) cite several factors that contribute to this variation: differences in injury scale values, inaccuracies in reporting occupants' belt status and variation in sampling criteria. Attempts in recent years to standardize injury coding and the application of sampling principles to obtain regional or national estimates should produce more consistent values.

Regardless of the precise effectiveness of seat belts, the NHTSA realizes that voluntary belt use is the quickest way to achieve major injury and fatality reduction. This is true regardless of the final decision on the automatic restraint provision of Standard 208. The agency has therefore embarked on a program to increase understanding of the benefits of safety belts and to increase the use of them.

The purpose of this paper is to give estimates of restraint use and effectiveness that are based on relatively recent observation and accident data. Most of the data reported and utilized have been collected since January 1, 1977. These estimates provide a consistent picture of current belt use and effectiveness.

DATA SOURCES

Both accident and observational data were used for this report. National data come from the National Accident Sampling System (NASS), the National Crash Severity Study (NCSS) and the Fatal Accident Reporting System (FARS). State data came from North Carolina, New York

and Maryland. The observational data came from a nationwide survey which was conducted in numerous urban locations.

Accident Data Files

Although three of the accident data files contain nationwide data, only one was designed to be truly nationally representative. The NASS is NHTSA's nationally representative accident data base. It consists of a network of fifty teams located at randomly selected sites which collect nationally representative accident data by investigating all types of police-reported traffic accidents. Accidents are placed into strata according to accident severity and the types of vehicles involved, and are then selected for investigation according to the stratum in which they fall. Using data from 1979 and 1980 an average (of the two years) for the total number of passenger car occupants involved in police-reported accidents in a year is calculated. That national estimate is roughly 14,000,000. The unweighted number of passenger car occupants in the sample averaged approximately 5500 for 1979 and 1980 (6).

Another nationwide accident data file which was used in this study is the National Crash Severity Study (NCSS). It was a study specifically designed to link vehicle damage to occupant injury by investigating towaway accidents in which a passenger car (case vehicle) was towed. The NCSS consists of seven areas purposively selected to have almost the same distribution of central city, suburban, small town, and rural population as the nation, and the areas are distributed throughout the nation. These were also locations in which accident-investigating teams had already been established. Within each of the seven areas comprising the NCSS, accidents were sampled at a rate according to the stratum in which they fell. These strata were defined on the basis of accident severity. The number of unweighted case vehicle occupants involved in the study totaled about 25,000. Weighted, this figure increases to approximately 106,000 (7).

The third accident data file queried for its information on restraint use was the Fatal Accident Reporting System (FARS). Now in its eighth year of operation, FARS provides a complete census of fatal accidents in all States, the District of Columbia and Puerto Rico. In 1980, roughly 67,000 passenger car occupants were involved in fatal accidents (8).

The three individual state accident files used were North Carolina, New York and Maryland. Each of these States has provided police-reported restraint use and injury information for occupants of passenger cars involved in police-reported accidents. For the accident years 1979-1981 North Carolina reported restraint use and injury information for 864,901 occupants of passenger cars involved in police-reported accidents. Additional data from North Carolina, Maryland and New York were used in a study of automatic belts in accident-involved Volkswagen Rabbits (9). For accident year 1980 New York reported restraint use and injury information for 1807 front-seat occupants of Rabbits. In 1981 New York reported this information for 2031 front-seat occupants. For accident year 1980 Maryland provided restraint use and injury data for 617 front-seat occupants of accident-involved Rabbits.

Observational Data Files

The observational data used in this report came from a survey which was conducted in nineteen cities across the United States (10). The survey collected information on restraint use of passenger car occupants. The observations made were on approximately 63,000 drivers and 87,000 passengers during a two-year period ending October of 1982.

RESTRAINT USAGE

Estimating Restraint Usage From Accident Data

The accident data files mentioned earlier are a source of estimates for restraint use. Of all passenger car occupants NASS estimates that approximately 11.0% were restrained (see Table 1). It is important to note that the denominator for this rate was restricted to those occupants who were known to be either restrained or not restrained. Approximately 10% of the occupants, those with unknown restraint use, have been excluded. The numerator includes all forms of restraint. This method was used to compute usage rates throughout the study. Comparing restraint usage for drivers and passengers shows that drivers are more often restrained than passengers. NASS estimates driver usage to be 13.7% while passenger usage is only 6.9%.

The NCSS file yields another estimate of restraint use among passenger car occupants. Overall, NCSS estimates restraint use to be 7.4% (see Table 2). NCSS is consistent with NASS in that driver usage is greater than passenger usage. Drivers were restrained at a rate of 9.3% while passengers were restrained at a rate of 4.1%.

The FARS file also collects information on restraint use. The data give a relatively low estimate of restraint use, namely 3.5% (see Table 3). Again, comparing driver usage to passenger usage the same pattern of greater usage among drivers is observed. FARS estimates driver usage to be about 4.1% while passenger usage stands at only 2.7%. These occupants were involved in fatal accidents.

Restraint rates from NASS to NCSS to FARs show a general decline in usage. One hypothesis which has been generally accepted and which existing data support is that usage decreases with an increase in accident severity. In NASS the only necessary outcome is that the accident be

Table 1. NASS (79 and 80 average) restraint use for all passenger car occupants.

Restraint type	Driver			Passengers			Total occupants		
	N	Percent	Percent	N	Percent	Percent	N	Percent	Percent
None	6,486,467	86.34		4,563,391	93.11		11,049,858	89.01	
Lap and shoulder Belt	740,645	9.86		191,658	3.91		932,303	7.51	
Lap belt only	282,253	3.76		117,127	2.39		399,380	3.22	
Child seat	0	0		28,774	0.59		28,774	0.23	
Used unknown type	3,407	0.05		0	.00		3,407	0.03	
Total known Use—non-use	7,512,772	100.00	85.78	4,900,950	100.00	95.09	12,413,722	100.00	89.23
Unknown if restrained	1,245,139		14.22	253,239		4.91	1,498,378		10.77
Total	8,757,911		100.00	5,154,189		100.00	13,912,100		100.00

Restrained	Driver			Passenger			Total Occupants		
	N	Percent	Percent	N	Percent	Percent	N	Percent	Percent
Yes	1,026,305	13.66		337,559	6.89		1,363,864	10.99	
No	6,486,467	86.34		4,563,391	93.11		11,049,858	89.01	
Total known Yes—No	7,512,772	100.00	85.78	4,900,950	100.00	95.09	12,413,722	100.00	89.23
Unknown if restrained	1,245,139		14.22	253,239		4.91	1,498,378		10.77
Total	8,757,911		100.00	5,154,189		100.00	13,912,100		100.00

Table 2. NCSS restraint use for all passenger car occupants.

Restraint type	Driver			Passengers			Total Occupants		
	N	Percent	Percent	N	Percent	Percent	N	Percent	Percent
None	53,301	90.68		33,491	95.92		86,792	92.63	
Lap and shoulder Belt	2,981	5.07		603	1.73		3,584	3.83	
Lap belt only	2,414	4.11		636	1.82		3,050	3.26	
Shoulder belt only	86	0.15		40	0.11		126	0.13	
Child seat	0	.00		144	0.41		144	0.15	
Total known Use—non-use	58,782	100.0	86.79	34,914	100.0	89.44	93,696	100.0	87.76
Unknown if restrained	8,944		13.21	4,123		10.56	13,067		12.24
Total	67,726		100.0	39,037		100.0	106,763		100.0

Restrained	Driver			Passenger			Total Occupants		
	N	Percent	Percent	N	Percent	Percent	N	Percent	Percent
Yes	5,481	9.32		1,423	4.08		6,904	7.37	
No	53,301	90.68		33,491	95.92		86,792	92.63	
Total Known Yes—No	58,782	100.00	86.79	34,914	100.00	89.44	93,696	100.00	87.76
Unknown if restrained	8.944		13.21	4,123		10.56	13,067		12.24
Total	67,726		100.00	39,037		100.00	106,763		100.00

Table 3. FARS 1980 restraint use for all passenger car occupants.

Restraint type	Total occupants		Percent
	N	Percent	
None	50,002	96.51	
Lap and shoulder belt	782	1.51	
Lap belt only	612	1.18	
Shoulder belt only	107	0.21	
Child seat	55	0.11	
Used un-known type	251	0.48	
Total known use—non-use	51,809	100.00	77.67
Unknown if restrained	14,893		22.33
Total	66,702		100.00

An additional source of restraint use data is the North Carolina state accident file for the years 1979-81. Data collected on police-reported accidents in that State show restraint use of all passenger car occupants to be 7.4% (see Table 5).

In addition to restraint and injury information NASS collects information on vehicle size. Higher restraint usage is observed among occupants of smaller vehicles. Occupants of full size vehicles were restrained at a rate of 8.6%, mid-size 10.6%, compact 12.6%, and sub-compact 13.5% (see Table 6). Vehicle size is not available in North Carolina but model year is. Since vehicles of model year '68-'74 are generally larger than vehicles of model year '75-'82, this is used as a crude surrogate for size. Combining data for accident years '79-'81, usage for occupants of '68-'74 model year passenger cars averaged 5.1% while usage among occupants of '75-'82 model year vehicles averaged 9.5% (Table 5). Thus North Carolina is consistent with NASS.

Restraint Usage as Estimated by Observational Data

Based on observations of approximately 63,000 drivers for 1980 to 1982, the estimate of driver usage is 11.5%

Restrained	Driver			Passenger			Total Occupants		
	N	Percent	Percent	N	Percent	Percent	N	Percent	Percent
Yes	1,214	4.10		591	2.67		1,805	3.49	
No	28,406	95.90		21,511	97.33		49,917	96.51	
Total known yes—no	29,620	100.00	76.49	22,102	100.00	79.40	51,722	100.00	77.71
Unknown if Restrained	9,103		23.51	5,736		20.60	14,839		22.29
Total	38,723		100.00	27,838		100.00	66,561		100.00

police-reported whereas FARS includes only fatal accidents. Since people wearing belts are much less likely to be killed in an accident, some of the decrease in restraint use from NASS to FARS is explained. Data collected in NASS and NCSS on the change in velocity at impact (delta-V) also support this theory. In NASS as delta-V goes from the lowest to the highest category restraint use decreases from 9.5% to 3.2% (see Table 4). In NCSS as delta-V goes from the lowest to the highest category restraint usage decreases from 10.2% to 3.2%.

Table 4. Restraint usage rates in crashes of given severity as estimated by NASS (79 and 80 average) and NCSS "change in velocity" data.

Δ V (MPH)	NASS	NCSS
1–10	9.5	10.2
11–20	7.1	6.4
21–30	5.6	5.0
31–40	4.8	2.7
41–99	3.2	3.2

(see Table 7). Based on roughly 87,000 passengers usage was estimated at 8.4%. Again, passenger usage is less frequent than driver usage.

Restraint Usage—Automatic Restraints vs. Manual Restraints

The observational data were not only a source of driver-passenger restraint use but also of restraint use by vehicle make. Observations of restraint use for drivers of manual-restraint-equipped Rabbits and automatic-restraint-equipped Rabbits yield two usage rates. After observing 354 automatic Rabbits and 766 manual Rabbits driver usage was estimated to be 87.6% and 29.0% in the two systems, respectively. From this one can see the benefit of the automatic system as far as usage is concerned. This increased usage for automatic restraints is also evident in available State accident data files. For the accident years 1975 through 1981 North Carolina recorded a 15.6% usage rate for front seat occupants of manual Rabbits

Table 5. North Carolina (79–81) restraint use for all passenger car occupants.

Restrained	Model year 68–74			Model year 75–82		
	N	Percent	Percent	N	Percent	Percent
Yes	21,517	5.09		42,082	9.52	
No	401,525	94.91		399,777	90.48	
Total known yes—no	423,042	100.00	98.57	441,859	100.00	98.41
Unknown if restrained	6,141		1.43	7,161		1.59
Total	429,183		100.00	449,020		100.00

Table 6. NASS (79 and 80 average) restraint use for all passenger car occupants of given car sizes.

Restrained	Sub-compact			Compact			Mid-size			Full size		
	N	Percent	Percent	N	Percent	Percent	N	Percent	Percent	N	Percent	Percent
Yes	318,869	13.52		321,365	12.62		305,976	10.61		297,809	8.63	
No	2,039,374	86.48		2,225,443	87.38		2,577,760	89.39		3,154,427	91.37	
Total known Yes—no	2,358,243	100.00	93.04	2,546,808	100.00	92.64	2,883,736	100.00	91.94	3,452,236	100.00	87.78
Unknown if restrained	176,445		6.96	202,417		7.36	252,960		8.06	480,681		12.22
Total	2,534,688		100.00	2,749,225		100.00			100.00			100.00

Table 7. Observed restraint use (in 19 cities).

Restrained	Driver		Passengers		Total	
	N	Percent	N	Percent	N	Percent
Yes	7,241	11.5	7,336	8.4	14,577	9.7
No	55,723	88.5	79,994	91.6	135,717	90.3
Total	62,964	100	87,330	100	150,294	100

and a significantly greater usage of 45.7% for the front seat occupants of automatic Rabbits (see Table 8). In Maryland, for accident year 1980, front seat occupants restrained in manual systems represented only 27.9% of the total while front seat occupants restrained in automatic systems represented 60.6% of the total front seat occupants in automatic-restraint-equipped Rabbits. Accident data from New York for 1980 and 1981 again show higher usage in automatic systems compared to manual systems. In 1980 usage for the automatic system was 54.7% and 23.7% for the manual system. In 1981 the corresponding rates were 50.1% and 22.8% (see Table 9).

Summary—Usage

Restraint usage varies with a number of factors. Based on NASS almost 14% of drivers are restrained while only about 7% of passengers wear their belts. According to delta-V data usage decreased from 10% to 3% as delta-V increased from its least severe category to the most severe category. Vehicle size also seems to influence belt usage since only 9% of large car occupants were restrained but nearly 14% of sub-compact occupants were restrained based on NASS. Automatic restraints increased belt usage by nearly 30%. State data on occupants of VW Rabbits shows usage rates which go from just over 20% for manual systems to around 50% for automatic systems. Overall, the sources of restraint use, consisting of accident data and observational data, point to a general restraint rate of about 11% for occupants of passenger cars.

RESTRAINT EFFECTIVENESS

Definition

Restraint effectiveness is defined as the relative decrease in injuries (or fatalities) as one compares restrained with unrestrained vehicle occupants. In equation form, effectiveness (E) is given by

$$E = \frac{\text{Unrestrained Injury Rate} - \text{Restrained Injury Rate}}{\text{Unrestrained Injury Rate}}$$

Strictly speaking, this formulation is only valid if the restrained and unrestrained groups are alike with respect to accident types and severities, vehicles involved, and driver and passenger characteristics. If this similarity fails to exist one must then control for the differences before applying the formula above. This ideal of identical groups or the ability to control for differences is rarely, if ever, achieved. The available accident data simply do not contain all the required information. Further, the restrained

Table 8. Restraint use in Volkswagen Rabbits. Manual vs. automatic restraint systems.
North Carolina

1975–1979	Front-seat occupants					
	Manual		Automatic		Total	
Restrained	N	Percent	N	Percent	N	Percent
Yes	186	16.3	145	42.6	331	22.4
No	952	83.7	195	57.4	1,147	77.6
Total	1,138	100	340	100	1,478	100

1980	Front-seat occupants					
	Manual		Automatic		Total	
Restrained	N	Percent	N	Percent	N	Percent
Yes	110	15.6	192	51.6	302	28.1
No	594	84.4	180	48.4	774	71.9
Total	704	100	372	100	1,076	100

1981	Front-seat occupants					
	Manual		Automatic		Total	
Restrained	N	Percent	N	Percent	N	Percent
Yes	113	14.5	164	42.8	277	23.8
No	667	85.5	219	57.2	886	76.2
Total	780	100	383	100	1,163	100

Table 9. Restraint use in Volkswagen Rabbits. Manual vs. automatic restraint systems.
Maryland

1980	Front-seat occupants					
	Manual		Automatic		Total	
Restrained	N	Percent	N	Percent	N	Percent
Yes	117	27.9	120	60.6	237	38.4
No	302	72.1	78	39.4	380	61.6
Total	419	100	198	100	617	100

New York

1980	Front-seat occupants					
	Manual		Automatic		Total	
Restrained	N	Percent	N	Percent	N	Percent
Yes	307	23.7	281	54.7	588	32.5
No	986	76.3	233	45.3	1,219	67.5
Total	1,293	100	514	100	1,807	100

1981	Front-seat occupants					
	Manual		Automatic		Total	
Restrained	N	Percent	N	Percent	N	Percent
Yes	316	22.8	324	50.1	640	31.5
No	1,068	77.2	323	49.9	1,391	68.5
Total	1,384	100	647	100	2,031	100

Table 10. NASS 1979–80 yearly average number of occupants by restraint use and MAIS.

Restrained	MAIS = 0–2	MAIS = 3–6	Total	MAIS = 3–6 injury rate
Yes	229019	3920	232939	.01683
No	2548847	110564	2659411	.04157

E = 60%

Table 11. NASS 1979–80 yearly average number of occupants by restraint use and MAIS (known and estimated).

Restrained	MAIS = 0–2	MAIS = 3–6	Total	MAIS = 3–6 injury rate
Yes	242012	7192	249204	.02972
No	2735198	235579	2970777	.07930

E = 63%

are usually small in number and it is not possible to generate adequate distributions of the variables of interest for comparison with the larger unrestrained group of occupants. As data bases grow, as we expect NASS to do, the opportunity of controlling for significant factors will increase, and more precise estimates of effectiveness will become available. No attempt has been made in this paper to detect or control for restrained and unrestrained group differences. It is important, of course, that the criteria for selection of an accident for inclusion in an accident data file be independent of occupant use or non-use of restraints. It is believed that this independency holds for the data files used in this study.

Restraint Effectiveness in Injury Reduction

In addition to providing restraint use information, the NASS provides detailed injury information on most occupants. Injury severity is measured on the Abbreviated Injury Scale (AIS), which measures severity on a scale from 0 (no injury) to 6 (maximum injury, virtually unsurvivable). Although the NASS includes occupants of vehicles not towed as a result of the accident, this analysis includes only occupants of vehicles that had to be towed from the scene. A first estimate of effectiveness uses only occupants for whom there is AIS injury data. Each occupant is assigned a maximum AIS (MAIS) derived from the occupant's AIS data. It was decided to measure effectiveness on the basis of a reduction in MAIS = 3 to MAIS = 6 injuries. The injury rates for MAIS = 3 – 6 provide an effectiveness estimate of 60 percent (see Table 10). Thus restrained occupants had 60 percent fewer serious to fatal injuries than their unrestrained counterparts.

A second estimate of effectiveness uses occupants with known MAIS and those for whom one can be estimated. The estimated MAIS is obtained from other than AIS injury data. Table 11 shows restraint use and MAIS for occupants with known and estimated MAIS combined. Here the injury rates produce an effectiveness estimate of 63 percent, which agrees well with the estimate of 60 percent above.

The NCSS provides estimates of restraint effectiveness that can be considered the counterparts to those obtained above from NASS. Again, only occupants of vehicles towed as a result of the accident are considered. The NCSS equivalent to the NASS MAIS is the Overall AIS. The Overall AIS = 3—6 injury rates produce an injury reduction effectiveness estimate of 50 percent (see Table 12).

The NCSS counterpart to the NASS injury classification which includes known and estimated MAIS is called the NEWOAIS. Table 13 shows that these data provide an effectiveness estimate of 53 percent.

The two NCSS estimates of restraint effectiveness in injury reduction, as the two NASS estimates, are about the same magnitude.

A final data source for estimating the injury reducing effectiveness of restraints is the police-reported accident file for the State of North Carolina. The three accident years 1979-81 were selected for this analysis. Only passenger cars of model year 1968-82 are included. The complete file contains accident information on both towed and non-towed vehicles. Occupants of the non-towed vehicles have not been excluded as in the NASS estimation of effectiveness. In this police-reported accident file, injury severity is measured by what is commonly called the KABCO scale: K—Killed, A—Incapacitating (Injury obviously serious enough to prevent carrying on normal activities for at least 24 hours), B—Nonincapacitating (Other than K or A evident at the scene), C—No visible sign of injury but complaint of pain or momentary unconsciousness, O—No Injury.

Since it is not possible to convert the KABCO to the AIS scale, the K and A categories are selected as the injury criteria for estimating effectiveness. Table 14 shows occupant distributions by injury category and restraint use. The effectiveness estimate of 56 percent falls roughly

Table 12. NCSS file passenger car occupants by restraint use and overall AIS.

Restrained	Overall AIS 0–2	Overall AIS 3–6	Total	Overall AIS 3–6 injury rate
Yes	4478	99	4577	.02163
No	57828	2620	60448	.04334

E = 50%

Table 13. NCSS occupants by restraint use and NEWOAIS.

Restrained	NEWOAIS 0–2	NEWOAIS 3–6	Total	NEWOAIS 3–6 injury rate
Yes	5,455	120	5,575	.02152
No	61,810	2,951	64,761	.04557

E = 53%

midway between the estimate obtained from the NASS and NCSS data.

In summary, it is estimated that restraints reduce serious injuries (AIS 3-6) by 50 to 60 percent. The NASS and NCSS estimates differ by 10 percent (60 and 63 vs. 50 and 53) and the North Carolina State estimate falls midway between the NASS and NCSS values. Although the 10 percent difference between NASS and NCSS estimates might well be attributed to sample variation, there are differences between the two samples that could be factors. The most obvious is the difference in sampling periods: NCSS—January 1977 to March 1979, NASS—January 1979 to December 1980. On average, the model years differ by about two years. This means that the NASS sample had a larger proportion of lighter, smaller cars and a larger proportion of the three-point lap and shoulder restraints. It is not clear what the overall effect of these differences might have on restraint effectiveness.

Reinfurt et al. (4) in their study of restraint effectiveness in 1973-75 model cars controlled for crash configuration, damage severity, vehicle weight and occupant age. Their estimates of restraint effectiveness in reducing serious injuries (AIS 3-6) were 46 percent (lap belts) and 57 percent (lap and shoulder belts). These values are somewhat less than their unadjusted values of 53 and 62 percent, respectively. The NASS and NCSS estimates agree well with these estimates from one of the first major studies of restraint effectiveness.

Restraint Effectiveness In Fatality Reduction

The three data files used for estimating restraint effectiveness in injury reduction are also used in this analysis. Again, only occupants of passenger cars that are towed as the result of an accident are included in the analysis of the NASS and NCSS files.

Table 15 shows the NASS estimate of effectiveness to be 61 percent, a value that is essentially equivalent to the two injury reduction estimates (60, 63) based on the NASS.

The fatality reduction experienced by the restrained according to the NCSS file is 49 percent (see Table 16). This value, too, is similar to the injury reduction estimates (50, 53) for NCSS car occupants.

The North Carolina Accident file, contrary to the NASS and NCSS files, does not give an estimate of fatality

Table 14. North Carolina passenger car occupants by restraint use and injury category.

Restrained	Not (A + K)	(A + K)	Total	(A + K) injury rate
Yes	62,560	1,039	63,599	.01634
No	771,776	29,526	801,302	.03685

E = 56%

Table 15. NASS 1979–80 yearly average number of occupants by restraint usage and mortality.

Restrained	Not fatal	Fatal	Total	Fatality rate
Yes	238,954	957	239,881	.003864
No	2,655,832	26,752	2,682,584	.009972

E = 61%

Table 16. NCSS file occupants by restraint use and morality.

Restrained	Not fatal	Fatal	Total	Fatality rate
Yes	6,731	34	6,765	.005026
No	81,446	813	82,259	.009883

E = 49%

Table 17. North Carolina car occupants (1979–81) by restraint use and mortality.

Restrained	Not Fatal	Fatal	Total	Fatality rate
Yes	63541	58	63599	.000912
No	799051	2251	801302	.002810

E = 68%

reduction that is close to its estimates of injury reduction (see Table 17). The effectiveness estimate here of 68 percent differs considerably from the 56 percent for effectiveness in injury reduction.

Effectiveness of Automatic Restraints Compared to Manual

In the previous section the effectiveness of restraints was based on the difference between two injury rates—one rate for unrestrained occupants and one for the restrained. In this section the comparison will not be of unrestrained and restrained occupants, but of occupants of vehicles equipped with automatic restraint systems and those equipped with manual restraint systems. Whether or not the occupants are or are not restrained by their respective systems will not be considered. The restraint systems being compared in this analysis are the automatic and manual systems in Volkswagen Rabbits since model year 1975. By the end of 1981, approximately 300,000 automatic restraint-equipped Rabbits and 600,000 manual-equipped had been sold in the United States. Table 18 shows for each Rabbit type the number of front-seat fatalities, the exposure in millions of vehicle months, and the number of fatalities per million vehicle months of exposure (Fatality Rate). The fatality figures are obtained from the Fatal Accident Reporting System. The exposure numbers assume no attrition and are simply the sum, across all vehicles having the same restraint type, of the months between date of sale and January 1, 1982.

Table 18. Fatality data by Volkswagen Rabbit restraint type for accident years 1975–81.

Restraint	Fatals	Exposure	Fatality rate
Manual	590	29.29	20.1
Automatic	206	12.36	16.7

$$E = \frac{20.1 - 16.7}{20.1} = 17\%$$

These data show that front-seat occupants of automatic restraint-equipped Rabbits experience 17 percent fewer fatalities than their counterparts in the manual restraint-equipped. This benefit is attributed to the higher restraint usage rate for automatic restraint Rabbit occupants. If the effectiveness of restraints when used is between 50 and 60 percent, the 17 percent is consistent with usage rates for Rabbit front-seat occupants found in several State accident files. The North Carolina rates of 16% (manual), 46% (automatic) and New York rates of 23% (manual), 52% (automatic) support the 17 percent as a reasonable estimate of the effectiveness of automatic restraint-equipped Rabbits in reducing fatalities.

Chi and Reinfurt (9), in their comparison of Rabbits with automatic and manual systems, found a reduction in (A+K) injury rates for occupants of automatic-restraint Rabbits. Using the accident files of four States, they obtained estimates of effectiveness in injury reduction ranging from 17 to 38 percent.

OVERALL ESTIMATES OF RESTRAINT USAGE AND EFFECTIVENESS

Restraint usage rates, as noted earlier, vary with the data source, more precisely, with the general accident severity level in the data file. If one seeks a single usage estimate for occupants of towed vehicles, the NCSS file and NASS towaway file may be used. There is no reason to prefer one file over the other. The NCSS contains the larger sample of towaway vehicle. The NASS provides the more current estimate. The NCSS file estimate is 7.4 percent (Table 2) and the NASS file estimate is 8.4 percent (Table 15). The approximate average of the two estimates provides a good working number, 8 percent, as the overall estimate of the restraint usage rate for occupants of towed vehicles. Alternatively, if one seeks a usage estimate for all passenger car occupants, data on towed vehicle occupants are not pertinent, since these occupants comprise only about 2 percent of all occupants. Two estimates remain for consideration—the observed value of 10.2 per-

cent and the NASS subset of occupants of non-towed vehicles for whom the usage rate is 12 percent. Since each of these is a reasonable estimate of the usage rate for all occupants, the approximate average of the two, 11 percent, provides an overall estimate of the restraint usage rate for all passenger car occupants.

Estimates of restraint effectiveness also vary between accident files. Although the estimates from the NASS and the NCSS differ by about 10 percentage points, they do agree in that both show restraints to be as effective in injury reduction as in fatality reduction. The North Carolina file estimates do not have this characteristic. The difference between the injury and fatality reduction estimates of 12 points (56-68 percent) is not supported by other data. For this reason, only the NCSS and NASS estimates are used in arriving at an overall estimate of effectiveness. The NASS estimates of injury reduction (60 and 63 percent) and fatality reduction (61 percent) and the NCSS corresponding values of 50, 53, and 49 percent have an approximate average of 56 percent. The overall, working number estimate of the effectiveness of restraints in reducing serious injuries and fatalities is thus 56 percent.

LIFE SAVING AND INJURY REDUCING POTENTIAL OF RESTRAINTS

Restraints save lives and reduce injuries. The extent to which restraints do this depends on the restraint usage rate and the effectiveness of restraints. The overall estimates given in the previous section not only make it possible to estimate the benefits of restraints under the current usage rate, but also the potential benefit of increased usage. An estimate of the number of lives saved per year for usage rate R and effectiveness E is given by the formula:

$$\text{Lives Saved} = \frac{F}{1 - RE} - F,$$

where F is the actual number of car occupant fatalities per year.

For an estimate of the reduction in the number of serious injuries, the number of seriously injured is substituted for F. In each of the past several years, the number of fatalities in the U.S. has been about 27,000 and the number of seriously injured (AIS 3-6) about 200,000. For the current estimates of usage and effectiveness, R = 8% and E = 56%,

$$\text{Lives Saved} = \frac{27{,}000}{1 - .08\ (.56)} - 27{,}000$$

$$= 28{,}266 - 27{,}000 = 1266.$$

The 28,266 is an estimate of the number of fatalities there would have been had *no* occupants used their restraints.

For each one percent increase in restraint usage the additional lives saved would be

$$.01\ (.56)\ 28{,}266 = 158.$$

In general, for an R % usage rate, the lives saved would be

$$.01\ R\ (.56)\ 28{,}266 = 158\ R.$$

Thus, for 100% usage, an estimated 15,800 lives would be saved.

The injury reduction estimates are obtained in the same way.

$$\text{Injury Reduction} = \frac{200{,}000}{1 - .08\ (.56)} - 200{,}000$$

$$= 209{,}380 - 200{,}000 = 9380.$$

$$\text{Reduction (1\% usage increase)} = .01\ (.56)\ 209{,}380 = 1173$$

$$\text{Reduction (R \% usage)} = 1173\ R$$

$$\text{Reduction (100\% usage)} = 117{,}300$$

It should be noted that the results obtained for the 1 percent increase in restraint usage can only be realized if occupants of vehicles that will be towed increase their usage rate by 1 percent. If the entire 1 percent increased usage occurred in the occupants not involved in towaway accidents, there would be no lives saved or injuries reduced. It is thus clear that any campaign to promote restraint usage will succeed only to the extent to which accident involved occupants increase their belt use.

REFERENCES

1. Grimm, Ann C., "Use of Restraint Systems: A Review of the Literature," The HSRI Research Review, University of Michigan Highway Safety Research Institute, Ann Arbor, MI, Vol. II, Nos. 2 & 3, September-October/November-December 1980, pp. 11-28.
2. Auto Industries Highway Safety Committee, Washington, D.C., "Seat belt installation up, use down, nationwide survey reveals," October 1967.
3. Griffin, Lindsay I. III, "Analysis of the Benefits Derived from Certain Presently Existing Motor Vehicle Safety Devices: A Review of the Literature," University of North Carolina Highway Safety Research Center, Chapel Hill, North Carolina, December 1973.
4. Reinfurt, D. W., Silva, C. Z., Seila, A. F., "A Statistical Analysis of Seat Belt Effectiveness in 1973-1975 Model Cars Involved in Towaway Crashes," DOT-HS-802-035, September 1976.
5. Campbell, B. J., Reinfurt, Donald W., "The Degree of Benefit of Belts In Reducing Injury—An Attempt to Explain Study Discrepancies," SAE Technical Pa-

per Series Number 790684, Warrendale, Pennsylvania, June 1979.
6. "National Accident Sampling System (NASS) Analytical User's Manual, 1979 File," National Center for Statistics and Analysis, National Highway Traffic Safety Administration, Washington, D.C., October 8, 1980.
7. Partyka, S., "NCSS—The Analyst's Companion," DOT-HS-805-871, National Highway Traffic Safety Administration, Washington, D.C., April 1981.
8. "Fatal Accident Reporting System 1980," DOT-HS-805-953, National Center for Statistics and Analysis, National Highway Traffic Safety Administration, Washington, D.C., October 1981.
9. Chi, George Y. H., Reinfurt, Donald W., "A Comparison of the Automatic Shoulder Belt/Knee Bolster Restraint System with the Lap and Shoulder Belt System in VW Rabbits," DOT-HS-805-856, March 1981.
10. Phillips, Benjamin M., Unpublished "Progress Report on Contract DTNH22-80-C-07283, Restraint System Usage in the Traffic Population," August 18, 1982.

The Main Causes of Risk Differences for Restrained Drivers and Their Restrained Front Passenger in Frontal Collisions

C. THOMAS, G. FAVERJON, C. TARRIÈRE, F. HARTEMANN
Laboratory of Physiology and Biomechanic of Peugeot S.A./Renault Association

C. GOT, A. PATEL
I.R.O.-I.R.B.A.-Hôpital R. Poincaré 92380-Garches-France

ABSTRACT

In large samples, differences in terms of death rate or injury patterns between drivers and front passengers are not entirely due to the presence of the steering system. Numerous biases such as differences in frontal violence, asymmetrical intrusion, age effect or rear over-loading must be eliminated first before a risk comparison between belted front occupants involved in frontal car accidents.

The possible over-risk for the driver due to the steering system can be stressed if the driver's situation is compared with that of his front passenger without side effects.

This comparison is made on a sample of 337 cars involved in frontal collision. No significant difference is observed between the proportion of severe injuries among drivers and their front passenger, but on one hand, thoracic injuries are more frequent for the front passenger and on the other hand, severe injuries to the head are more frequent for drivers.

It cannot be assumed that the steering system generates a manifest over-risk for drivers.

INTRODUCTION

In frontal collisions in the PEUGEOT S.A./RENAULT multidisciplinary investigation, 3-point belted death rates of 3,7 and 3,0 are respectively observed among the 1018 drivers and the 525 right front passengers.

Various reasons can explain the difference:

—presence of a steering system
—greater violence of frontal collisions for the 46% of cars having just the driver on board (Figure 1)
—the higher frequency (near 50%) and the severeness of the intrusion phenomena on the driver's side be-

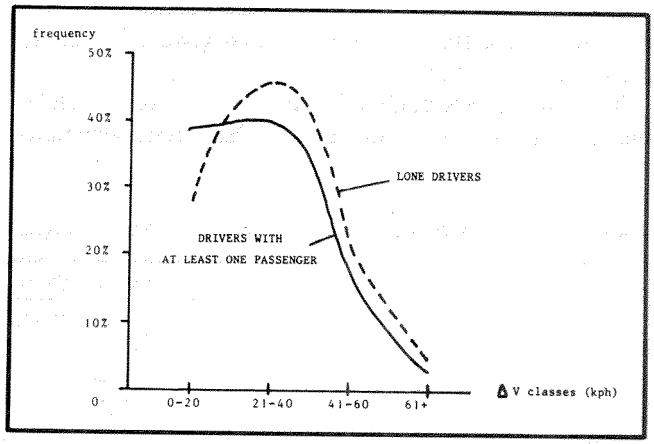


Figure 1. Frequency comparison of ΔV in frontal accidents according to the presence of one passenger or not (N = 1 786 cars).

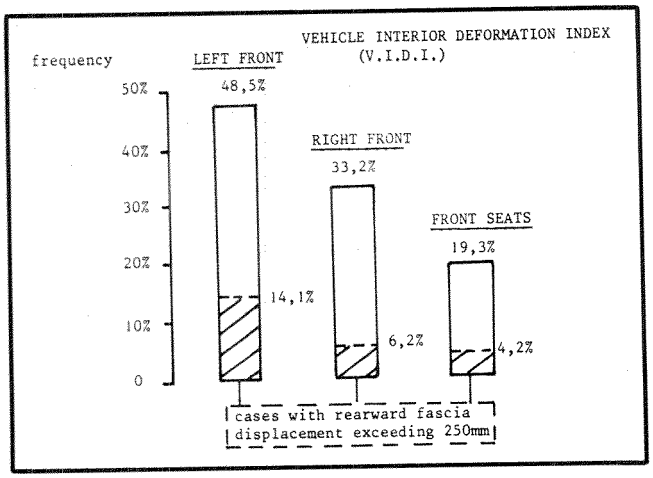


Figure 2. Distribution (in %) of intrusion phenomena in frontal car collisions (N = 904 cars).

cause of the higher number of head-on collisions with offset to the left front of the cars (Figure 2).

So, it is not surprising to find rather different injury rates between restrained front occupants especially if overload by a rear adult is taken in account as shown in Table 1. The increasing order of death rate for restrained front occupants involved in frontal collision is as follows:

—front passenger without overload	2,4
—driver accompanied without overload	3,3
—lone driver	4,0
—drivers with overload	4,1
—front passengers with overload	4,4

The absence of rear adult overload gives more benefit to the front passenger than to the accompanied driver. The higher relative frequency of intrusion in the driver's compartment, as previously mentioned, is one reason for differences of injury levels. The effect of overload is more pronounced for the front passenger than for the driver's despite the intrusion effect. The reason seems to be the presence of the steering system which gives a benefit to drivers in such cases.

The lone drivers don't, of course, suffer from overload but they sustain higher death rates than front occupants without overload. The explanation is, as previously mentioned, their involvement in higher frontal car crash violence. But it must be mentioned that the death rate of lone drivers is reduced by the fact that they are relatively younger compared with accompanied drivers, but this influence is masked by the fact that their accidents are studied especially when they are sent to hospital. The consequence is that very few of them are taken into the sample when they are uninjured.

The over-risk for the driver due to the steering assembly in frontal collisions can be validly stressed if the driver's state is compared with the front passenger's one, provided all other significant side effects are excluded.

METHODOLOGY

This chapter includes information on:

- characteristics of the selected sample
- frontal violence representativeness of the sample
- disparity between front occupants according to passenger compartment damage
- pair disparity in age and sex
- belt wearing quality disparity
- disparity in rear adult overload

• Characteristics of the two sub-samples used

A sample of 337 cars involved in frontal collisions was drawn from the accident file which contained 3000 frontal car collisions. The selection criteria were as follows;

—two front occupants wearing 3-point belts
—parameters of estimated frontal collision violence, i.e., ΔV (occupant velocity variation) and mean γ (mean vehicle deceleration) (1)

• Representativeness of collision severity in the sample

The sample of 337 selected frontal car collisions differs but little from the whole population from which it is

Table 1. Comparison of injury rates of belted front occupants involved in frontal collisions.

	Drivers (N = 1018)			Front Passengers (N = 525)	
	lone	accompanied with overload	accompanied without overload	with overload	without overload
(N)	(472)	(150)	(396)	(157)	(368)
Death rate	4,0	4,1	3,3	4,4	2,4
0.AIS ≥ 3 Involved	12,1	16	10,8	20,4	11,1

drawn as far as the ΔV of the occupant and the mean deceleration are concerned (Figure 3). There are a little more cases of low violence collision (under 45 kph of ΔV or 10 g) and less at higher violence impacts. This observation is in good agreement with the previous findings about higher frontal violence involvement of lone drivers.

• Disparity between front occupants according to damage to the passenger compartment

72% of pairs are involved without intrusion (or with little reduction of the passenger compartment, less than 150 mm) (Figure 4). This large sub-sample of 266 pairs is the basis of the results obtained. The intrusion cases are separately studied because the steering system effect is masked by the type of intrusion. Moreover, intrusion cases occur mostly in very severe frontal violence impacts as shown in Figure 5.

• Pair disparity in age and sex

The disparity in age between front occupants may induce a bias in the comparison of injuries. A difference of less than 20 years between front occupants is observed in 83% of the cases in which ages are known.

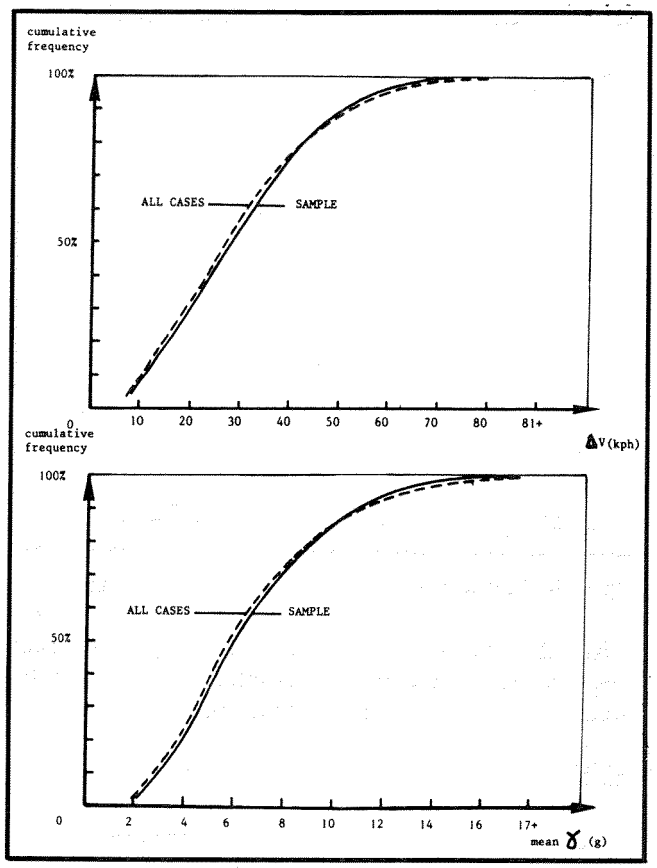


Figure 3. ΔV and mean γ distributions in the sample and in the whole population.

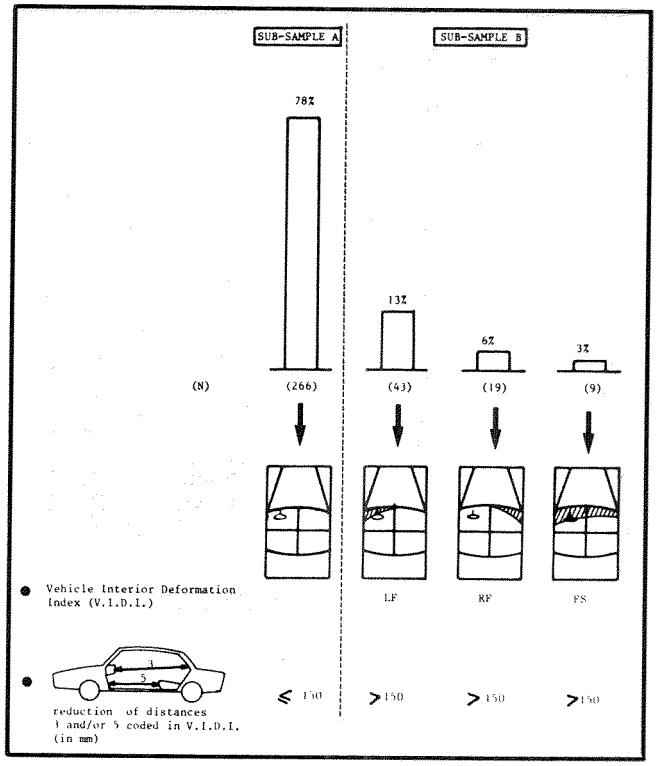


Figure 4. Distribution of the 337 cases of the sample according to front damage of the passenger compartment.

Differences of more than 20 years between front occupants are noted in an equal percentage unfavorable to the driver (9%) and to the front passenger (8%) (Figure 6).

Disparity in sex for driver and front passenger is more obvious. As expected, the front seat occupation—male driver/female front passenger—is frequent (59%)—(Figure 7).

• Belt wearing

In 117 pairs, retractor belts were used. The static belt wearing quality is estimated for 151 out of 220 pairs. Equal conditions of static belt wearing were found in 131 pairs. Unequal conditions were observed unfavorable to the driver and to the front passenger in a similar low percentage (respectively 3% and 5%) (see Figure 8).

• Adult rear overload comparison

Similar conditions for front occupants are observed in 82% of the pairs. The higher frequency of adults (≥ 10 years) in the rear right passenger seat explained the small high frequency of overload for the right front passenger compared with that of the driver (respectively 11% and 7%) (see Figure 9).

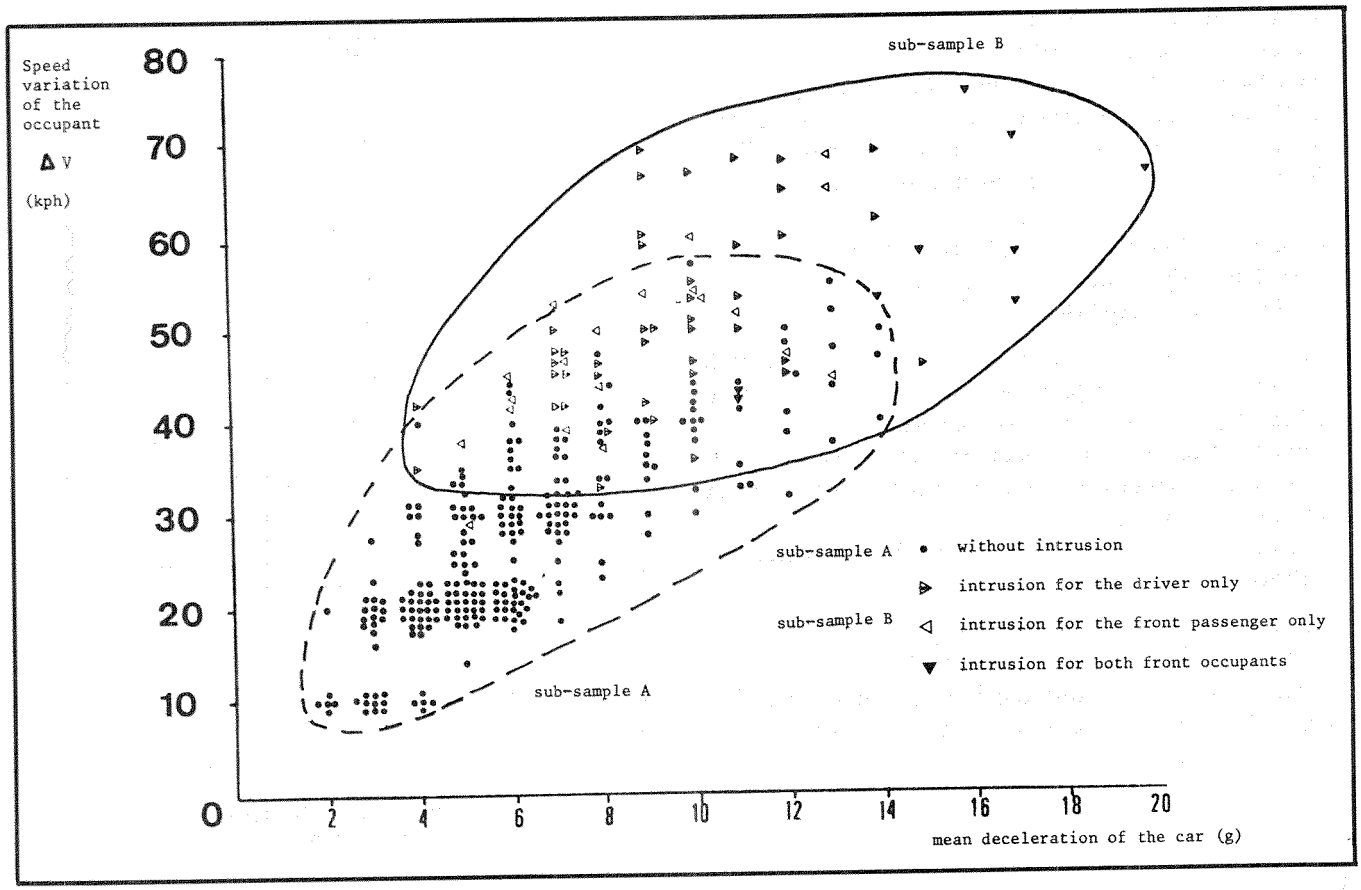


Figure 5. Diagram "ΔV-mean γ" according to damage to the passenger compartment in the studied sample.

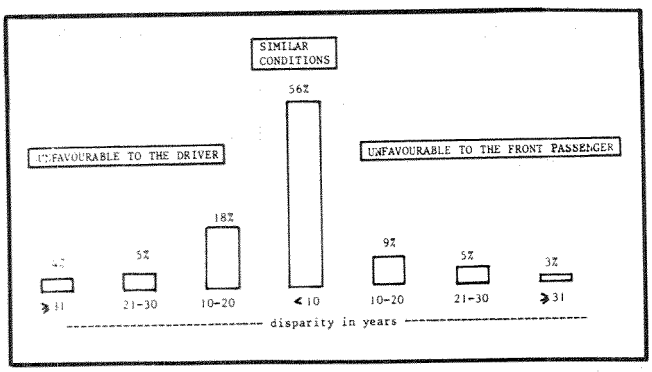


Figure 6. Age class comparison (71 cases unknown).

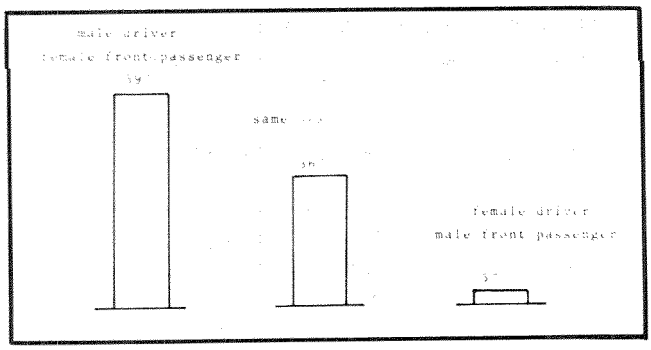


Figure 7. Sex disparity in pairs (41 cases unknown).

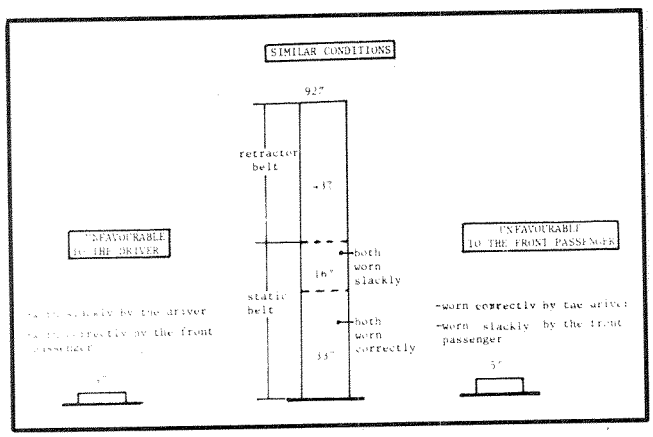


Figure 8. Belt wearing (unknown: 31 static belt cases).

Results are given now separately for the two sub-samples according to the presence of intrusion (or not) in the front part of the passenger compartment.

RESULTS

Results are given first for the 266 pairs without intrusion involved in the lower range of the frontal violence spectrum and secondly for the 71 pairs with intrusion involved in high violence car accidents. Effects of restraint

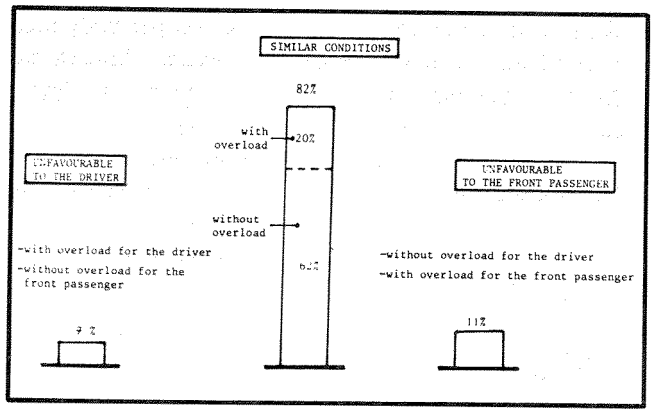


Figure 9. Adult rear overload comparison.

type (static or retractor belt) or overload is especially taken into account.

COMPARISON OF INJURIES BETWEEN THE 266 RESTRAINED DRIVERS AND THEIR RESTRAINED FRONT PASSENGERS IN FRONTAL COLLISIONS WITHOUT INTRUSION (or less than 150 mm)—SUB-SAMPLE A—

The comparison of the 266 pairs of front restrained occupants involved in frontal collisions without (or less than 150 mm) is evaluated by;

—the overall injury severity (O.AIS scale)* (2)
—the frequency and severity of injuries per body area (3)

Disparities in Overall Severity of Injuries (O.AIS)

The distribution of O.AIS sustained by drivers and front passengers is given in the following Table 2. As shown in Figure 10, the frequency of severely injured occupants (O.AIS $\geq$ 3) is twice higher among front passengers than for drivers respectively 8,2% and 4,1%. There is no difference of O.AIS between front occupants in half of the sub-sample. Differences of two points or more (Δ O.AIS $\geq$ 2) are observed in 12% (33 cases out of 266 pairs) (Figure 11). Δ O.AIS $\geq$ 2 is more frequently unfavorable for the passenger (25 cases) than for the driver (8 cases). High differences between front occupants are found in the 174 pairs wearing static belts.

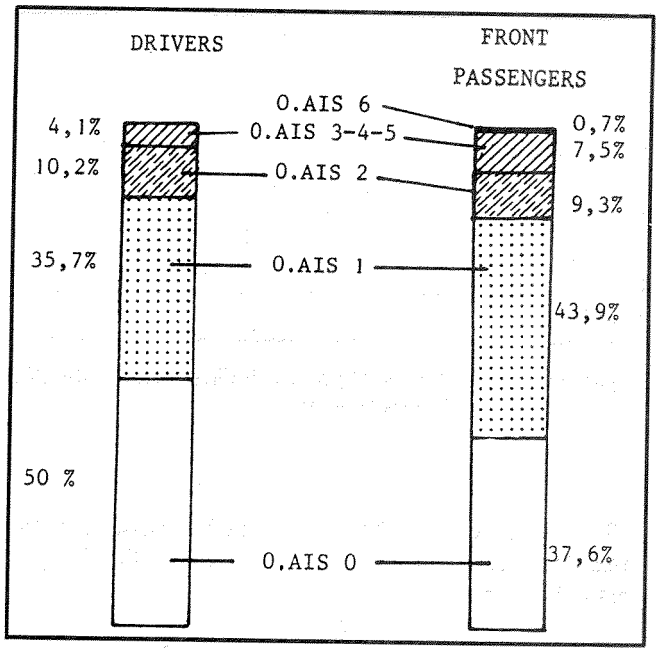


Figure 10. Distribution (in %) of the overall AIS for the 266 pairs of restrained front occupants without intrusion. (Sub-sample A).

O.AIS 2 are found unfavorable 18** times for the passenger against 3 times only for the driver. Among the 92 pairs wearing retractor belts, differences of two points of O.AIS are similar for the driver and the front passenger respectively 5 times and 6 times.

Table 2. Breakdown of overall severeness of injuries (O.AIS) for drivers and their front passenger.

		Drivers							
	O.AIS	0	1	2	3	4	5	6	Total
Front passengers	0	74	26	1	1	0	0	0	102
	1	44	52	17	2	1	1	0	117
	2	9	9	4	1	2	0	0	25
	3	5	5	3	2	0	0	0	15
	4	0	3	1	0	1	0	0	5
	5	0	0	0	0	0	0	0	0
	6	1	1	0	0	0	0	0	2
		133	95	27	6	4	1	0	266

* In this scale, except for fatal cases (code 6) there isn't significant change with the maximum AIS.

** One killed front passenger wearing a static belt was not autopsied. So, the pair is eliminated from the sub-sample of 266 cases as regards the following analysis.

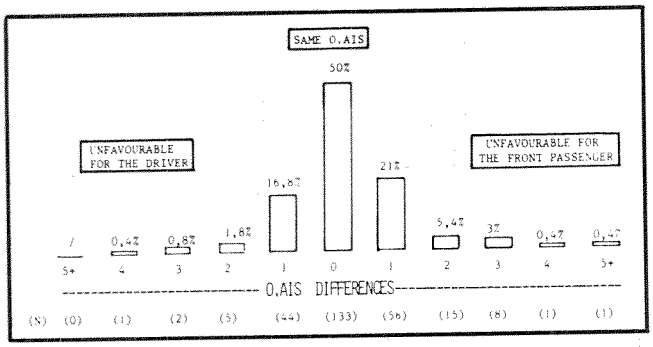


Figure 11. Distribution (in %) of O.AIS differences in the 266 pairs (Sub-sample A).

Table 3 gives, for the driver and his passenger, the breakdown of the body area making the Δ O.AIS ≥ 2 versus belt type.

It is pointed out that slack or poor geometry in some cases of static belts affects much more the front passenger than the driver, especially the thorax, abdomen and members. This phenomenon is reduced for the retractor belt group. Differences according to areas will now be analysed.

Injuries Per Body Area

Differences Between the Driver Group and the Passenger Group

Severe injuries (AIS $\geq$ 3) were more often sustained by front passengers than by drivers—25 severe injuries were found among the passenger group against only 15 in the driver group. Injuries more than minor (AIS $\geq$ 2) are also more frequently sustained by front passengers (n = 67) than by drivers (n = 51).

As shown in Figure 12, the comparison per body area between front occupants revealed noticeable differences.

Drivers sustained relatively more injuries to lower members and head. For the front passenger, abdomen, thorax and upper members suffer more serious injury.

These results highlight that the presence of the steering system changes the pattern of injuries for the front occupants. But it cannot be assumed that this change is unfavourable for the driver.

Differences in Risk Per Body Area for the Driver and His Respective Passenger in the 265 Pairs

Differences in AIS per body area for pairs of belted front occupants are given in Table 4.

Differences of 4 points of AIS are found for the head (unfavourable to the driver), neck and abdomen (unfavourable to the driver).

Numerous cases of differences of 2 or 3 points of AIS are found for the thorax and upper members (unfavourable to the passenger).

The difficulty of this table is due to the fact that the AIS scale is not linear. However, differences of 3 points of AIS are not equivalent between AIS 5 and AIS 2 between AIS 3 and AIS 0, but in the Table 4, such cases are taken into account in the same way.

A calculation, per body area, on the basis of a cubic scale for the AIS is given in Table 5 in order to be more realistic and closer to disability and societal cost. The comparison of $\sum$ AIS^3 between drivers and passengers point out that the head, lower members and pelvis are more endangered for the driver than for the passenger. On the contrary, the importance (mix "frequency $\times$ severity") of injuries is relatively higher for the passenger for the thorax, upper members, abdomen and spine.

The highest differences, in terms of $\sum$ AIS^3, were found for the abdomen (one to 10), head and upper members (one to three) and for the thorax and neck (one to two).

Comments about each body segment are now given.

Table 3. Breakdown of the causes of difference of Δ O.AIS $\geq$ 2 versus belt type and body areas between front occupants (n = 32 cases).

Origin of the difference	Static belt (N=21 pairs)		Retractor belt (N=11 pairs)	
	Unfavourable to the driver	f. passenger	driver	f. passenger
Head	1	1	1	0
Neck	0	1	1	1
Thorax	1	6	1	2
Upper members	0	3	1	2
Abdomen	0	4	0	0
Thoracic-lumbar spine	0	0	0	1
Pelvis	0	0	0	0
Lower members	1	3	1	0
Total	3	18	5	6

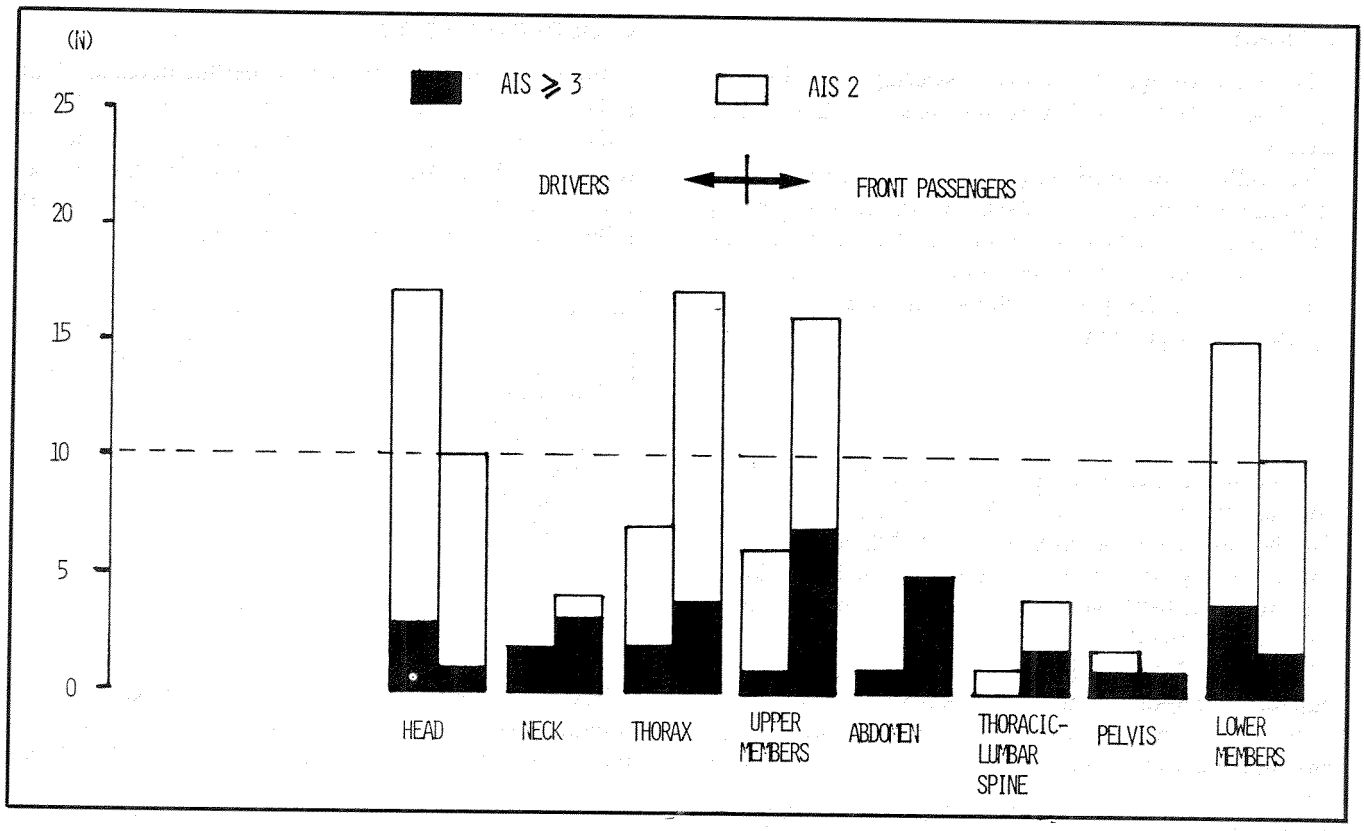


Figure 12. Number of AIS $\geq$ and AIS 2 versus body areas for the 265 drivers and their respective front passengers.

Table 4. Differences in AIS for the 265 pairs.

AIS	Unfavourable for drivers				Equal		Unfavourable for front passengers				
	5/0	4/2	3/0	2/13	1/25	0/192	1/29	2/4	3/0	4/0	5/0
Head	0	0	2	0	10	223	26	2	1	0	1
Neck	0	0	1	3	18	182	48	11	2	0	0
Thorax	0	0	1	3	8	212	28	7	6	0	0
Upper members	0	0	1	0	1	243	15	0	1	4	0
Abdomen	0	0	0	1	7	243	10	3	1	0	0
Thoracic-lumbar spine											
Pelvis	0	0	0	1	8	249	7	0	0	0	0
Lower members	0	0	0	6	37	184	33	4	1	0	0

Table 5. Breakdown of injuries to drivers and their front passengers according to frequency and seriousness per body area.

DRIVERS								FRONT PASSENGERS						
	0	2	3	4	5	ΣAIS^3		0	1	2	3	4	5	ΣAIS^3
207	41	14	1	1	1	369	HEAD	217	38	9	1	0	0	137
246	17	0	1	1	0	108	NECK	228	33	1	2	0	1	220
205	53	5	0	2	0	221	THORAX	167	81	13	3	1	0	330
237	22	5	1	0	0	89	UPPER MEMBERS	210	39	9	7	0	0	300
262	2	0	1	0	0	29	ABDOMEN	244	16	0	1	4	0	299
256	8	1	0	0	0	16	THORACIC-LUMBAR SPINE	251	10	2	2	0	0	80
254	9	1	1	0	0	44	PELVIS	256	8	0	1	0	0	35
198	52	11	4	0	0	248	LOWER MEMBERS	196	59	8	2	0	0	177

• Head

Drivers head injuries are due to steering wheel impact. The 3 AIS HEAD $\geq$ 3 were sustained by static belted drivers.

The AIS 3 to the head of a passenger wearing a retractor belt was due to impact with the fascia which moved eighty millimeters rearward in a rather severe frontal collision (ΔV = 40 km/h-mean γ = 10 g).

In this pair, the driver sustained an AIS head 2 due to steering wheel impact.

• Neck

A passenger retractor-belt user was killed in a frontal collision of 50 km/h of ΔV and 12 g of mean deceleration for the car, with rear overload. The AIS neck 5 was a carotid artery occlusion due perhaps to compression of the "shoulder belt" on the neck, according to the doctor. In this case, the driver was uninjured.

AIS neck 2 or 3 are due either to rear overload (occupants or objects) or to head direct impact.

It is noticeable that neck pain is twice more frequent among passengers than among drivers. This must be related to the high frequency (66%) of female front passengers against 12% as drivers. In fact, it is well known that females have an over-risk of neck pain due to their relatively fragile cervical spine, (especially muscles and ligaments).

• Thorax

Rib fractures occurred more frequently among the passenger group than in the driver group. ΔAIS of two points or more are unfavourable to the driver and to the passenger respectively 4 times and 13 times (ΔAIS = 1 respectively 18 times and 48 times). Rear overload is an aggravating factor found in 4 out of the 7 drivers who sustained more than minor thorax injuries (AIS $\geq$ 2) and in 8 out of the 17 passengers with AIS thorax $\geq$ 2. The main reason is that higher restrained forces are applied to the thorax of passengers. This fact is in agreement with the lower frequency of lower member injuries of passengers in comparison with drivers. The slack in static belt wearing is one cause of this disparity as shown in the following table:

AIS Thorax $\geq$ 2.

	Drivers	Passengers
Static belt (173 pairs)	3	12
Retractor belt (92 pairs)	4	5

Retractor belt usage reduces sharply differences of thorax injuries between front occupants.

• Upper members

Injuries more than minor to upper members are found 6 times for drivers and 16 times for passengers. This, the unfavourable result for front passengers, is due to fractures to the hand areas mainly caused when the occupant tries to brace himself or herself against the fascia. The following table gives AIS $\geq$ 2 injuries to front occupants.

	Drivers	Front passengers
Finger fractures (metacarpus)	3	2
Radius fractures (including Colles)	0	10
Clavicle fracture	1	2
Shoulder dislocation	1	2

• Abdomen

Five static belt passenger wearers sustained severe abdominal injury due to the lap belt (4). Slack wearing and poor geometry of some static belts associated with rear overload in four out of the five cases may explain this result. The reason why their drivers did not sustain any abdominal injury is probably due to the knee contact with the lower panel or the steering column which limited forward displacement of the body and decreased the restraining forces applied by the belt by energy dissipation through knees contacts.

A bladder rupture (AIS = 3) to a retractor belted driver with rear overload isn't well explained.

• *Thoracic-lumbar spine:* Differences of injuries to this body segment are unfavourable to passengers in two passengers cases, the role of the lap belt as cause of fractures of T12 in the first case, and L1 in the second one is highly probable. In the two cases with fractures respectively of T11 and T12 the role of the lap belt is possible but more questionable. The mechanism of injuries through lap belt penetration in the abdomen is the same as previously described for passenger abdominal injuries.

For drivers, only one case was recorded. It was a spinous process lumbar fracture probably due to the lap belt. It is interesting to notice that three out of the five thoracic-lumbar spine fractures occurred with retractor belt types and not only with static belts. This observation leads one to think that the pelvis isn't well restrained by the lap belt and even with a retractor belt in cases of poor geometry.

• *Pelvis:* More than minor pelvis injuries among belted front occupants involved in frontal collision without intrusion are rare. In the sub-sample, the only two AIS $\geq$ 2 were hip dislocations (one to the driver and one to the front passenger). They were found in the same pair of front occupants wearing slackly static belts.

Such injuries due to knee impacts under the panel in such conditions are eliminated by retractor belts with good restraint geometry.

- Lower members

15 AIS $\geq$ 2 were found among drivers against 10 AIS $\geq$ 2 among front passengers. Differences of more than than minor injuries between belted front occupants are reduced with retractor belts in relation to static belts as shown in the table.

	Drivers	Front passengers
Static belts (n = 173 pairs)	11	7
Retractor belts (n = 92 pairs)	4	3

Results concerning the 71 pairs with intrusion in the passenger compartment are now given here after.

COMPARISONS OF INJURIES BETWEEN THE 71 RESTRAINED DRIVERS AND THEIR RESPECTIVE RESTRAINED FRONT PASSENGERS—IN FRONTAL COLLISIONS WITH INTRUSION (more than 150 mm)—SUB-SAMPLE B—

The three types of frontal intrusion inside the passenger compartment in accordance with the Vehicle Interior Damage Index (V.I.D.I.) are:

Left Front (LF): intrusion in the driver compartment
Right Front (RF): intrusion in the front passenger compartment
Front Seats (FS): intrusion for both front occupants.

These various kinds of damage to the passenger compartment masked the steering system influence in the comparison of injuries in the 71 pairs of belted front occupants.

Disparities in Overall Severeness of Injuries (O.AIS)

The severeness of injuries to drivers and their passenger depends on the location of the intrusion (Fig. 13). Death rate and O.AIS $\geq$ 3 frequencies versus various types of intrusion for drivers and their respective passengers are given in the following table:

	V.I.D.I.	Left front	Right front	Front seats
Death Rate	Drivers	23%	10%	33%
	Front passengers	7%	16%	22%
O.AIS $\geq$ 3 Frequency	Drivers	60%	26%	89%
	Front passengers	42%	48%	55%

In "Front Seats" (FS) intrusion cases, severeness of injuries is very high due to the highest frontal violence, especially in mean deceleration of the car (See Figure 5). In such cases, intrusion effect affected both front occupants, but the rearward movement of the fascia is more frequently higher on the driver's side. The little number of recorded cases prohibits any conclusion regarding this point.

Differences in O.AIS between the 71 Pairs with Intrusion

Comparison results of Overall AIS differences in various types of intrusion are given in Figure 14. This doesn't indicate a significant over-risk for drivers as far as intrusion type is concerned.

Intrusion differences (measured at the upper panel sides) between left front and right front part of the passenger compartment are given versus Overall AIS differences for the 71 drivers of the sub-sample in Figure 15. It is obvious that O.AIS differences for the driver are mainly related with front intrusion differences.

Comparisons of Head Injuries between Drivers and Their Respective Passenger in Intrusion Cases

This study is focused only on head injuries, which is the body area mainly affected by the presence of the steering system.

Comparisons of head injuries between front occupants are given in Table 6. When the intrusion concerns the driver compartment, 5 AIS Head $\geq$ 3 out of 34 drivers were found for the driver against only one among passengers. This tendency is reversed as far as front passenger compartment intrusion cases are concerned.

The over-risk of severe head injuries to belted drivers (compared to the consequences to belted front passengers) is not entirely due to the steering wheel. Only two out of the seven known severe belted driver head injuries were due to steering wheel impact. "A" pillar, fascia and hood provided the five other cases. The low percentage of steering wheel impacts in severe accidents was found also by Gloyns et al. (5). They found 9% of steering wheel head impacts among a representative sample of fatally injured restrained drivers.

All the seven severe driver's head injuries of the subsample with intrusion are plotted in the Figure 16 which

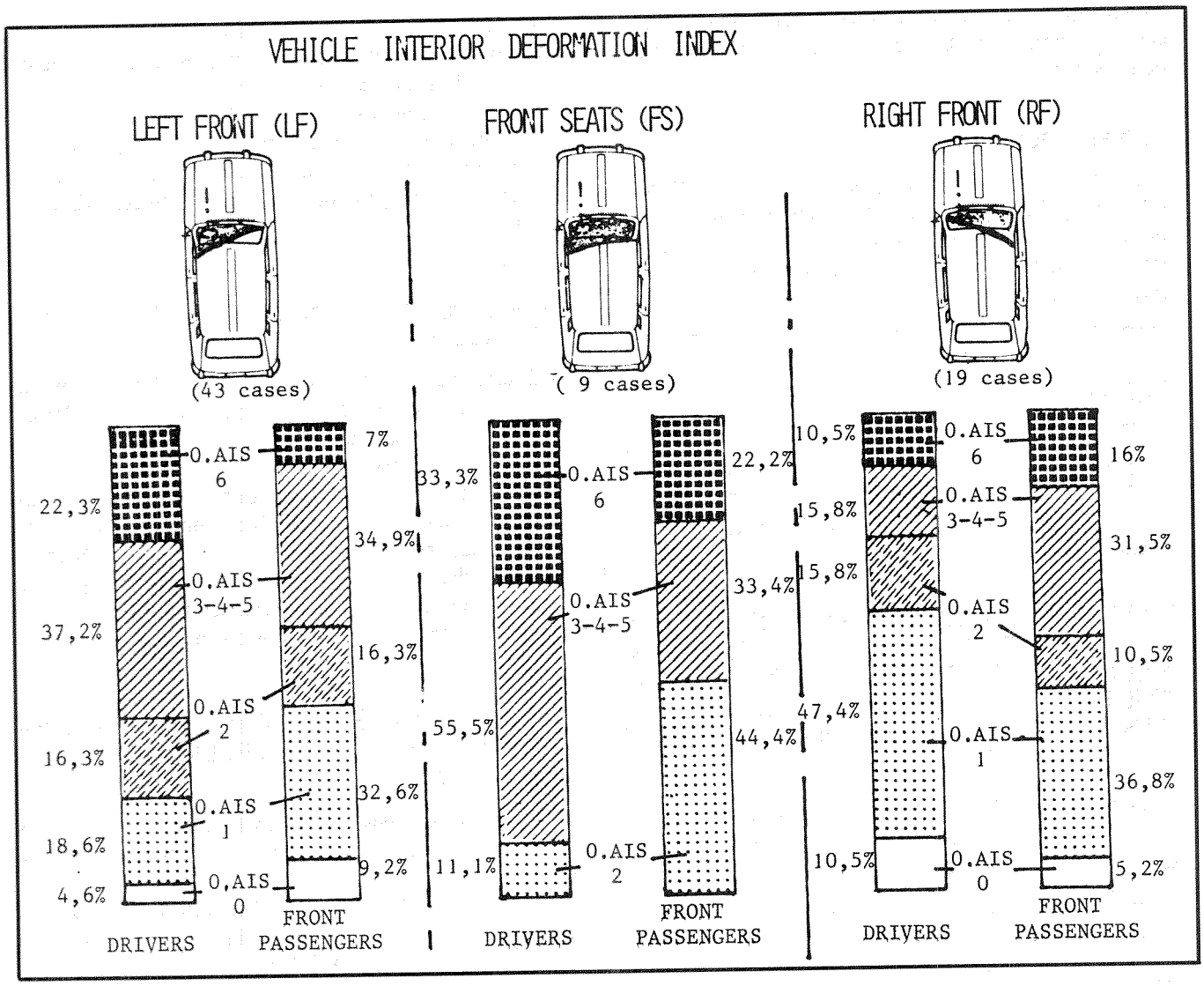


Figure 13. Distribution (in %) of the injury severeness (O.AIS) versus the three different types of intrusion.

gives the upward and backward displacements of the steering wheel.

CONCLUSIONS

Before evaluating the specific influence of the steering system on restrained drivers involved in frontal collisions, a sample of 337 cars (266 without intrusion and 71 with) was formed to compare the state of drivers with their *respective* front restrained passengers.

The presence of the steering column is the main difference between the two belted front occupants. A second difference related to the over-representation of male drivers (88%) and the over-representation of female passengers (66%) also holds.

Differences in age, quality of belt wearing and rear adult overload are not significant. A comparison of pairs of front restrained occupants gives the following results:

—Front passengers are rather more severely injured than drivers. The percentage of O.AIS $\geq$ 3 is respectively 4,1% for the driver and 8,2% for the passenger. The percentage of uninjured is respectively 50% for the driver and only 37% for the passenger.

Equal O.AIS are observed in only half of the 266 pairs without intrusion. Differences of two degrees of O.AIS is observed in 33 pairs (12%). The ΔO.AIS $\geq$ 2 is unfavourable 22 times to the front passenger and 11 times to the driver.

—Lesser differences of O.AIS are observed for front occupants wearing retractor belts compared to those wearing static belts in the sample without intrusion. The elimination of slack in the belt wearing is the first explanation. Poor geometry of belt restraining

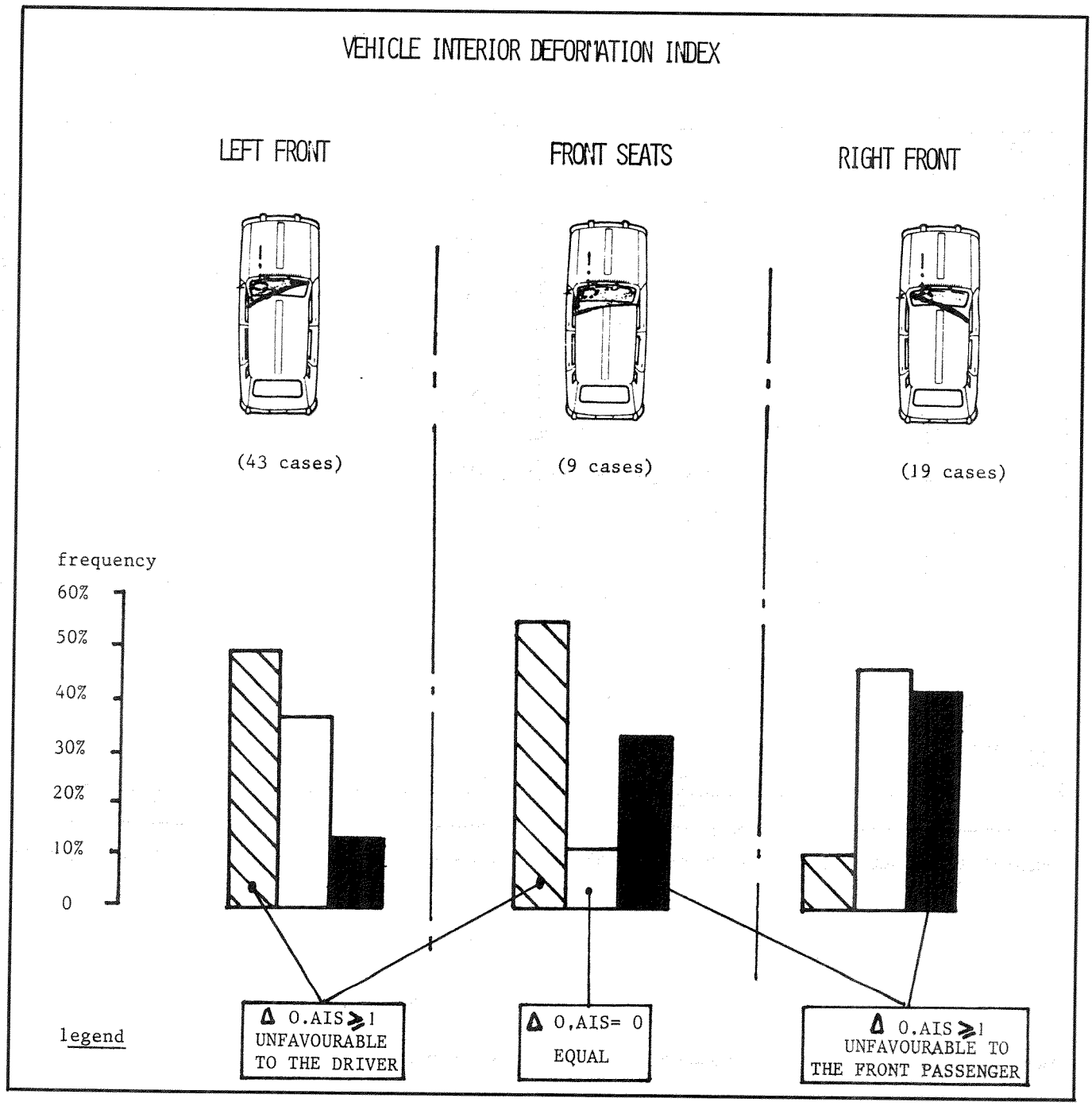


Figure 14. Breakdown (in %) of Δ O.AIS between belted front occupants versus various types of intrusion.

still exists among retractor types but the proportion is lower than with old static belt types.

—The most affected body areas are, in decreasing order: head, lower members and thorax for drivers and respectively thorax, members and abdomen for front passengers. The reason for these differences seems to be that restraining forces are entirely applied to the passenger belt whereas the driver braces himself against the steering wheel and has lower members contacts which may decrease the forces applied to the thorax.

—In the sample with large intrusion, severeness of injury is closely related to the type of intrusion, either in the driver compartment or in the passenger one. Severe "head-steering wheel" impact occurred mainly into displaced rearward and upward steering wheels in very severe frontal accidents.

In short, when there is no considerable intrusion, it

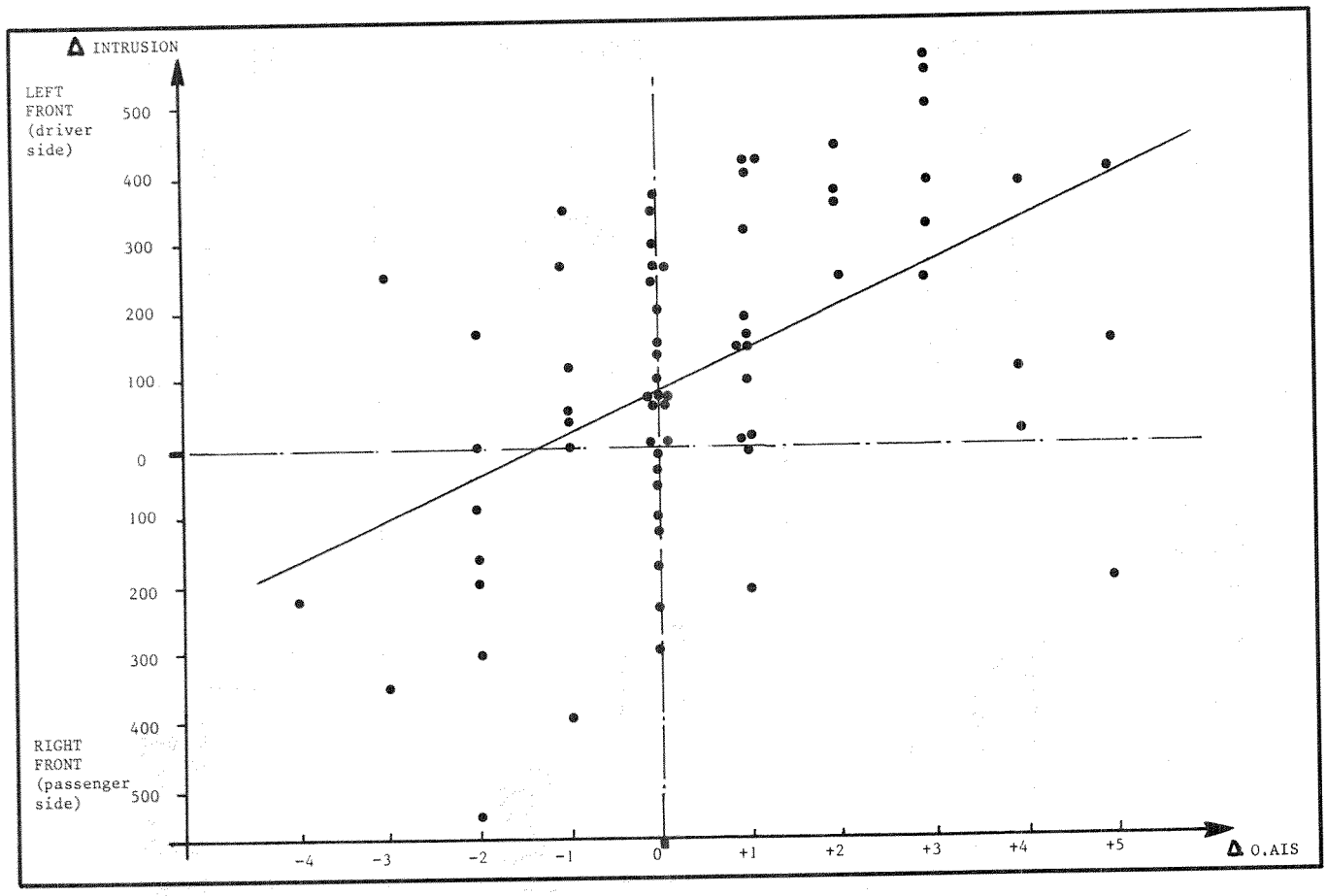


Figure 15. Overall AIS differences versus intrusion differences for the 71 drivers of the sub-sample B (compared to their respective passengers).

Table 6. AIS Head for belted front occupant (pairs) in various types of intrusion.

		AIS head						N AIS ≥ 3	Σ AIS³
		0	1	2	3	4	5		
LF (34 pairs*)	drivers	7	13	9	3	0	2	5	416
	passengers	22	5	6	1	0	0	1	80
RF (17 pairs*)	drivers	8	7	2	0	0	0	0	23
	passengers	5	10	1	0	0	1	1	143
FS (7 pairs*)	drivers	1	2	2	0	0	2	2	268
	passengers	4	1	1	0	1	0	1	73

* The lack of autopsies for some killed front occupants eliminates 9 pairs in LF intrusion, 2 pairs in RF intrusion and 2 pairs in FS intrusion.

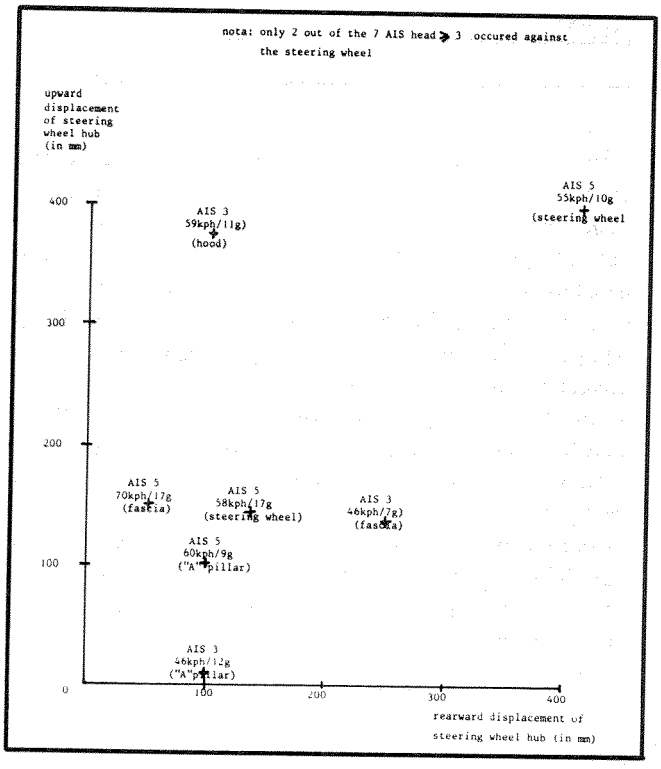


Figure 16. AIS driver head ≥ 3 in intrusion cases in the driver compartment versus displacement of the steering wheel.

cannot be assumed that the steering system generates a manifest over-risk of serious injury for belted drivers.

Findings suggest that a better ride-down of the belted occupant with the passenger compartment and good geometry of the belt system are still needed and thus would make it possible to decrease the frequency and severeness of head, abdomen and lower member injuries and, moreover, restraint thoracic forces.

Improvement of the steering system especially in the lower panel and of the steering wheel would contribute to give to restrained drivers a good protection which may be higher than for front passengers, when there is no or less intrusion.

These conclusions for driver protection are in agreement with criteria for the planned frontal integrated test in which on one hand, femur loads will be measured and on the other hand, head impact violence will be controlled by the Head Injury Criterion. This test could be usefully associated with a criterion on the basis of a dummy driver facial model.

REFERENCES

1. C. Tarrière, A. Fayon, F. Hartemann and P. Ventre. "The Contribution of Physical Analysis of Accidents Towards Interpretation of Severe Traffic Trauma". Proceedings of 19th STAPP Car Crash Conference, Nov. 17-19, 1975, San Diego, California.
2. Joint Committee on Injury Scaling of Society of Automotive Engineers, American Medical Association and the American Association for Automotive Medicine. "The Abbreviated Injury Scale (1975 revision)". In Proceedings of the 19th AAAM. Conference San Diego, California, November 20-22, 1975.
3. Committee on Injury Scaling. "The Abbreviated Injury Scale 1980 Revision" Booklet published by the American Association for Automotive Medicine.
4. Y. C. Leung, C. Tarrière, C. Got and A. Patel. "Abdominal Injuries of 3-Pt. Belted Occupants in Frontal Collisions: Description, Mechanisms and Protection". Proceedings of 26th STAPP Car Crash Conference, October 20-21, 1982, Ann Arbor, Michigan.
5. P. F. Gloyns, S. J. Rattenbury, A. Z. Rivlin, H. R. M. Hayes, J. K. Hanstead and S. Proctor. "Steering wheel induced head and facial injuries amongst drivers restrained by seat belts." Proceedings of VIth International IRCOBI Conference on the Biomechanics of impacts. September 8-9-10, 1981, Salon de Provence (France).

Field Performance of Volkswagen Automatic Restraint System (Progress Report)

JOHN D. STATES
Rochester General Hospital,
Department of Orthopedics, USA
WOLFGANG ROSENAU
GEORGE M. WELKEY
Volkswagenwerk AG, Wolfsburg,
W. Germany

ABSTRACT

This paper contains the observed performance of the VW-RA in the field, with respect to mitigation of injuries demonstrated through statistical and narrative data.

The paper reintroduces the constituent components of the system: seat, sensor/retractor mechanism with its attachments to the seat frame, the belt itself, knee bolster and the total vehicle crash management system. Also included will be brief descriptions of those component changes made in the VW-RA since the presentation of the prior data review.

Supportive data include results of 234 real-world accidents.

INTRODUCTION

As of this writing, the passive restraint provision of FMVSS 208 has been reinstated, as a result of litigation brought by insurance interests in the U.S. A Federal Appeals court has ruled that implementation of the provision will be effective with the 1984 model year's vehicles, more specifically September 1, 1983. The NHTSA is currently under the court's direction to advise as to whether the compliance date is capable of being met.

Since 1975, Volkswagen has sold over 500,000 vehicles equipped with the VW-RA system. Volkswagen will continue to offer the VW-RA, as optional equipment on Golf/Rabbit and Jetta vehicles.

The following section summarizes previous papers in providing background information relative to the VW-RA system.

SYSTEM DESCRIPTION

Figure 1 shows the four major subassemblies which comprise the system: torso belt with dual-mode locking retractor, knee bolster, seat and seat belt retractor anchorage components on seat frame. Over the last two years, some small modifications to the components of the Rabbit have taken place, as follows: the knee bolster, formerly a padded steel structure which extended outward from the base of the fascia, has been superseded by a flush-mounted structure of aluminum construction. This new component has the same force/deflection characteristics as its predecessor, and was provided as an element in the overall redesign of the fascia in the vehicles so-equipped (Figure 2). The geometry of the redesigned knee bolster has not been altered, and remains compatible with a dimensional range encompassing the standard fifth percentile female, through the ninety-fifth percentile male.

In addition, the upper latch/release mechanism, formerly fixed, will now be modified to allow it to pivot through a degree range of approximately horizontal motion. This improvement was made to increase the comfort and convenience of the system (Figure 3). The range of motion is approximately 66 degrees.

The other components remain unmodified.

PERFORMANCE IN VW LABORATORY TESTS

Prior to its release for general use in 1975, the entire system was subjected to exhaustive laboratory testing. Frontal impact tests were performed in the range of 50 km/h at 0° and to 30° left and right of center.

Similar tests were performed with dummies restrained by conventional belts. These resulted in slightly higher HIC values for the occupants, due to the greater tendency for head rotation attributable to the three-point restraint, but the overall performance of both systems are almost equal.

VW-RA FIELD PERFORMANCE

This writing presents the actual results of 234 real-world accidents of all types in the United States. The sample is random and derived solely through the cooperation of VW dealer organizations in the U.S. The only criterion for reporting such incidents was a base damage value of US $2,500. No other requirements were given to the participating dealers, in order that the sample might remain uncolored.

Upon receipt of notification of the following, actions were undertaken:

1. The Rabbit vehicle was located, damage documented and deformation extent measured.
2. The collision partner was determined and, where possible, documented.
3. The accident site was visited.
4. Police report, if any, was obtained.

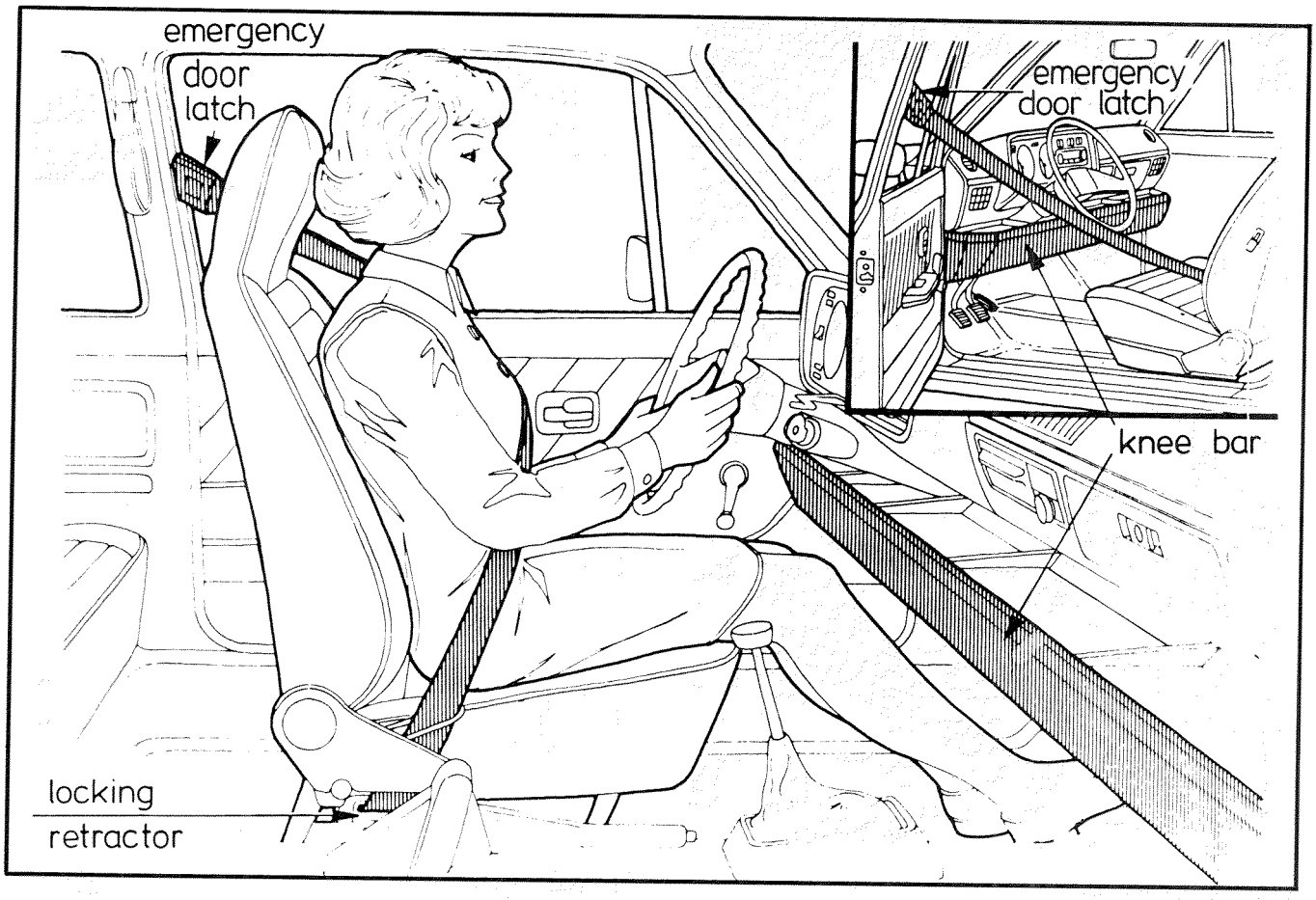


Figure 1. VW-RA Passive Restraint System.

5. Medical records, if any, were obtained.
6. Occupants were interviewed.
7. If applicable, the body shop repair estimate was obtained.

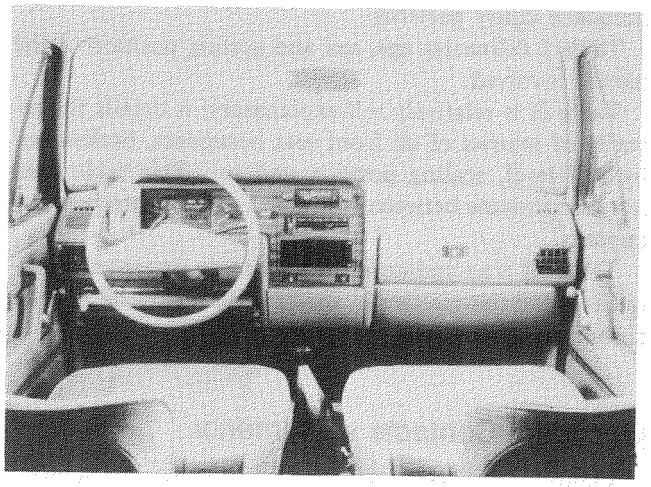


Figure 2. Interior of VW Rabbit with aluminum knee bolster.

ACCIDENT INVESTIGATION RESULTS

Accident Type and Distribution

Figure 4 illustrates in graphic terms the location and direction of impacts of the involved vehicles. The gradation of shadings additionally shows injury severity for the various occupants. We have restricted ourselves only to driver and right front passengers, since they are the ones protected by the VW-RA.

The percentage distribution of accidents by mode is as follows:

Impact Direction	*% Frequency*
Frontal (+45°)	63.7
Lateral (combined R + L)	21.8
Rear	8.9
Rollover	5.6

The usage rate is as follows:

Based on our survey of 234 accidents, the data indicate an observed usage rate of 92.3%; the previously observed rate was 95.4%.

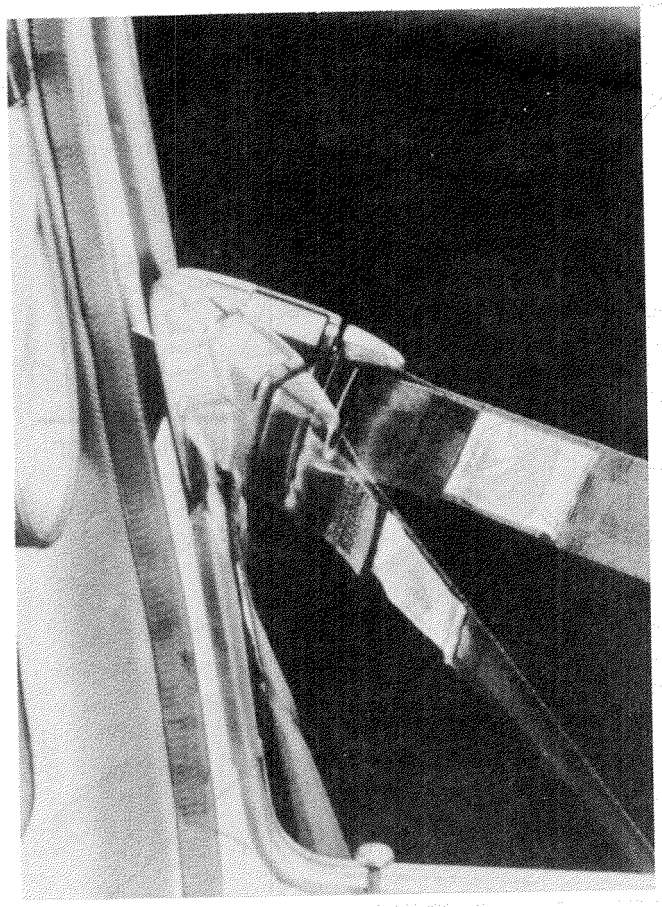


Figure 3. RA II latch.

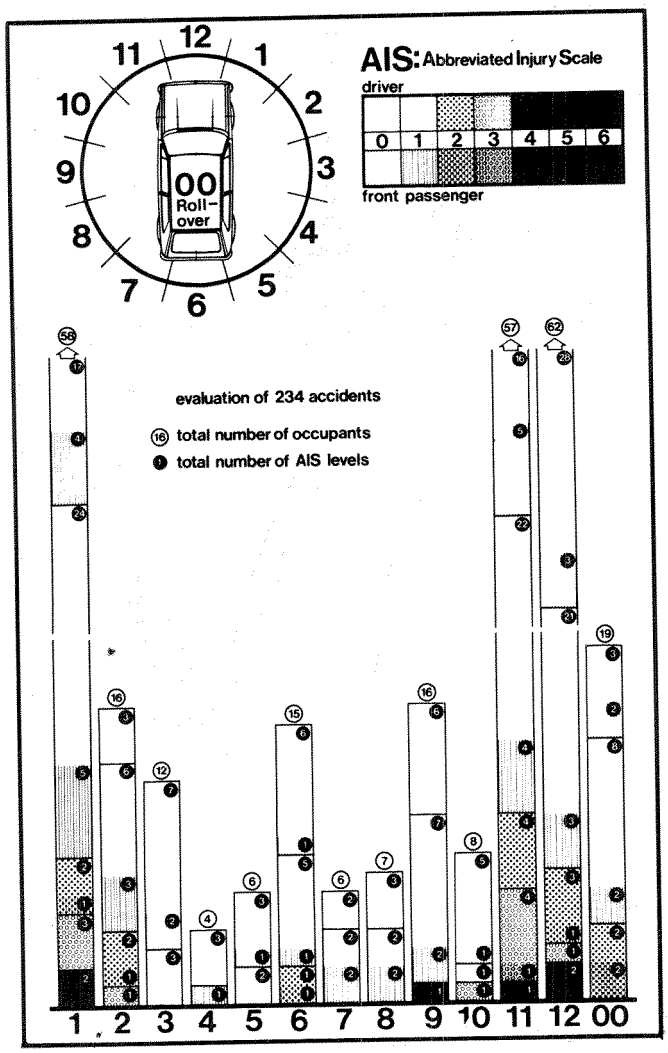


Figure 4. Occupant injury distribution by impact direction.

The question of overall usage rate and possibilities for defeat of the system has not yet been fully resolved. Chi and Reinfurt, in their recent paper, postulate of a range of usage in the area of 55% to 60%, based on a six-state police accident data survey.

Their data show reported usage running from 43% to 73%. In another real-world study, Appleby et al., observed a usage rate of approximately 23%, over a smaller sample size.

Regarding the issue of system defeat, Volkswagen recognizes that there is a population segment which will resist the use of any sort of restraint, irrespective of its efficacy or convenience. Volkswagen feels, however, that making defeat absolutely impossible may present certain problems post-crash.

Volkswagen has opted to make defeat inconvenient, rather than impossible, through the employment of an ignition interlock system. It is significant, however, that even with the potential for system non-use, the usage rate observed remains relatively high.

Frequency and Severity of Injury

Figure 4 is also useful in establishing the statistical dominance of the frontal collision. Such collisions are of particular significance, in that generally, they produce the highest Delta V's and can be expected to produce greater number of injuries.

Sex, age and seating position, among other things, can influence injury patterns.

Table I delineates age, sex and seating position of the parties involved.

Table II is relatively self-explanatory; it details the severity of injuries of all front seat occupants, broken out by AIS-level, seating position and sex. This table does not discriminate between restrained and unrestrained occupants.

Table III is an update of the previously presented injury outline, and summarizes by major body region, all injuries sustained.

Occupant Contacts with Interior

Figure 5 depicts those points in the vehicle interior with which occupants came into contact. There is no

Table 1.

Age group	Total		Driver		Passenger	
	M	F	M	F	M	F
0–15 yrs	2	5	0	1	2	4
16–25	49	29	39	20	10	9
26–45	88	45	81	37	7	8
46–65	38	15	35	11	3	4
66+	4	2	3	1	1	1
unknown	7	2	6	0	1	2
Total	188	98	164	70	24	28

Table 2.

AIS	Total	Drivers		R.F. Passenger Injury ratio + percent				
		M	F	Total	M	F	Driver only	Overall
0	102	77	25	19	9	10	102/234 43,6%	121/286 42,3%
1	103	66	37	25	12	13	103/234 44,0%	128/286 44,7%
2	14	12	2	6	1	5	14/234 6,1%	20/286 7,0%
3	10	6	4	1	1	0	10/234 4,2%	11/286 3,9%
4	5	3	2	1	1	0	5/234 2,1%	6/286 2,1%
	234	164	70	52	24	28		

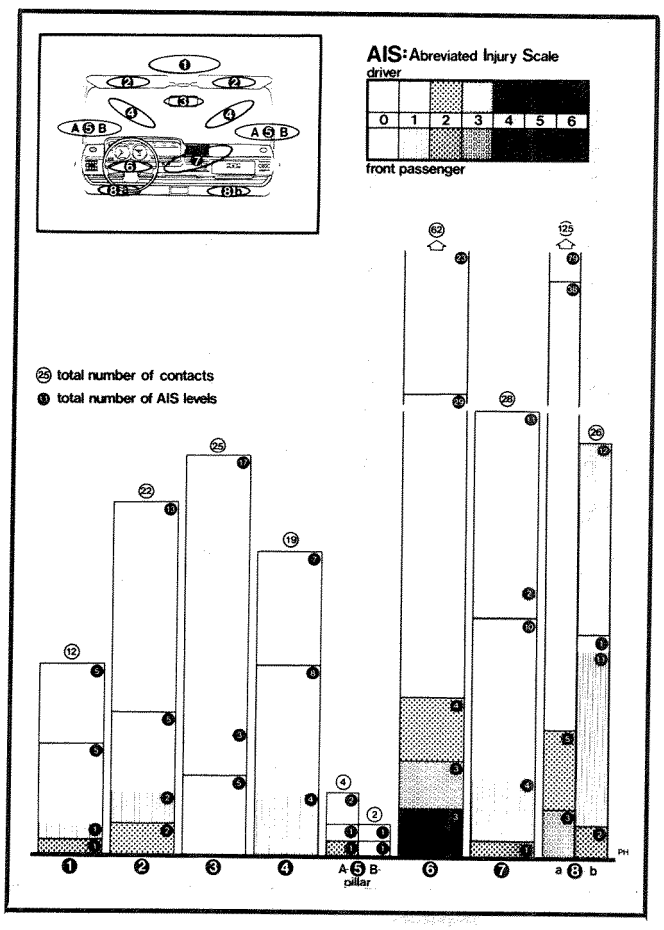


Figure 5. Occupant contact areas with interior in frontal collisions.

Table 3. Injury diagnosis/body regions injured.

	Total	Driver		R.F. passenger	
		With belt	Without belt	With belt	Without belt
Head, excl. face					
Concussion	6	5	0	0	1
Scalp laceration	9	8	1	0	0
Contusion/abr.	13	11	0	1	1
Skull fracture	1	1	0	0	0
Face					
Fracture, deprsd.	2	1	0	1*	0
Laceration	13	8	1	2	2
Contusion/abr.	13	8	0	4	1
Fracture/nose	7	6	0	1*	0
Lac./lips/mouth	4	4	0	0	0
Eye, cornea det.	1	0	0	1	0
Tooth, avulsed	1	1	0	0	0
Neck					
Sprain	37	30	2	5	0
Contusion	4	3	0	1	0
Chest					
Contusion/sprain	39	32	0	6	1
Fracture/ribs	9	8	1	0	0
Fracture/clvl.	5	4*	0	1	0
Fracture/strnm.	3	2	0	1	0
Thoracic spine/sprain	4	4	0	0	0
Pneumothorax/hemothorax	4	3	1	0	0
Hemopneumothorax	1	1	0	0	0
Collapsed lung	1	1	0	0	0
(* one case, apparently bilateral)					
Abdomen					
Bruised kidney	2	2	0	0	0
Contusion	2	2	0	0	0
Hematuria	2	2	0	0	0
Lumbar sprain	3	3	0	0	0
Liver laceration/ Hemorrhage	2	1	0	1	0
Ruptured spleen	1	1	0	0	0
Upper Extremity					
Fracture/shoulder	1	1	0	0	0
Laceration	7	7	0	0	0
Contusion/sprain	41	37	1	3	0
Fracture/wrist	1	0	0	1	0
Fracture/elbow	1	1	0	0	0
Fracture/hand/fingers	3	3	0	0	0
Fracture undet. long bones	1	1*	0	0	0
Torn lig. thumb	1	1	0	0	0
(* arm fractured in 7 places)					
Lower Extremity					
Contusion/sprain	50	37	1	11	1
Fracture/pelvis	4	2	0	1	1
Fracture/femur	2	2	0	0	0
Fracture/foot	2	2	0	0	0
Fracture/tibia/f	3	2	0	1	0
Lacerations	2	2	0	0	0
Patella/cont./abr.	31	23	2	6	0
Torn lig. ankle	1	1	0	0	0
Fracture dislocation of hip	1	1	0	0	0

* Denotes 3½ year old child, using R. A., single accident—lost sense of smell.

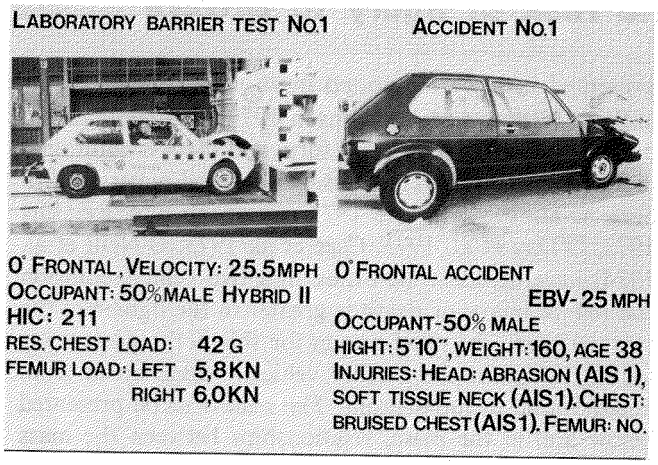


Figure 6.

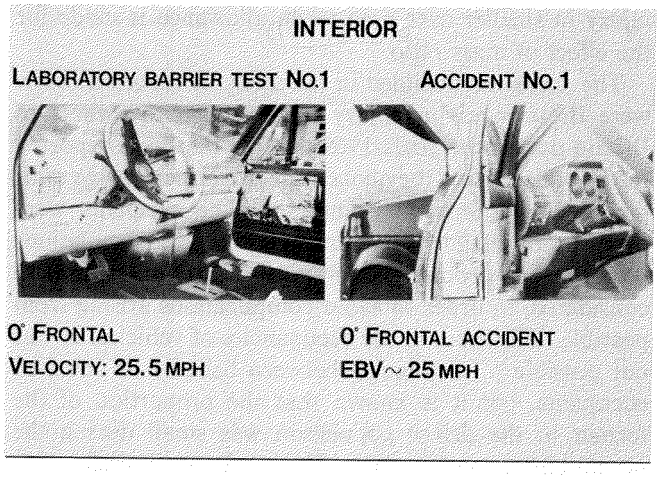


Figure 7.

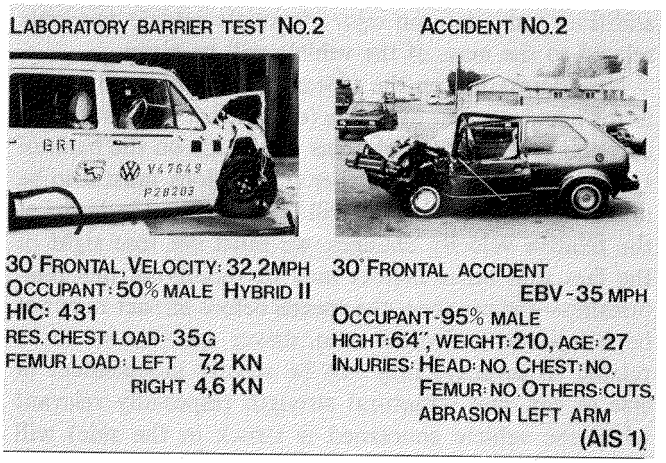


Figure 8.

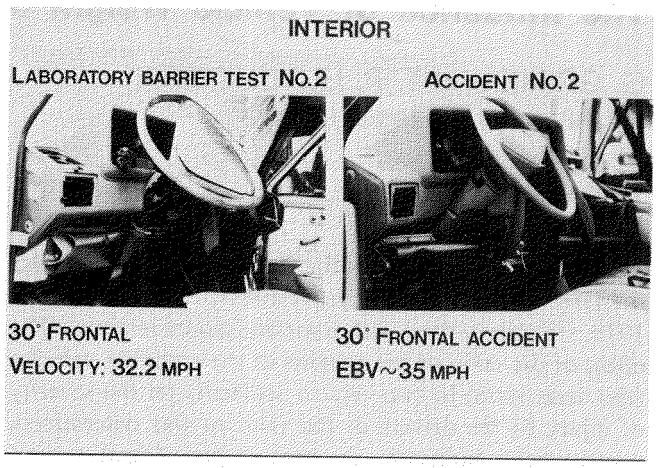


Figure 9.

distinction between belted and unbelted occupants. Significant in this illustration is the relatively high incidence of occupant contact with the knee bolster. This is expected as a function of the system. In conjunction with this, the low number of injuries of the lower extremities is to be noted. Abdominal injuries were uncommon, presumably due to absence of a lap belt.

Comparison of Field Results with Barrier Collisions

This section will be illustrated with photographs of two real-world accidents and comparable barrier impacts (Figures 6 through 9). A significant advantage of accident analysis of this type for a manufacturer is the ability to compare barrier collision tests with the accident field data in order to assign an appropriate EBV. The general correspondence between predicted performance and observed performance is to be noted.

SUMMARY AND CONCLUSION

This paper presents data compiled from a study of 234 actual accidents. The survey and data collection effort have been concluded, for the purpose of this study.

The data continue to sharpen our focus on injury mechanism in real-world accidents. Results achieved have borne out Volkswagen's projections as to the efficacy of the VW-RA. There are approximately 400,000 VW-RA equipped vehicles in current service in the U.S. Use averages about 14,000 kilometres per year.

Volkswagen continues to be gratified by the results generated by the employment of the VW-RA. The system has provided substantially increased usage rates and, thereby, contributed to the overall mitigation of automobile crash-related injuries.

The Influence of Vehicle Weight on the Risk of Injury to Drivers

G. GRIME and T. P. HUTCHINSON
University College, London

ABSTRACT

The results of analyses of the national accident statistics for Great Britain for the years 1969-1972, published in 1979, are summarised with some additional material. The effect of the ratio of the weights of the colliding vehicles (the mass ratio) in two-vehicle accidents on the severity of injury to the drivers of the vehicles was determined, severity being judged by the percentages of fatal, serious and slight injury and of uninjured drivers. The colliding vehicles included in the analysis ranged in weight from the lightest cars (kerb weight about 800 to 1700 lb—350 to 800 kg) to heavy commercial vehicles weighing up to 30,000 lb (13,608 kg). Separate analyses were made for head-on and intersection collisions, both in rural and urban areas. With single-vehicle accidents, these collisions account for most of the fatal and serious injuries in cars and commercial vehicles.

In both types of collision mass ratio was found to have its greatest effect on deaths and least on slight injuries. For example, when one of the vehicles in each of a number of head-on collisions was twice the weight of the other, the percentage of deaths in the lighter vehicles was about 7 times that in the heavier vehicles. For serious injuries the ratio of the percentages was about 3. The ratios for all severities of injury were rather higher in urban than in rural areas. The effect of mass ratio in intersection accidents was similar to that in head-on collisions.

The relation of injury severity to vehicle weight in collisions in which the two vehicles were of approximately equal weight (mass ratio 0.95 to 1.05) was examined, and no effect of weight in reducing deaths or serious injuries was found either in head-on or intersection collisions; there was some indication of an increase in the percentage of deaths in commercial vehicles with weights of 6000 to 30,000 lb (2722 to 13,608 kg). In single-vehicle accidents, whether they were of the overturning or non-overturning type, there was little or no effect of vehicle weight.

INTRODUCTION

This paper is concerned with the relation between size of vehicle and the degree of injury sustained by its driver in road accidents. The complementary question of whether different sizes of vehicle have different rates of involvement in accidents is not dealt with; this is a very difficult question owing to the lack of data on mileage driven by different sizes of vehicle. Most of the results presented here were reported in an earlier paper by the authors (Grime and Hutchinson 1979), but some of the data are set out in a different form and there is additional material on two-vehicle collisions. Several papers (Kihlberg et al. 1964, Grime 1971, Campbell and Reinfurt 1973, O'Day et al. 1973, Case et al. 1973, O'Neill et al. 1974) have demonstrated that, in a two vehicle collision the risk of injury or death is greater in the lighter of the two vehicles. The chief reason for this is the greater velocity change in the smaller vehicle, which arises from conservation of momentum. The results to be presented below are, in the main, relationships between the mass ratio of the vehicles involved and some measure of the drivers injury severity. The effect of vehicle mass itself is also determined. This is particularly relevant in view of the fact that evidence from the USA (Joksch 1976) suggests that under American road conditions there is greater injury in smaller cars even when allowance is made for the effect of mass ratio.

The accidents included in the analyses reported below were those involving injury occurring in the whole of Britain during the years 1969 to 1972 that were reported to the police. Thus they constitute a more extensive sample than any previously analysed. The accidents were recorded on magnetic tape and the required tabulations performed by computer. Injuries to drivers only were considered, in order to avoid complications arising from possible differences in the occupancies of vehicles. It was not possible to distinguish between belted and unbelted occupants, but it is known that the proportion of the former in the driver population was small during the period under consideration. The results are therefore approximately representative of the unrestrained driver.

Head-on and intersection collisions, together with single vehicle accidents, account for most of the deaths and serious injuries in vehicles. Separate analyses have been made for head-on and intersection collisions, and each of these was separated into urban and rural accidents. In addition, some data on injury in single-vehicle accidents related to the mass of the vehicle will be given.

No information on the speeds of the vehicles involved in the accidents was available (except that the distinction between urban and rural areas was made on the basis of speed limit), and some further reservations must also be made: although the results will be interpreted in terms of the relative velocity changes, we must not lose sight of the fact that other factors may be modifying this relationship—for instance, the speeds before impact may not be independent of mass ratio, driver age (known to be related to severity) may not be strictly independent of size of car, and structural strength (especially relevant when the vehicle concerned is struck in the side) will generally be greater for the heavier vehicles.

DEFINITIONS

The *weights* assumed for cars were the kerb weights, as given by the makers or sometimes as stated in test reports. But for commercial vehicles graphs were prepared relating the gross vehicle weight to the usual load carrying capacity: for particulars of the resulting overall weights used in the analysis reference should be made to Grime and Hutchinson 1979.

Mass ratio can be defined in a number of ways: (i) as (mass of heavier vehicle)/(mass of lighter vehicle); (ii) as the inverse of this (which is often more convenient for plotting on a linear scale); (iii) as $M_1/(M_1 + M_2)$ for vehicle 1; (iv) as $M_2/(M_1 + M_2)$ for vehicle 1, this being the relative velocity change. There are also a number of ways of expressing mass ratio: as a fraction (2/3 rds), a decimal (.67), a percentage (67%), or as two integers separated by a colon (2:3). We will always make it clear what we mean.

Injury—Casualties were classified by the police, according to standard definitions laid down by the Department of Transport, into fatal, serious, and slight. These definitions are as follows:

Slight injury:	an injury of a minor character such as a sprain or bruise.
Serious injury:	an injury for which a person is detained in hospital as an 'in-patient', or any of the following injuries whether or not he is detained in hospital: fractures, concussion, internal injuries, crushings, severe cuts and lacerations, severe general shock requiring medical treatment.
Death:	died within 30 days of an accident.

In addition, there is the uninjured category, which, it should be noted, refers only to people who are involved in an accident in which at least one person is reported to be injured.

Urban accidents are those occurring where a speed limit of not more than 40 mile/h is in force, *rural* accidents are those elsewhere.

Classification of the accident into *head-on* or *intersection* or neither was based on the movement of the vehicle before the accident and the vehicle manoeuvres as reported by the police. Head-on collisions are those in which the two vehicles were proceeding in opposite directions on the same road and damage was not confined to the sides of the vehicles (which would be called "sideswipes"). Intersection collisions are those in which the accident was reported as being within 20 yards of a junction and either the vehicles were travelling on different roads or they were on the same road and one was turning and the other was going ahead. It did not prove possible to identify which was the striking and which was the struck vehicle in intersection accidents. However, it was thought worthwhile to present the data without this distinction being made.

RELATIVE FREQUENCIES OF DIFFERENT MASS RATIOS AND CORRELATIONS BETWEEN THE TWO VEHICLES

Distributions of mass ratio were derived for head-on and intersection accidents, both urban and rural. The resulting histograms showed the percentage of collisions in each 0.05 interval of mass ratio (when expressed as (mass of lighter vehicle)/(mass of heavier vehicle)).

In every case the percentages of collisions between vehicles having mass ratios between 0.5 and 1.0 (mainly car-car collisions) was high, ranging from 80 percent of the total in urban intersection accidents to 65 percent in rural and urban head-on collisions. The percentages of collisions in the range of mass ratio 0.05 to 0.20, representing collisions with commercial vehicles, was greatest for head-on collisions (25 per cent in each area) and least for intersection collisions, being 15 per cent for rural and only 10 per cent for urban intersection collisions. The detailed results were presented in Hutchinson 1979.

It was also noted that the masses of the two vehicles involved were not statistically independent of each other: vehicles tended to collide more frequently with vehicles of similar weights than would be expected by chance. For car-car collisions alone, however, no systematic departure from expected frequencies was observed, and the tendency was interpreted as being due to commercial vehicles being likely to travel on a restricted number of roads.

METHODS OF PRESENTATION OF INFORMATION ABOUT INJURY SEVERITY IN RELATION TO MASS RATIO

The data were originally obtained in the form of tables giving the numbers of cases in which each combination of injury in the two vehicles occurred. In this paper, however, we shall be concerned only with the marginal totals of such tables. The reader is referred to Hutchinson 1977 for a method of analysing the joint occurrence of injuries. Note that the number of cases in which both drivers escaped injury is unknown because such accidents are not reported (unless a passenger was injured).

The results of the analysis of collisions can be expressed in several ways.

(a) *As tables*; for example Table 1a relates to rural head-on collisions and Table 1b to those on urban roads. The entries in these tables are in pairs, one row for the lighter and one for the heavier vehicles in collisions at a particular pair of mass ratios. (For each pair of entries there are, of course, two mass ratios one for the heavier vehicles and the other, its inverse, for the lighter vehicles.) The numbers of impacts in the two rows are always equal

Table 1a. Percentages of drivers classified into each of the four categories of injury, according to the mass ratio of the vehicles involved (head-on accidents in rural areas).

Mass ratio (lighter/heavier)		Percentages of drivers				Number of collisions
		Deaths	Serious injuries	Slight injuries	Uninjured	
0.00-0.04	H*	0.0	0.0	5.4	94.6	56
	L	14.3	48.3	33.9	3.6	
0.05-0.09	H	0.0	1.7	9.1	89.2	2396
	L	11.9	38.7	46.8	2.6	
0.10-0.14	H	0.0	1.8	9.9	88.3	1541
	L	10.5	28.9	58.4	2.3	
0.15-0.19	H	0.3	3.1	14.3	82.4	652
	L	8.3	37.4	49.8	4.4	
0.20-0.24	H	0.0	2.8	15.7	81.4	318
	L	6.6	32.7	55.3	5.3	
0.25-0.29	H	0.3	7.5	19.6	72.6	332
	L	6.3	33.4	51.5	8.7	
0.30-0.34	H	0.4	10.9	23.2	65.5	284
	L	8.5	32.7	48.6	10.2	
0.35-0.39	H	0.0	11.8	28.3	59.8	254
	L	7.9	28.0	55.5	8.7	
0.40-0.44	H	0.3	17.4	27.5	54.7	298
	L	6.4	25.5	53.4	14.8	
0.45-0.49	H	0.7	16.4	32.0	51.0	604
	L	4.5	29.6	47.8	18.0	
0.50-0.54	H	1.0	16.1	34.8	48.1	597
	L	5.5	27.5	49.7	17.3	
0.55-0.59	H	0.2	15.9	25.5	58.3	439
	L	5.9	32.6	49.4	12.1	
0.60-0.64	H	0.9	14.3	32.0	52.7	840
	L	2.4	30.8	54.8	12.0	
0.65-0.69	H	1.4	19.0	36.8	42.8	1505
	L	3.5	27.2	47.5	21.8	
0.70-0.74	H	2.0	21.7	42.3	33.9	938
	L	2.6	33.4	43.7	20.4	
0.75-0.79	H	1.5	20.9	37.6	39.9	1185
	L	3.2	28.4	49.5	18.8	
0.80-0.84	H	1.3	19.0	37.7	42.0	1137
	L	2.7	28.9	50.7	17.6	
0.85-0.89	H	1.7	23.2	40.5	34.6	1436
	L	2.2	28.0	46.0	23.7	
0.90-0.94	H	2.3	24.1	39.6	34.0	1224
	L	3.1	27.5	47.1	22.4	
0.95-0.99	H	2.0	26.3	42.9	28.7	1367
	L	2.0	26.1	43.3	28.7	1265
1.00		2.5	26.0	41.9	29.6	
					Total	18668

* H: drivers of the heavier vehicles, L: drivers of the lighter vehicles

since the injuries or lack of injury in each of the two vehicles in every collision was recorded. To be included in the tables, one or other or both drivers must have been injured; in most cases only one was injured.

(b) *As a diagram* such as Figures 1a and 1b in which the percentages of drivers at the 4 levels of injury are plotted against mass ratios up to 9, both scales being linear. The advantage of these diagrams is that they give a straightforward picture of the effect of mass ratio on injury, but have the disadvantage that mass ratios between 0 and 1.0, which represent all the heavier vehicles in the collisions, are compressed into a small corner of the diagram.

(c) *In Figures 2a and 2b* the percentages of drivers recorded at the 3 levels of injury are given in terms of the velocity change of the vehicle expressed as a fraction of the relative velocity at impact ($V_1 - V_2$); for car 1, this is $M_2/M_1 + M_2$, and for car 2 $M_1/M_1 + M_2$. Thus the 0.50 point represents a mass ratio of 1.0; 0.40 and 0.60 the velocity changes of the heavier and lighter cars in collisions at mass ratio 1.5 for the lighter car, and so on. Deaths are shown on a separate Figure 3 to avoid

Table 1b. Percentages of drivers classified into each of the four categories of injury, according to the mass ratio of the vehicle involved (head-on accidents in rural areas).

Mass ratio (lighter/heavier)		Percentages of drivers				Number of collisions
		Deaths	Serious injuries	Slight injuries	Uninjured	
0.00-0.04	H*	0.0	0.0	4.2	95.8	
	L	14.6	25.0	60.4	0.0	48
0.05-0.09	H	0.0	1.2	6.2	92.6	
	L	9.2	32.5	56.3	2.0	1774
0.10-0.14	H	0.1	1.6	8.8	89.5	
	L	6.8	34.4	55.6	3.1	1258
0.15-0.19	H	0.0	2.4	10.6	87.0	
	L	5.5	33.8	57.6	3.1	491
0.20-0.24	H	0.5	5.2	17.0	77.4	
	L	5.7	27.8	57.1	9.7	212
0.25-0.29	H	0.0	4.1	16.8	79.1	
	L	2.9	28.7	61.9	6.6	244
0.30-0.34	H	0.0	3.7	24.2	72.1	
	L	1.6	28.4	59.5	10.5	190
0.35-0.39	H	0.9	8.6	28.0	62.5	
	L	3.9	27.2	54.3	14.7	232
0.40-0.44	H	0.0	11.1	28.8	60.2	
	L	4.9	32.7	51.3	11.1	226
0.45-0.49	H	0.2	10.8	31.7	57.2	
	L	3.2	25.5	55.1	16.2	463
0.50-0.54	H	0.4	13.4	34.2	52.0	
	L	2.2	26.9	52.8	18.0	494
0.55-0.59	H	0.8	12.5	30.0	56.7	
	L	2.3	26.4	57.4	13.8	383
0.60-0.64	H	0.3	10.3	32.8	56.7	
	L	2.1	24.9	58.2	14.8	766
0.65-0.69	H	0.8	14.3	35.7	49.2	
	L	2.9	27.4	52.3	17.4	1296
0.70-0.74	H	0.7	15.2	40.4	44.6	
	L	1.8	25.1	53.1	20.9	896
0.75-0.79	H	0.8	15.1	41.7	42.4	
	L	1.3	21.5	54.6	22.5	981
0.80-0.84	H	0.1	13.8	46.7	39.4	
	L	1.8	22.1	52.9	23.2	1087
0.85-0.89	H	0.5	17.1	43.7	38.7	
	L	1.0	22.2	52.5	24.3	1216
0.90.0.94	H	1.0	17.9	45.1	36.0	
	L	1.2	21.1	51.9	25.8	1049
0.95-0.99	H	0.7	19.8	49.4	30.1	
	L	0.7	19.6	48.2	31.5	1103
1.00	H	1.2	19.5	45.9	33.4	968
					Total	15377

* H: drivers of the heavier vehicles, L: drivers of the lighter vehicles

confusion of points. Important mass ratios are picked out; for example, most car-car collisions lie within the range 0.5 to 2.0.

This method of presentation gives equal weight to mass ratios above and below 1.0, and shows more clearly than Figure 1 how injuries in the heavier vehicles in collisions are dependent on mass ratio. As might be expected the relationships between velocity change and injury are simpler than between mass ratio and injury.

(d) *The percentages of* fatal, serious, and slight injuries, and of uninjured, enable comparisons to be made of the overall effect of mass ratio, as given in tables such as Tables 1, and very often this is the answer wanted. They are not completely satisfactory, however, if an answer is required to the questions 'What is the effect of mass ratio in slight accidents, in serious accidents, or in fatal accidents?'.

A large percentage of the slight injuries in the heavier vehicles in collisions are received in serious or fatal accidents, so that a straight comparison of the percentages in Tables 1 does not answer the first question; the same is true, to a similar extent, of serious injuries. In an earlier

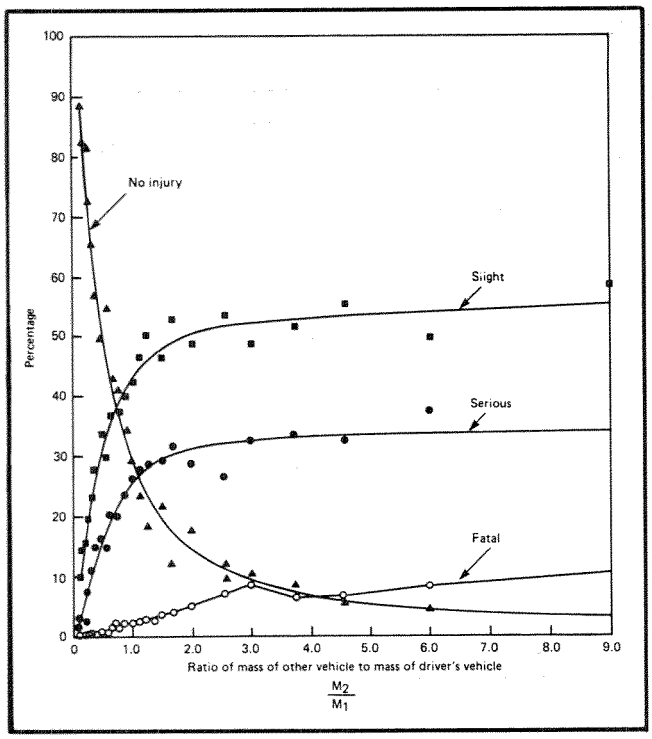


Figure 1a. Percentages of drivers at four levels of injury versus mass ratio in head-on collisions (rural areas).

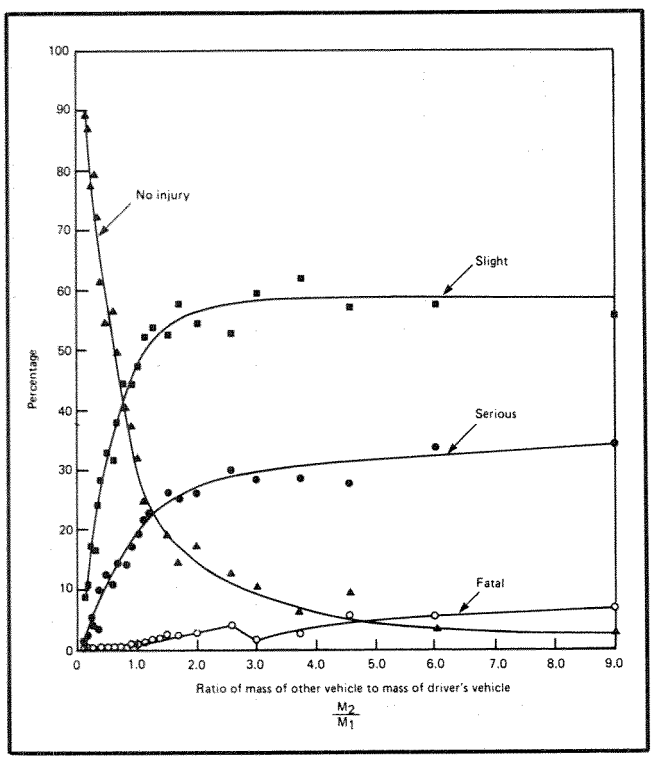


Figure 1b. Percentages of drivers at four levels of injury versus mass ratio in head-on collisions (urban areas).

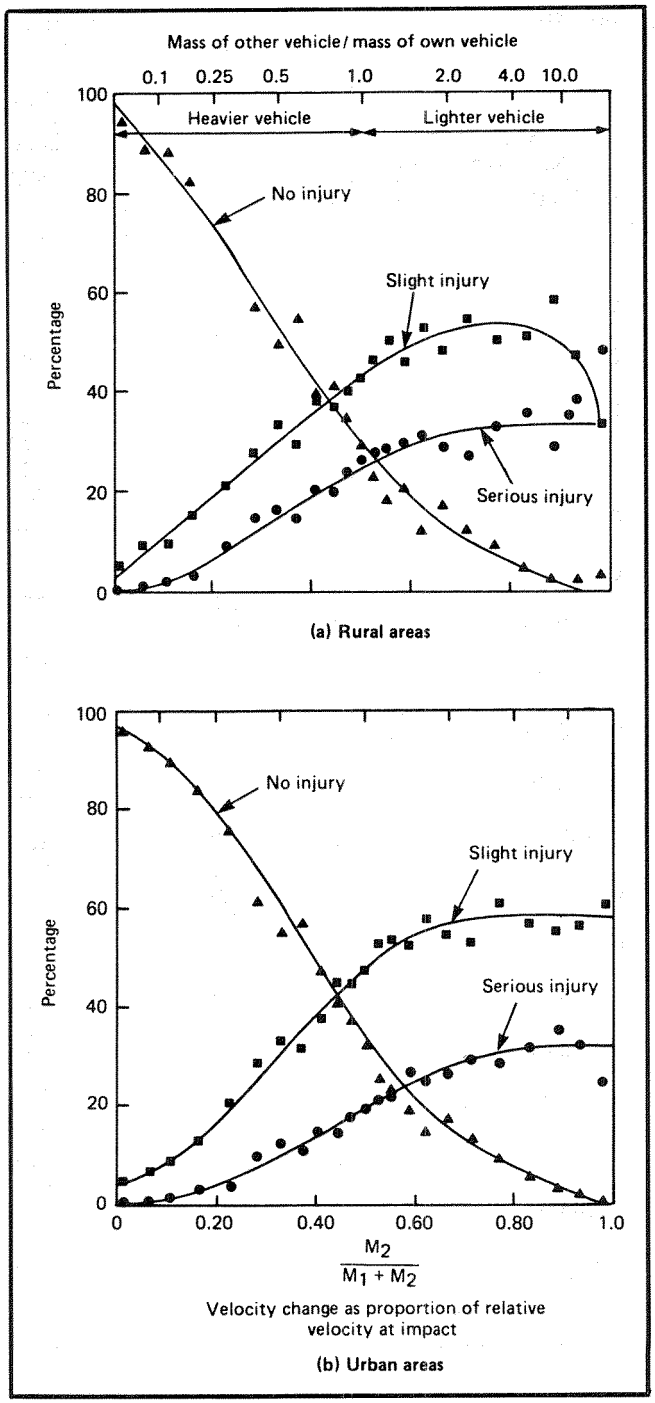


Figure 2. Percentages of drivers injured in head-on collisions versus velocity change.

paper (Grime 1971), one of the authors used as a measure of the effect of mass ratio in fatal and serious collisions the number of injuries per impact in fatal and serious collisions alone; and similarly, as a measure of the effect of mass ratio in slight accidents, the number of slight injuries per impact for slight accidents alone.

This procedure was used to construct Figures 4a, 4b and 4c which give the injuries per impact in head-on collisions for fatal, serious, and slight collisions respec-

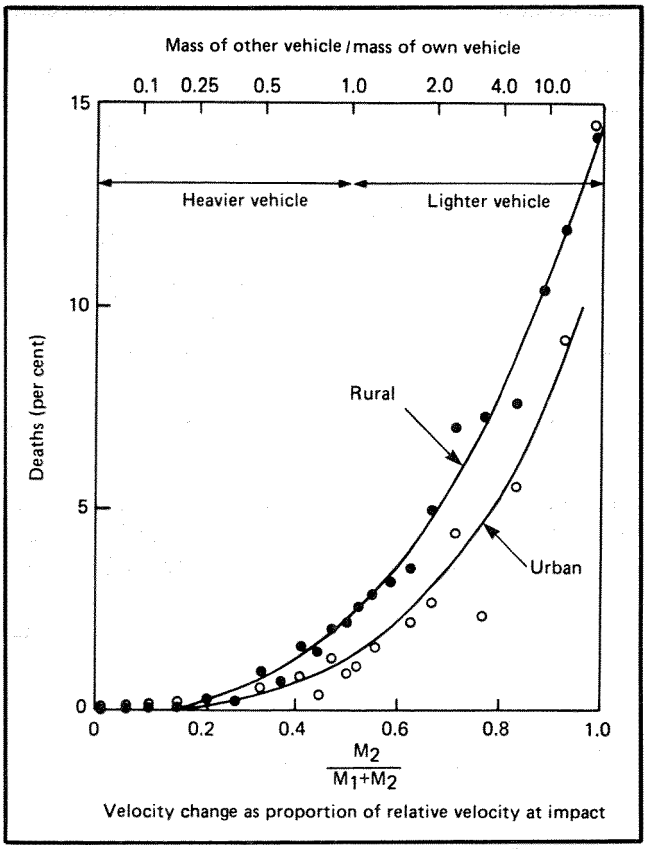


Figure 3. Driver deaths in head-on collisions.

tively. The points for rural and urban areas are separately indicated, but agree so well that in each diagram a single curve for the two areas could be drawn. The number of injuries of given severity per impact at a particular level of velocity change in accidents of a certain kind is defined to be the ratio

$$\frac{\text{number of drivers injured with that severity in vehicles experiencing that velocity change}}{\text{number of vehicles experiencing that velocity change}}$$

in accidents of that kind in the set of data being studied, the velocity change being expressed, as in Figures 2 and 3, as a proportion of the relative velocity at impact.

To make the meaning of these diagrams clear, consider 1000 collisions between cars in which 1000 cars weigh 1.5 times the weight of the opposing 1000, and in which one or more drivers is killed. This situation corresponds with points 0.4 and 0.6 on the horizontal scale of Figure 4a. The expected number of drivers killed in the 1000 lighter cars

$$\left(\frac{M_2}{M_1 + M_2} = 0.6\right)$$

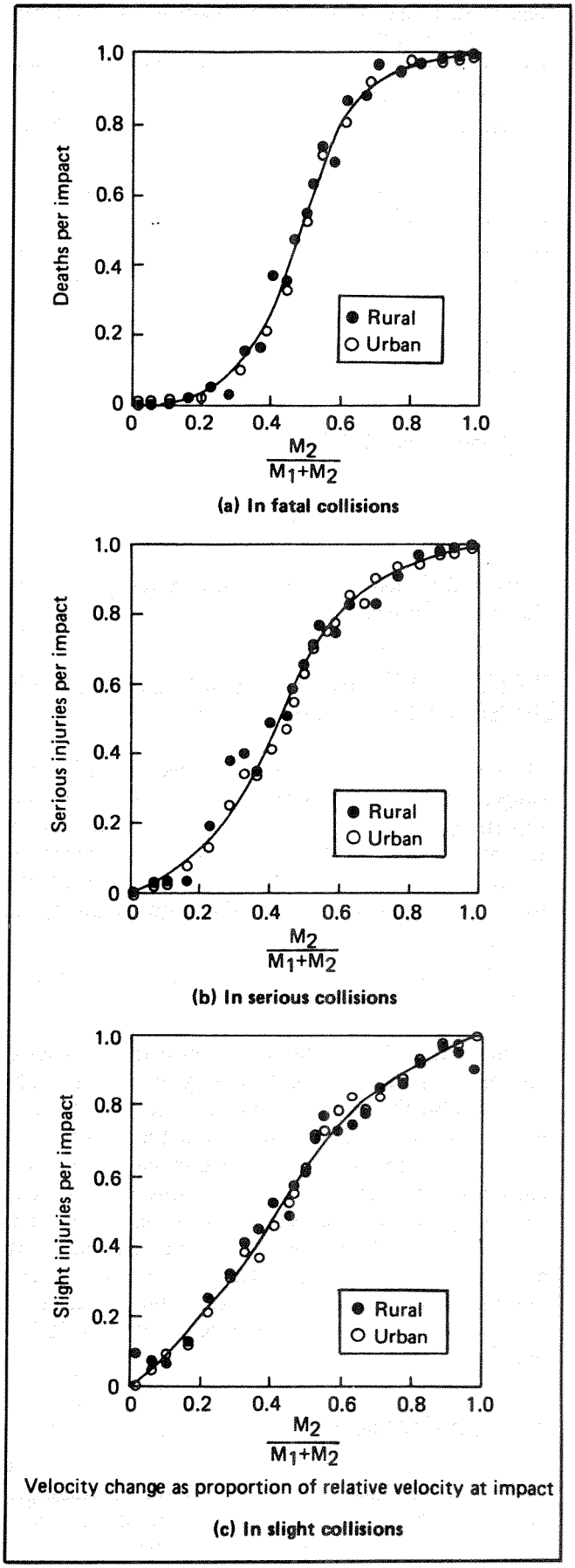


Figure 4. Driver injuries per impact in head-on collisions versus velocity change.

Table 2. Ratio of number of driver injuries in lighter vehicles to number in heavier vehicles in head-on collisions of all severities taken together (from Figures 1 and 3).

Ratios of the masses of the vehicles	Deaths		Serious injuries		Slight injuries	
	Rural	Urban	Rural	Urban	Rural	Urban
1.0	1.0	1.0	1.0	1.0	1.0	1.0
1.5	2.9	3.6	1.6	1.8	1.8	1.4
2.0	6.3	8.3	2.2	2.8	0.8	1.9
3.0	20	35	3.6	5.0	2.3	2.7
4.0	33	49	5.6	7.9	2.9	3.6
5.0			7.3	10.7	3.4	4.5
6.0			11	16	3.9	5.3
9.0			21	20	5.0	7.3

is 800 and in the 1000 heavier cars

$$\left(\frac{M_2}{M_1 + M_2} = 0.4\right)$$

is 260; and similarly for other mass ratios and for the other two diagrams.

EFFECT OF MASS RATIO ON INJURY SEVERITY IN TWO-VEHICLE ACCIDENTS

It is well known that when two vehicles collide, the changes of velocity of their centres of gravity are inversely proportional to their masses. If M_1, V_1 and M_2, V_2 are the masses and velocities of two vehicles in a particular direction, then assuming the collision to be inelastic, the respective changes of velocity of the centre of gravity are

$$\frac{M_2}{M_1 + M_2}(V_1 - V_2) \quad \text{and} \quad \frac{M_1}{M_1 + M_2}(V_1 - V_2).$$

In symmetrical (centre front to centre front) head-on collisions with the vehicles travelling on parallel paths these are also the velocity changes of the driver, but it can also be shown (Grime and Jones 1969-70) that although most head-on collisions are asymmetrical, i.e., not centre front to centre front, and the paths of the vehicles not exactly parallel, the velocity change of the driver is almost as great if the collision had been symmetrical with the vehicles travelling on parallel paths. All head-on collisions have therefore been included in these analyses, if the masses (represented by the weights) of the colliding vehicles could be estimated.

Head-on Collisions

If accidents which involved pedestrians or two-wheeled vehicles are excluded, in 1972 head-on collisions accounted for about 20 per cent of injury accidents in rural areas, and about 8 per cent of those in urban areas; but in terms of serious and fatal injuries, these proportions were higher in both areas (22 per cent in rural areas, and 13 per cent in urban areas). Probably some of the other accidents would normally be considered 'head-on' as well.

The results of the analysis of head-on collision data are given in Tables 1a and b, Figures 1a and b, 2a and b and 3. The methods of presentation used in these tables and figures have been described.

From Figures 2 and 3, Table 2 has been constructed to show how the ratios of the percentages of injuries in the lighter vehicles to those in the heavier ones are influenced by mass ratio.

Mass ratio affects deaths most and slight injuries least. The effect on deaths is dramatic; at the limit of the car-car range, which coincides approximately with a ratio of 2 to 1 in the weights of the colliding vehicles (and in the velocity changes), the percentage of deaths is about 7 times greater in the lighter than in the heavier vehicle.

Because speeds in urban areas are lower than on rural roads, the percentages of deaths and serious injuries are, as would be expected, less in urban than in rural areas (Tables 1) but there is little difference in the slight injuries. Judged from these data mass ratio has a more pronounced

Table 3. Ratios of number of driver injuries in lighter vehicles to number in heavier vehicles in head-on collision of different severities (from Figure 4).

Ratio of the masses of the vehicles	Deaths in fatal collisions	Serious injuries in serious collisions	Slight injuries in slight collisions
1.0	1.0	1.0	1.0
1.5	3.2	1.9	1.6
2.0	6.9	3.0	2.3
3.0	15.8	5.1	3.7
4.0	32	7.2	5.1
5.0		9.5	6.2
6.0		12	8
9.0		20	12

effect in urban than in rural areas. For deaths the figures give no more than an indication of this tendency, since the numbers are small, but the numbers of serious injuries are large enough to be sure that the effect is a real one. Figure 2 shows that the reduction in serious casualties in urban areas is greater for the heavier cars than for the lighter ones, and this is probably true for deaths as well.

For slight injuries, the increased risk in the lighter vehicles tails off in collisions with commercial vehicles (mass ratio greater than about 2), in rural areas, largely because injuries in cars involved in these collisions, tend to be serious or fatal rather than slight.

The effect of mass ratio in fatal, serious, and slight head-on collisions is shown in Figures 4, in terms of injuries per impact. As already mentioned, plotted in this way, the points representing the results for rural and urban areas are grouped closely together and so single curves to represent both areas have been drawn; and from Figures 4 Table 3 has been drawn up corresponding to Table 2, giving the ratios of injuries in the lighter vehicles to those in the heavier vehicles.

Differences between Tables 2 and 3 are mainly in the category of slight injuries, for which the ratios in Table 3 are considerably higher, that is, the effect of mass ratio in reducing slight injuries in the heavier car is much greater than was stated in Table 2, calculated from the overall percentages of injury. The difference is greatest for collisions with commercial vehicles.

The two pairs of tables are in agreement in showing that mass ratio has its greatest effect in fatal and its least effect in slight accidents, but Table 3 indicates that its effect is considerable even in slight accidents.

Intersection Accidents

In the sample of accidents analysed in this paper intersection accidents were about three times as common as head-on accidents in urban areas (but only twice among fatal and serious accidents), and about half as common in rural areas (rather less among fatal and serious accidents, rather more among the slights).

In head-on collisions the two colliding vehicles experience the same kind of impact, a frontal impact in which the main components of the forces acting on both vehicles are nearly always approximately parallel to the long axes of the vehicles. In an intersection collision, however, the striking vehicle experiences a mainly frontal impact, and the struck vehicle an impact to the side of the vehicle. Either or both vehicles may have an appreciable rotational velocity after impact, as determined by the direction and magnitude of their velocities at impact, the positions of the contact areas on the two vehicles, and their dimensions and masses. The dynamics of intersection collisions have been described by several authors (Grime and Jones, 1969-70; Emori and Tani, 1970; Bekiroglu, 1975). Data from police records in 3 areas of Britain suggest that the typical intersection collision is one in which the paths of the striking and struck vehicles are approximately at right angles and the struck vehicle is travelling at less than 20 mile/h (Grime and Jones, 1973).

It would have been useful to have been able to give the percentages of the various degrees of injury separately for the striking and struck vehicles, since the drivers of the two vehicles are probably exposed to different mecha-

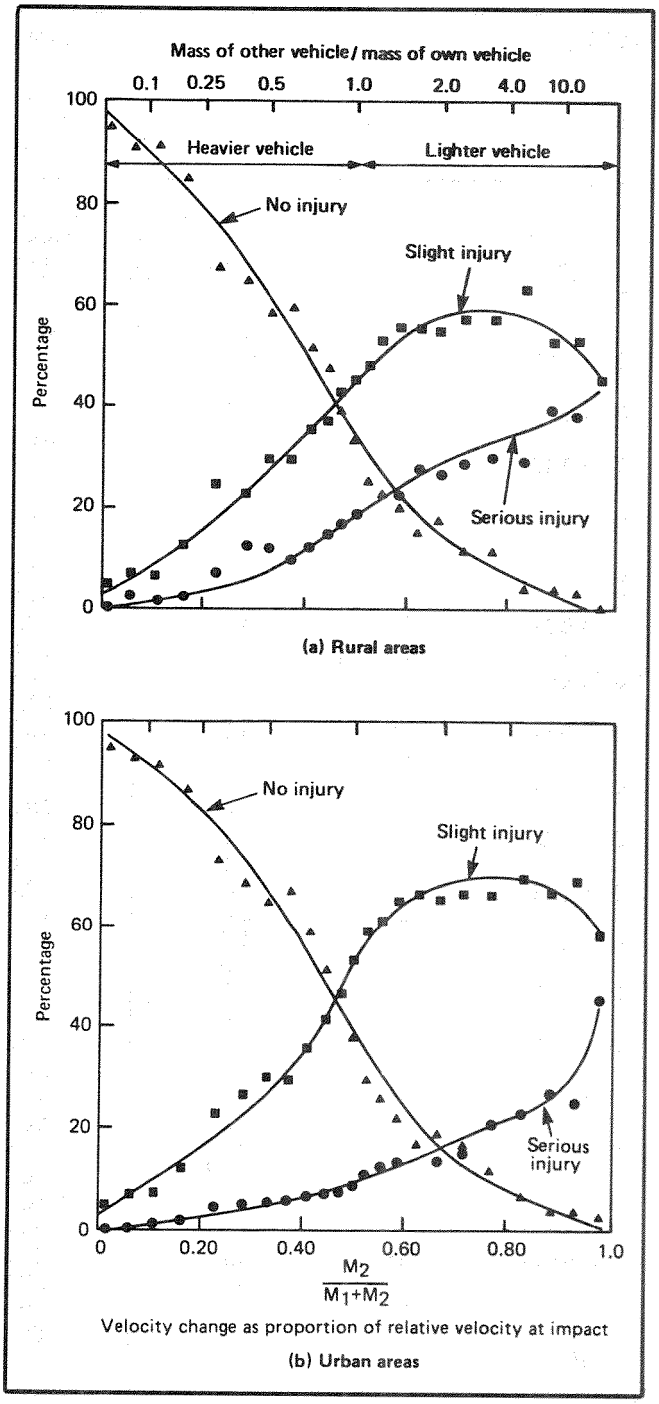


Figure 5. Percentages of drivers injured in intersection collisions versus velocity change.

nisms of injury production, but unfortunately this was not possible from the recorded information. American studies (McHenry et al., 1977) indicate that, for equal velocity changes, the occupants of struck cars are more likely to be seriously injured than those in the striking cars. This has to be remembered when considering the analysis of intersection accidents presented in the following tables and figures.

Tables 4a and b give the percentages of the various degrees of injury as influenced by mass ratio for rural and urban intersection collisions, and Figures 5a and b, and Figure 6 express the same results in graphical form. Table 5 has been constructed from Figures 5 and 6 giving the ratios of the percentages of injury in the lighter vehicles to those in the heavier ones. As in head-on collisions, the accuracy of the results for deaths is severely limited by the comparatively small number of fatal collisions.

Mass ratio has at least as great an influence on the ratios of serious and slight injuries in intersection as in head-on collisions, but deaths do not appear to be affected to the same extent. Calculations were also made of injuries per impact in fatal, serious, and slight intersection accidents. The results are given in Figures 7 and the derived

Table 4a. Percentages of drivers classified into each of the four categories of injury, according to the mass ratio of the vehicles involved (intersection accidents in rural areas).

Mass ratio (lighter/heavier)		Percentages of drivers				Number of collisions
		Deaths	Serious injuries	Slight injuries	Uninjured	
0.00-0.04	H*	0.0	0.0	4.6	95.5	
	L	9.1	45.5	45.4	0.0	22
0.05-0.09	H	0.0	2.2	6.6	91.2	
	L	6.4	38.0	52.7	2.8	808
0.10-0.14	H	0.2	1.8	6.4	91.6	
	L	5.2	39.2	52.6	3.0	595
0.15-0.19	H	0.0	2.7	10.2	87.1	
	L	4.5	31.1	60.6	3.8	264
0.20-0.24	H	0.0	1.9	17.1	81.0	
	L	2.9	25.7	67.6	3.8	105
0.25-0.29	H	0.0	7.4	24.8	67.8	
	L	0.7	34.2	54.4	10.7	149
0.30-0.34	H	0.8	7.5	24.1	67.7	
	L	1.5	25.6	60.2	12.8	133
0.35-0.39	H	0.0	14.4	24.0	61.7	
	L	3.6	27.5	55.7	13.2	167
0.40-0.44	H	0.5	10.2	22.0	67.3	
	L	2.4	28.8	58.5	10.2	205
0.45-0.49	H	0.0	9.7	30.8	59.4	
	L	1.6	23.6	56.9	17.9	318
0.50-0.54	H	0.5	13.9	28.5	57.1	
	L	2.1	29.0	52.4	16.5	431
0.55-0.59	H	1.0	9.4	29.4	60.3	
	L	2.6	26.1	55.5	15.8	310
0.60-0.64	H	1.0	10.1	30.0	59.0	
	L	1.5	28.7	55.2	14.6	536
0.65-0.69	H	0.8	11.8	36.6	50.8	
	L	1.9	22.4	54.7	21.0	897
0.70-0.74	H	0.7	12.8	33.5	53.0	
	L	1.3	23.1	56.7	18.9	689
0.75-0.79	H	0.1	15.6	35.3	48.9	
	L	1.5	26.8	51.2	20.5	787
0.80-0.84	H	0.8	13.2	39.6	46.5	
	L	1.5	19.9	54.5	24.0	783
0.85-0.89	H	0.9	16.4	42.6	40.1	
	L	1.2	24.4	49.9	24.6	1018
0.90-0.94	H	0.7	17.9	42.5	38.9	
	L	0.7	27.7	45.6	26.0	866
0.95-0.99	H	1.3	19.9	46.4	32.4	
	L	0.7	20.9	44.5	33.9	1009
1.00		0.9	19.0	46.3	33.8	1214
					Total	11306

* H: drivers of the heavier vehicles, L: drivers of the lighter vehicles

Table 4b. Percentages of drivers classified into each of the four categories of injury, according to the mass ratio of the vehicles involved (intersection accidents in urban areas).

Mass ratio (lighter/heavier)		Percentages of drivers				Number of collisions
		Deaths	Serious injuries	Slight injuries	Uninjured	
0.00-0.04	H*	0.0	0.0	4.7	95.3	
	L	4.7	34.9	58.1	2.3	43
0.05-0.09	H	0.1	0.7	6.6	92.7	
	L	3.0	24.6	69.0	3.4	1975
0.10-0.14	H	0.2	0.9	7.1	91.8	
	L	2.6	26.4	67.2	3.8	1286
0.15-0.19	H	0.2	0.9	10.1	88.8	
	L	1.3	23.1	70.3	5.4	555
0.20-0.24	H	0.0	1.9	16.7	81.4	
	L	0.9	22.1	68.8	8.2	317
0.25-0.29	H	0.2	3.9	22.4	73.4	
	L	0.7	20.1	68.8	10.4	433
0.30-0.34	H	0.3	4.3	22.9	72.5	
	L	0.3	21.7	64.6	13.3	345
0.35-0.39	H	0.0	4.1	29.9	65.9	
	L	0.2	14.6	68.6	16.6	458
0.40-0.44	H	0.0	5.6	23.3	71.7	
	L	1.3	15.9	66.4	16.4	536
0.45-0.49	H	0.1	5.3	30.9	63.7	
	L	0.4	13.5	66.4	19.7	1026
0.50-0.54	H	0.1	5.7	28.9	65.3	
	L	0.3	16.3	65.4	18.1	1172
0.55-0.59	H	0.0	5.9	30.7	63.4	
	L	0.6	18.6	62.5	18.4	899
0.60-0.64	H	0.1	4.4	27.0	68.5	
	L	0.5	15.8	68.4	15.2	1849
0.65-0.69	H	0.1	6.4	35.2	58.3	
	L	0.2	12.3	64.8	22.7	2873
0.70-0.74	H	0.1	5.3	36.1	58.5	
	L	0.2	13.3	65.3	21.2	2287
0.75-0.79	H	0.2	6.4	40.4	53.0	
	L	0.2	13.2	60.6	26.0	2612
0.80-0.84	H	0.1	7.1	42.6	50.1	
	L	0.3	11.9	62.2	25.6	2850
0.85-0.89	H	0.1	6.8	46.3	46.9	
	L	0.2	10.6	59.9	29.4	3236
0.90-0.94	H	0.2	7.9	46.3	45.5	
	L	0.2	10.5	59.7	29.5	2852
0.95-0.99	H	0.1	8.7	50.6	40.5	
	L	0.1	8.3	55.3	36.2	3376
1.00		0.2	8.4	54.3	37.0	3752
					Total	34732

*H: drivers of heavier vehicles, L: drivers of lighter vehicles

Table 6. The curves in Figures 7 could not be placed as accurately as was possible for those drawn to represent head-on collisions. This is particularly noticeable at the ends of the curves, where the numbers were small so that differences in probabilities of injury between the striking and struck cars might have a pronounced influence.

SEVERITY OF DRIVER INJURY RELATED TO VEHICLE MASS

Two-Vehicle Accidents

Vehicles falling within a particular range of weight at one time or another collide with vehicles of all other weights, and as a result they experience collisions at a large number of mass ratios. The resulting percentages of the various levels of injury are determined mainly by (i) the number of vehicles in each weight class, and (ii) the relative velocities at impact. As we have already seen, the relative velocities at impact will be lower in urban than in rural areas, and lower in intersection than in head-on collisions.

Figures 8 and 9 give the percentages of the levels of injury as functions of weight, and as expected, the percentages of all injuries are highest for light cars and lowest for heavy commercial vehicles. (Table 7 gives a key to the weight codes in Figures 8 and 9; some further group-

Table 5. Ratios of number of driver injuries in lighter vehicles to number in heavier vehicles in intersection collisions of all severities taken together (from Figures 5 and 6).

Ratio of the masses of the vehicles	Deaths		Serious injuries		Slight injuries	
	Rural	Urban	Rural	Urban	Rural	Urban
1.0	1.0	1.0	1.0	1.0	1.0	1.0
1.5	2.5	3.2	2.1	2.3	1.6	1.9
2.0	5.0	—	3.6	4.1	2.1	2.6
3.0	12.5	—	6.2	6.7	3.0	3.6
4.0	37	—	8.5	—	3.7	4.5
5.0	—	—	14.2	—	4.8	5.3
6.0	—	—	—	—	—	—
9.0	—	—	—	—	—	—

Table 6. Ratios of number of driver injuries in lighter vehicles to number in heavier vehicles in intersection collisions of different severities (from Figure 7).

Ratio of the masses of the vehicles	Deaths in fatal collisions	Serious injuries in serious collisions	Slight injuries in slight collisions
1.0	1.0	1.0	1.0
1.5	2.2	2.2	2.0
2.0	3.6	3.4	2.8
3.0		6.1	4.5
4.0		9.4	5.7
5.0		13.6	7.7

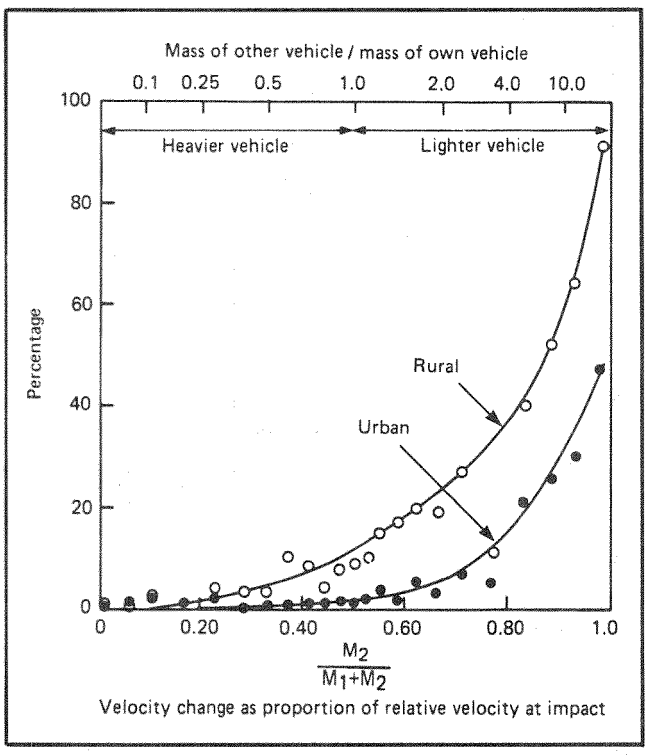


Figure 6. Driver deaths in intersection collisions.

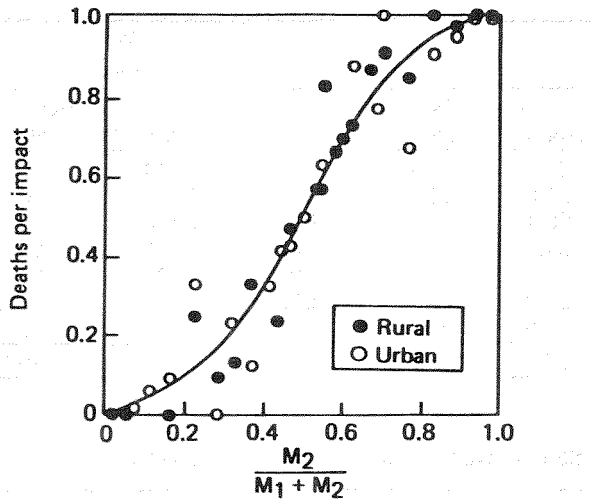
ing was made for Figure 9). The largest differences between the percentages in the different kinds of accident are found in Figure 9 for deaths; for example, the percentages of deaths in cars in rural head-on collisions are about 14 times those for cars in urban intersection accidents. For serious injuries the corresponding ratio is about 4.

As mentioned in the Introduction, data from America suggest that greater injury occurs in smaller cars even when allowance is made for the effect of mass ratio. To see whether this is so in British conditions, data were obtained on degree of injury related to mass of vehicle (a) in two-vehicle accidents in which the mass of the lighter vehicle was at least 90 per cent of the mass of the

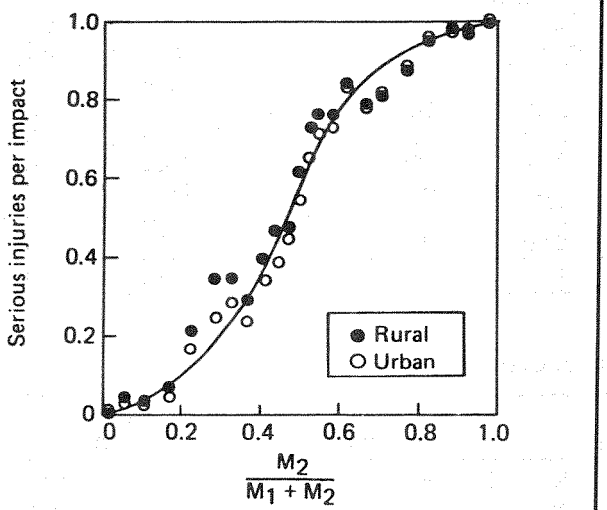
Table 7. Weight codes used in Figure 8.

Vehicle weights (tens of lbs)	Weight code
80- 150	1
151- 160	2
161- 170	3
171- 180	4
181- 190	5
191- 200	6
201- 225	7
226- 250	8
251- 275	9
276- 300	10
301- 350	11
351- 400	12
401- 600	13
601- 800	14
801-1000	15
1001-1500	16
1501-2000	17*
2001-3000	18

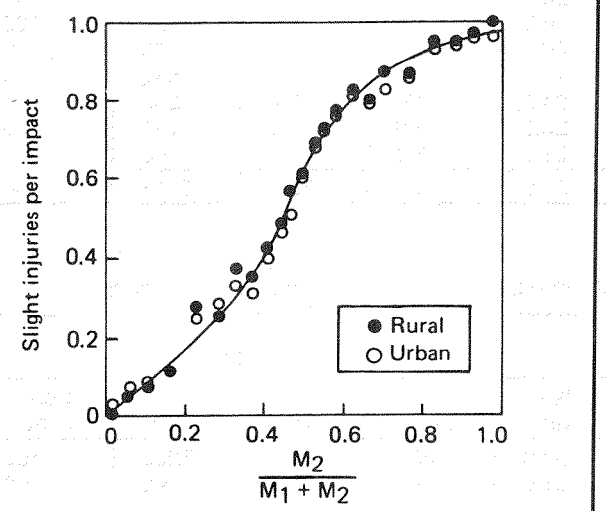
* Includes all PSV's



(a) In fatal collisions



(b) In serious collisions



Velocity change as proportion of relative velocity at impact

(c) In slight collisions

Figure 7. Driver injuries per impact in intersection collisions versus velocity change.

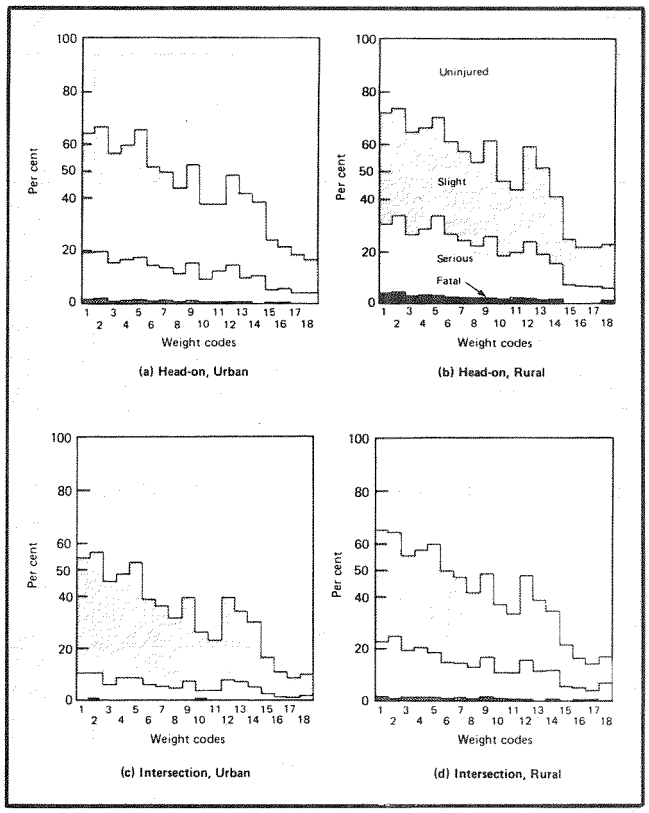


Figure 8. Severity of driver injury versus weight of vehicle driven in collisions with vehicles of all other weights in 1969–1972.

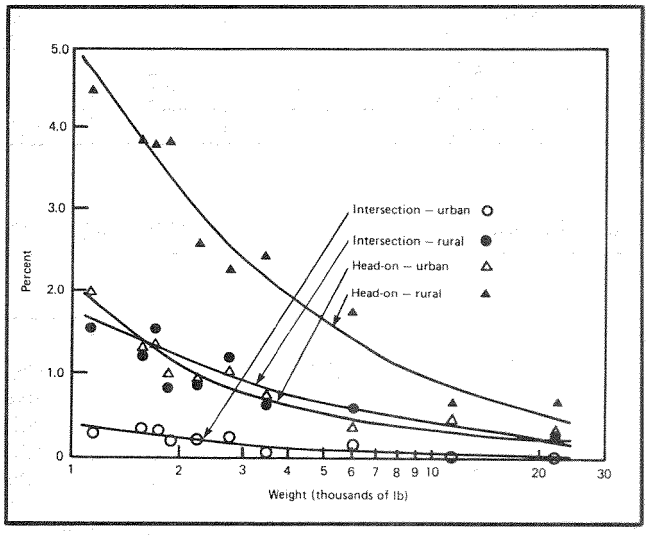


Figure 9. Percentages of drivers killed versus weight of vehicle driven in collisions with vehicles of all other weights in 1969–1972.

Table 8a. Effect of mass on severity of driver injury in single-vehicle overturning accidents in rural areas.

Weight (lb)	Fatal		Totals		No		Per-cent	
	Serious	Slight	No	Percent	Per-cent	No	No	Per-cent
800-1700	93	1.7	1780	31.5	3767	66.7	5640	100
1700-2000	175	2.17	2644	32.8	5234	65.0	8053	100
2000-2500	77	3.02	845	33.1	1631	63.9	2553	100
2500-3000	52	2.79	647	34.7	1167	62.5	1866	100
3000-4000	30	3.25	320	34.6	574	62.1	924	100
4000-8000	14	2.2	193	29.9	438	67.9	645	100
8000-30000	56	3.9	360	24.8	1034	71.3	1450	100
All weights	498	2.35	6789	32.1	13845	65.5	21131	100

Table 8b. Effect of mass on severity of driver injury in single-vehicle non-overturning accidents in rural areas.

Weight (lb)	Fatal		Totals		No		Per-cent	
	Serious	Slight	No	Per-cent	Per-cent	No	No	Per-cent
800-1700	123	2.0	2180	36.2	3711	61.7	6014	100
1700-2000	239	2.5	3611	37.1	5883	60.4	9733	100
2000-2500	105	3.3	1176	37.0	1897	59.7	3178	100
2500-3000	61	2.4	910	36.4	1529	61.2	2500	100
3000-4000	33	2.8	450	38.3	691	58.9	1174	100
4000-8000	14	2.4	209	36.2	355	61.4	578	100
8000-30000	40	2.3	462	27.0	1206	70.6	1708	100
All weights	615	2.47	8998	36.16	15272	61.37	24885	100

Table 8c. Effect of mass on severity of driver injury in single-vehicle overturning accidents in urban areas.

Weight (lb)	Fatal		Totals		No		Per-cent	
	Serious	Slight	No	Per-cent	Per-cent	No	No	Per-cent
800-1700	19	1.1	391	23.0	1289	75.9	1699	100
1700-2000	24	1.4	459	26.6	1243	72.0	1725	100
2000-2500	19	2.8	178	26.7	469	70.4	666	100
2500-3000	11	2.0	157	29.2	369	68.7	537	100
3000-4000	6	2.0	72	24.2	220	73.8	298	100
4000-8000	6	3.2	38	20.0	146	76.8	190	100
8000-30000	12	2.6	97	21.2	350	76.3	459	100
All weights	97	1.74	1392	25.0	4086	73.3	5575	100

Table 8d. Effect of mass on severity of driver injury in single-vehicle non-overturning accidents in urban areas.

Weight (lb)	Fatal		Totals		No		Per-cent	
	Serious	Slight	No	Per-cent	Per-cent	No	No	Per-cent
800-1700	100	1.4	2248	30.8	4951	67.8	7299	100
1700-2000	209	1.8	3623	31.5	7661	66.7	11493	100
2000-2500	100	2.2	1364	29.4	3169	68.4	4633	100
2500-3000	71	2.2	951	29.8	2173	68.0	3195	100
3000-4000	24	1.8	377	28.0	944	70.2	1345	100
4000-8000	9	1.4	185	28.9	447	69.7	641	100
8000-30000	31	2.0	332	21.2	1201	76.8	1564	100
All weights	544	1.80	9080	30.10	20546	68.10	30170	100

heavier vehicle, and (b) in single-vehicle accidents. Results from (b) are given in the next section.

In the original paper (Grime and Hutchinson, 1979), the results of (a) were presented in four separate diagrams, illustrating the results of head-on and intersection accidents in urban and rural areas. In each case for serious and slight injuries, over the range of weights up to 6000 lb (2730 kg) there was practically no effect of vehicle mass once mass ratio had been accounted for. However, in these plots, although the weight classes were combined so that there were at least 100 accidents in each weight group—200 possible casualties—the number of deaths were small, particularly in intersection accidents. To obtain more meaningful figures for deaths, the results are therefore presented, here in three Figures 10a, b and c the first two being the combined results for urban and rural areas for head-on and intersection accidents respectively and the third Figure 10c—giving the combined data for head-on and intersection accidents in both rural and urban areas. These diagrams confirm the results previously described and show that for deaths also there is practically no effect of vehicle mass alone. There is however a tendency for the percentages of deaths to increase when commercial vehicles collide.

Single Vehicle Accidents

In single vehicle accidents there is, of course, no effect of mass ratio, but the data were examined to see whether the mass (weight) of the vehicle influenced the percentages of the various levels of injury. No reliance could be placed on the recorded percentages of uninjured drivers, and so the results were expressed in terms of percentages of all injuries.

For the purpose of this study, single vehicle accidents have been divided into overturning accidents and non-overturning accidents. A small proportion of the overturning accidents occur after impact with a fixed object, but most occur without any such impact except perhaps with a kerb; most non-overturning accidents are head-on impacts with fixed objects, but a few are side impacts.

Tables 8a, b, c and d show that the influence of mass alone on the percentages of the various levels of injury is probably small, both in overturning and non-overturning accidents. There is an indication however, that in non-overturning accidents, the drivers of the heaviest vehicles are less likely to be seriously or fatally injured than are the drivers of cars and lighter commercial vehicles.

As with head-on and intersection collisions, all results for the different types of single vehicle accidents have been combined in Figure 11, so that the numbers of deaths in all weight classes are high enough for reliable results. Again it is found that vehicle mass alone has very little influence on severity of injury, although the lighter cars would appear to have lower percentages of deaths.

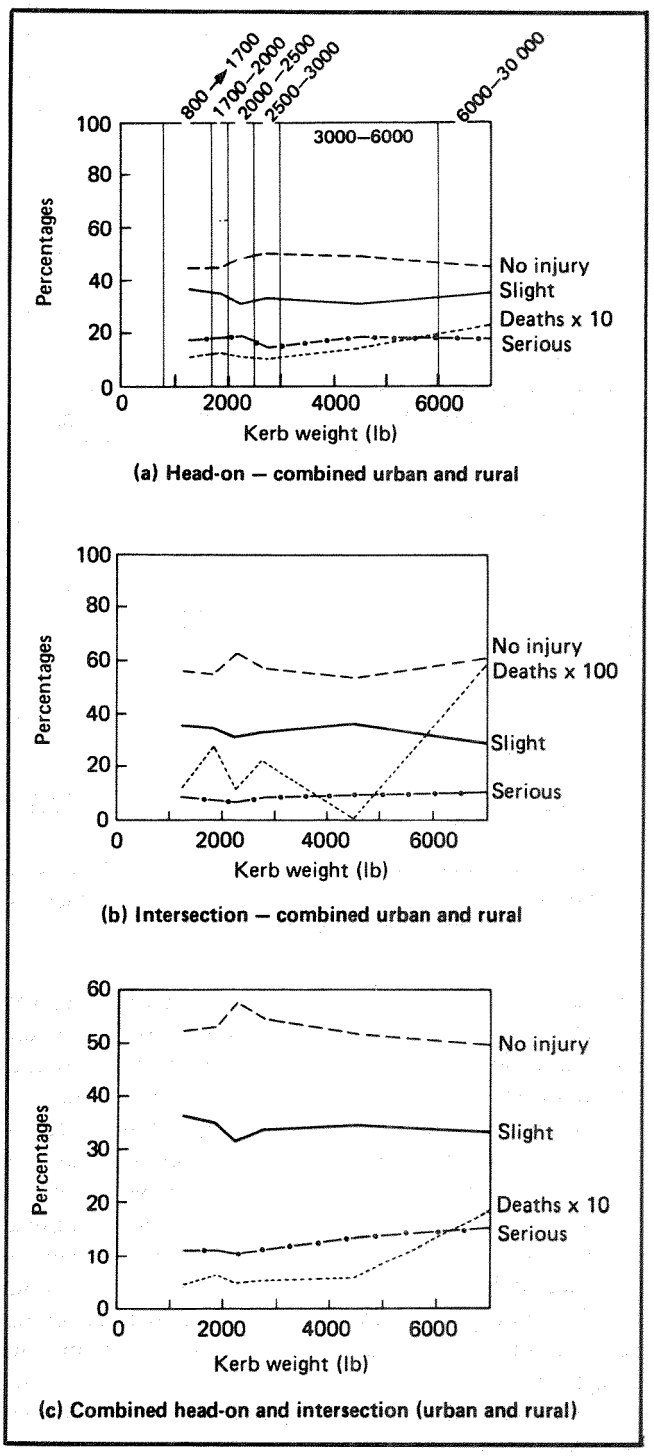


Figure 10. Drivers' injuries versus vehicle mass in collisions between vehicles of approximately equal mass.

CONCLUDING REMARKS

The large effect of mass ratio in injury accidents has been illustrated in the preceding sections. It is also of interest to examine its influence, not only on the percentages of injury in each of the two colliding vehicles,

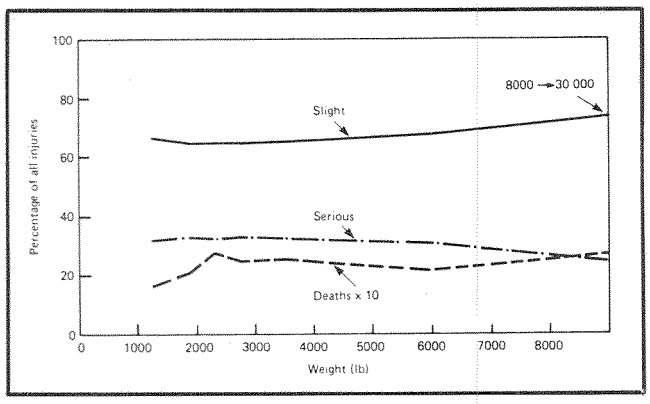


Figure 11. Single vehicle accidents—combined urban and rural: all types: percentages of all injuries.

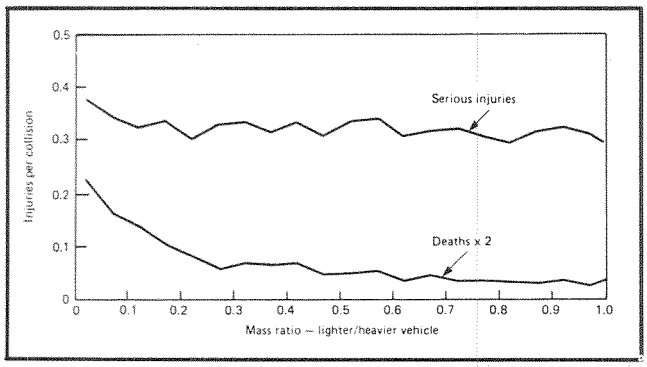


Figure 12. Injuries per collision—head-on and intersection (urban and rural) combined.

but also on the overall effect, that is, the injuries per collision. Reference to Tables 1 and 4 show that, while there is little variation over the car-car collision range, driver deaths per collision tend to be higher when cars are in collision with medium and heavy commercial vehicles. This is also true of serious injuries in urban but not in rural areas. Figure 12 shows the overall result when head-on and intersection data are combined. Since an increased severity of injury in the lighter vehicle is approximately compensated by a decreased severity in the heavier, and since mass of vehicle has little effect on severity, alterations in the proportions of cars of different weights in the car population would not have been expected to have strong effects on accident severity, at least in Great Britain in 1972.

Finally, it should again be emphasized that the effect of mass ratio on degree of injury is a large one, and thus it would be wise to take account of this factor when analysing others, for instance, age of casualty, model of car, or the effectiveness of safety devices.

ACKNOWLEDGEMENTS

The authors thank the Transport and Road Research Laboratory for financial support for the original research on which this paper was based and for access to national accident records.

REFERENCES

1. Bekiroglu, H. (1975). Automobile intersection collisions—an analytical and experimental investigation of the crash phase. Acc. Anal. Prev., 7. 225-237.
2. Campbell, B. J. and D. W. Reinfurt (1973). Relationship between driver crash injury and passenger car weight. Report from the Highway Safety Research Center, University of North Carolina at Chapel Hill.
3. Case, H. W., A. Burg and J. D. Baird (1973). Vehicle size and accident involvement: a preliminary study. Journal of Safety Research, *5,* 26-35.
4. Emori, R. I. and M. Tani (1970)., Vehicle trajectories after intersection collision. Soc. Automobile Engnrs, Paper No. 700176.
5. Emori, R. I. (1970). Vehicle mechanics of intersection collision impact. Soc. Automotive Engnrs. Paper No 70017Y.
6. Grime, G. (1966). Safety cars—principles governing the design of cars and safety devices. Report LR 8, Road Research Laboratory.
7. Grime, G. (1971). The effect of vehicle mass on the risk of injury in a collision. Report from the Research Group in Traffic Studies, University College London, February 1971.
8. Grime, G. (1975). Injuries to car occupants—theoretical considerations. Proc. I. Mech. E. 1975, Vol. 189, 51/75, 405-16.
9. Grime, G. and I. S. Jones (1969-70). Car collisions—the movement of cars and their occupants in accidents. Proc. I. Mech. E. 1969-70, Vol. 184 (2A), No. 5, 87-136.
10. Grime, G. and I. S. Jones (1973). The frequency and severity of injuries to the occupants of cars subjected to different types of impact in accidents: an investigation of British road accidents from police records. Proceedings of the Conference of the International Research Committee on the Biokinetics of Impacts, held in Amsterdam, 1973. (Lyon: L'Organisme National de Securité Routière.)
11. Grime, G. and T. P. Hutchinson (1979). 'Some implications of vehicle weight for the risk of injury to drivers'. Report from the Transport Studies Group, University College London, February 1979.
12. Hutchinson, T. P. (1977). 'Intra accident correlations of driver injury and their application to the effect of mass ratio on injury severity'. Accident Analysis and Prevention, *9,* 217-227, 1977.
13. Hutchinson, T. P. (1979). 'On the relative frequencies of collisions between vehicles of different masses', Zeitschrift fur Verkehrssicherheit *29,* 61-63, 1979.

14. Hutchinson, T. P. (1976). Statistical studies of road accidents and injury severity. PhD thesis, University of London.
15. Joksch, H. C. (1976). Analysis of the future effects of fuel shortage and increased small car usages upon traffic deaths and injuries. DOT-TS-COST-75-21, January 1976.
16. Kihlberg, J. K., E. A. Narragon and B. J. Campbell (1964). Automobile crash injuries in relation to car size. Report No VJ-1823-R11, Cornell Aeronautical Laboratory.
17. McHenry, R. R., A. S. Baum and D. O. Neff (1977). Yielding barrier test data base—a study of side impact cases in the multi-disciplinary accident investigation (MDAI) file. Report No ZR-5954-V-2, US Dept Transportation, National Highway Traffic Safety Administration, Washington DC.
18. O'Day, J., D. H. Golomb and P. Cooley (1973). A statistical description of large and small car involvement in accidents. HIT Lab Reports, *3*, No. 9.
19. O'Neill, B., H. Joksch and W. Haddon (1974). Relationship between car size, car weight, and crash injuries in car-to-car crashes. Proceedings of the 3rd International Congress on Automotive Safety, held in San Francisco, 1974. (Washington DC: US Government Printing Office.)

Evaluation of a Method for Determining the Velocity Change in Traffic Accidents

ANNA NILSSON-EHLE, HANS NORIN
CHRISTER GUSTAFSSON
Automotive Safety Centre
Volvo Car Corporation

ABSTRACT

An important parameter in the statistical evaluation of automobile accidents is the velocity change of the vehicle. The objective of this paper is to describe and evaluate a method for determining this parameter, in frontal collisions, in such a way that a reliable analysis of the Volvo accident material is achieved.

The paper begins by describing the general development from classifying accidents by the CDC-system to classification based on determination of velocity change—DV. Thereafter the early VOLVO DV calculations—based on the Campbell method—are explained and some drawbacks with this method are shown. The paper then proposes a more sophisticated method for calculating DV.

The ability of different methods to calculate correct velocity changes is compared in a few, well recorded, laboratory tests and traffic accidents. This comparison is a basis for an evaluation of the reliability of the proposed Volvo method. The influence of inaccuracy in the parameters in the model is discussed.

The paper then summarizes benefits of this method and suggests further activities in this field.

INTRODUCTION

The Volvo Accident Research System

To get a good knowledge of the crash behaviour of cars in the real traffic environment it is necessary to have a good traffic accident investigation system.

Volvo has a combination of multidisciplinary and statistical accident investigation (1). In this way we obtain both an overall representative picture of the whole traffic accident problem area and a deep insight into the specific vehicle behaviour and occupant injury mechanisms in a collision. This combination is illustrated in Figure 1.

The multidisciplinary accident investigation includes cases where our investigation team is directly called to the scene of the accident by the police or the S.O.S. alarmcentre.

At the scene of accident all data are recorded by means of interviews, photos and measurements. This documentation is followed by a thorough analysis of the crash behaviour of the vehicle at a Volvo garage.

Through this analysis we obtain knowledge of the event of the accident, the collision object and the vehicle deformations. Together with the injury pattern of the occupants in the vehicle we can get a very good picture of the accident.

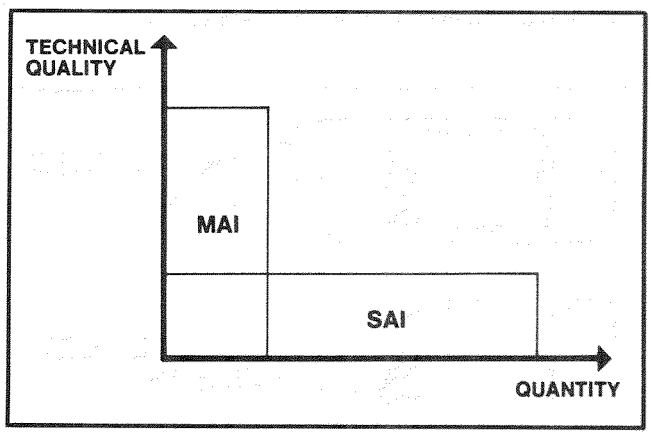


Figure 1. A schematic picture of the system for accident investigation.

The possibility to establish different characteristics of the accident, such as impact speed, forces acting on the occupants, is relatively good for these accidents.

The accidents investigated within the multidisciplinary system represent a limited amount of accidents. Our aim is to create the necessary conditions for establishing the characteristics mentioned above also for a large accident material.

In our statistical accident investigation we record data from about 2000 of the most severe accidents each year. The selection criterion is that the deformation is large and the vehicle is relatively new.

With the aid of the damage inspectors of Volvo's insurance company, VOLVIA, we get a recording of the vehicle deformation, documented through photos and certain measurements. Additional information on the accident is obtained through responses to a questionnaire sent to the occupants in the car, through injury information from hospitals and through police investigation reports.

With these data as a basis the vehicle deformation is coded according to the CDC-system (2) (as described later) and the occupant injuries are coded according to the AIS-scale (3).

All information is computer stored and can be analysed with respect to all input parameters.

As of now we have more than 12,000 severe accidents, with data on about 20,000 occupants, available for analysis.

Deformation Classification

As mentioned earlier the car deformation is classified according to the CDC-system which has been agreed on internationally (2). CDC means Collision Deformation Classification and is specified by SAE J 224B. This classification includes direction of force, area of damage, type of distribution and extent of deformation. The deformation is given as a discrete variable, VDI. An example of CDC-codification is given in Figure 2.

The CDC system gives a systematic recording of the remaining deformation and as long as only one car model is analysed, the extent of deformation can be the parameter used for sorting accidents according to severity. But this has to be done with great carefulness. Only cars that have experienced not only the same general accident type, e.g., frontal collision, but also the same distribution of damage and the same collision object may be compared.

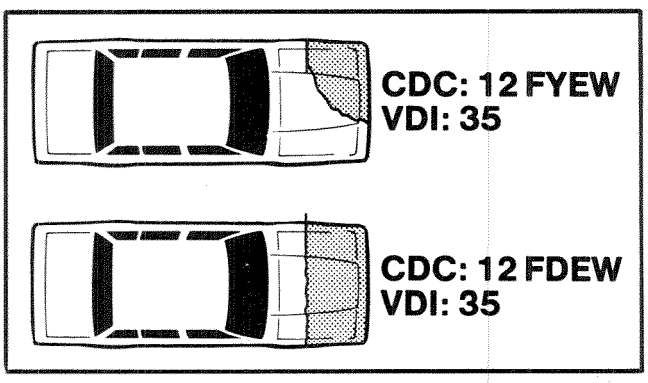


Figure 2. A typical CDC-codification of a Volvo car.

Due to the restrictions in the comparison of accidents with the extent of deformation as parameter, even a large accident material has to be broken down into several small homogeneous groups suitable for analysis. This makes the statistical uncertainty of the results unnecessarily large.

It is not possible at all, to include different car models in a CDC-based analysis. For the evaluation of the accident material there is a need of a better parameter than "extent of deformation" as a measure of accident severity.

For a car manufacturer it is obvious that the consequences for an occupant in a traffic accident depends on the whole course of deceleration of the vehicle. Thus during the engineering of a new car the restraint system is matched to the specific deceleration characteristics of the vehicle.

Also for the in-depth investigation of an accident it may be important to be able to reproduce the complete deceleration history of the vehicle. Through this it is possible to obtain a good understanding of the occupant injuries and their injuries mechanisms.

Accident reconstruction can be made mathematically, experimentally or as a combination of both. Mathematically, computer programs like SMAC (4) can be used but many investigation teams have their own simulation programs. Volvo has worked somewhat with mathematical simulation of accidents but rarely with experimental accident reconstruction.

An attractive alternative for the in-depth investigations is to equip cars with so-called crashrecorders—accelerometers that continuously record the motion of the vehicle. As of yet there are no crashrecorders cheap enough to fit as a standard equipment. There are however groups of cars, parts of research projects, that have been equipped with crashrecorders. They have then at the same time, been equipped with, e.g., an experimental restraint system.

The need of data for the statistical accident analysis is different from the need for the in-depth study. Where the in-depth study maps every detail and demonstrates the uniqueness of each accident, the statistical study is doing an analysis based on common characteristics for different accidents. The complex deceleration of the vehicle must be expressed in one or a few parameters. Each such parameter chosen will then have its limitations, of which the statistician must be aware.

THE DV PARAMETER

Theory

Due to the problems connected with CDC-based analysis, there has lately been a change, worldwide, towards

the use of another parameter which measures severity. This parameter is the velocity change of the vehicle in the accident, DV.

This parameter must also be connected to a direction of force. Accidents with the same general direction of force may be analysed together. The following parts of this paper deal with frontal accidents with a direction of force not deviating more than 30° from the longitudinal axis of the vehicle.

The velocity change can be calculated for two bodies engaged in a plastic impact. The formula is

$$\Delta\vec{V}_1 = \vec{V}_1 - \frac{m_1\vec{V}_1 + m_2\vec{V}_2}{m_1 + m_2}$$

where ΔV is the velocity change of vehicle 1
V_1, V_2 are the involved vehicles impact speed
M_1, M_2 are the involved vehicle masses.

DV is thus something different from impact speed, and it depends on the impact speeds and masses of the vehicles. To be able to determine DV in accidents there must be a possibility to calculate DV from postcrash instead of precrash data.

The Motive for Choosing DV

The violence to the occupant can be described in terms of the change of velocity and the rate of velocity change, the deceleration. The change of velocity is the same for both vehicle and occupant but the occupant deceleration depends on the coupling of the occupant to the compartment.

The compartment deceleration is of course dependent on the deformation characteristics of the car. Different vehicles can have different maximum deceleration and mean deceleration although they have the same DV = velocity change.

That DV is a suitable measurement of violence can be understood because the kinetic energy of the occupant during the crash is a function of DV and this energy has to be absorbed by a restraint system.

DV can be the same for a lot of different deformations. By DV, accidents with different deformation patterns can be analysed together. An example of this is given in Figure 3.

It has been shown in different studies (5, 6, 11) that estimated barrier equivalent speed has an outstandingly high correlation to occupant injury severity. This shows that DV is highly suitable as the accident severity parameter although it is not the total answer to the problem. The mean and peak deceleration during impact is of importance (12) and should be taken into account, for instance, when different car sizes are compared.

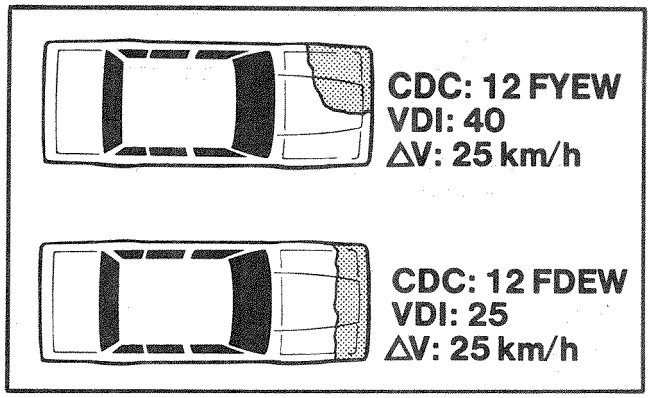


Figure 3. Example of different deformations giving the same DV.

Determination of DV

DV is determined in several ways, depending on the general system of investigation chosen by a certain investigation team.

Some investigation teams make estimations of DV based on an extensive recording of post-crash data, such as measurement of the involved vehicles, braking marks, skid marks, final positions, interviews with witnesses, etc. This requires a great amount of data but is nevertheless a judgment whose reliability is dependent on the experience of the investigators. This type of data can also be processed by mathematical collision simulation programs.

There have been several developments of such data models. Calspan Corporation has, on contract for NHTSA, made the CRASH program, which later has been revised to CRASH II and CRASH III (7, 8).

One way to gain experience is to perform a large amount of various collisions in the laboratory. By comparison between accident and laboratory results a barrier equivalent speed can be estimated for the accidents.

This method can be used together with reconstructions of actual collisions, thus "validating" the technique of the investigators.

Campbell shows in his SAE paper of 1974 (9) that there is a linear relationship between barrier impact speed and remaining deformation. His statement is based on barrier collisions with GM full size cars and Chevrolet Vegas.

From this Figure 4 the kinetic energy $\left(\frac{mv^2}{2}\right)$ required to create a certain remaining deformation can be derived.

Furthermore the energy needed to create an incremental increase of crush could be determined. Campbell makes the assumption that energy absorption is the same over the entire width and height of the front, and arrives at a description of the car front, as shown in Figure 5.

When the energy to create a certain deformation is known DV is calculated as

$$\Delta V_A = \frac{M_B}{M_A + M_B} \cdot \sqrt{\frac{(E_A + E_B)(M_A + M_B)}{M_A \cdot M_B}}$$

E = Absorbed energy
M = Vehicle mass

VOLVO'S FIRST APPROACH

Volvo had some specific requirements on the DV calculation method to be the successor of, or complement to the CDC system.

—Only postcrash should be required
—The data needed as input should be collected quickly and reliably
—The data collection should not require long experience
—The computation of DV should be quick and easy to handle
—It should not require inspection of the scene of the accident

The high emphasis on simplicity is due to the aim of using this system for all severe frontal accidents involving Volvo cars occurring in Sweden, most of which we never get the possibility to study in detail.

A survey was made of different possible DV calculation methods. We found the method described by Campbell very interesting. It seemed to suit us well because

—The only data needed from an accident is the car model, car weight and damage pattern.
—The registration of force-deflection characteristics is easily obtainable for Volvo models and hopefully possible to establish with other cars, perhaps with somewhat less accuracy.

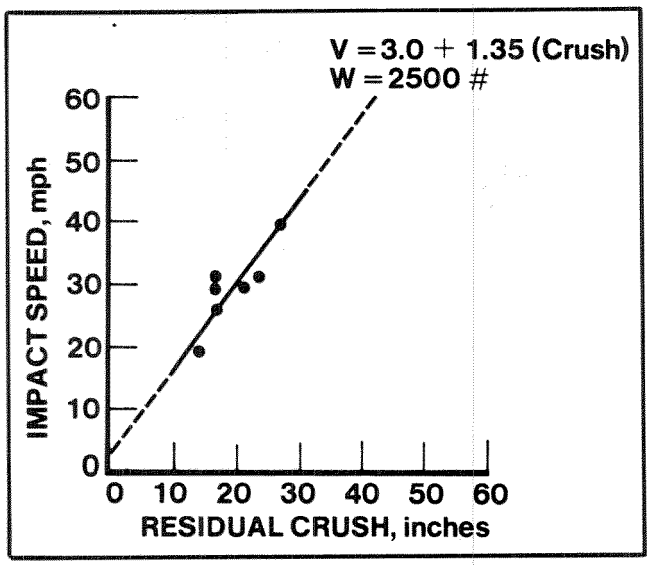


Figure 4. The crush VS impact line (from Campbell).

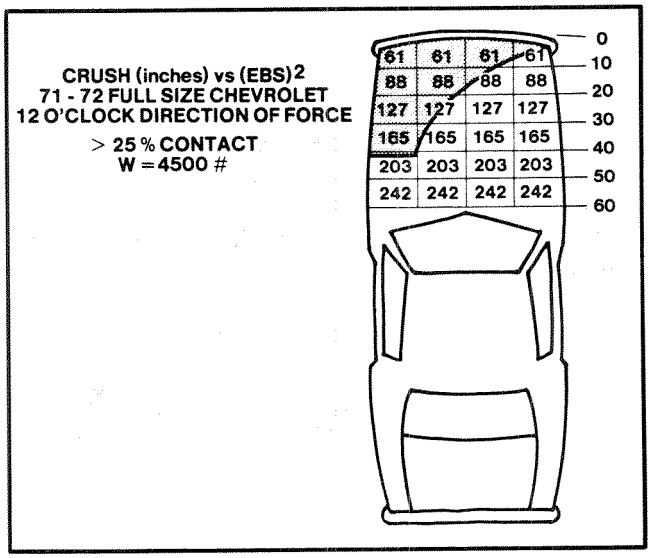


Figure 5. The energy description of a full size Chevrolet 72-73 (from Campbell).

—The model was said to work even when as little as 25% of the width of the vehicle is involved.
—The computation of DV could easily be performed by "easy to handle" computer programs.

Plots of impact speed versus residual crush from full frontal barrier tests showed that the Volvo models, 240

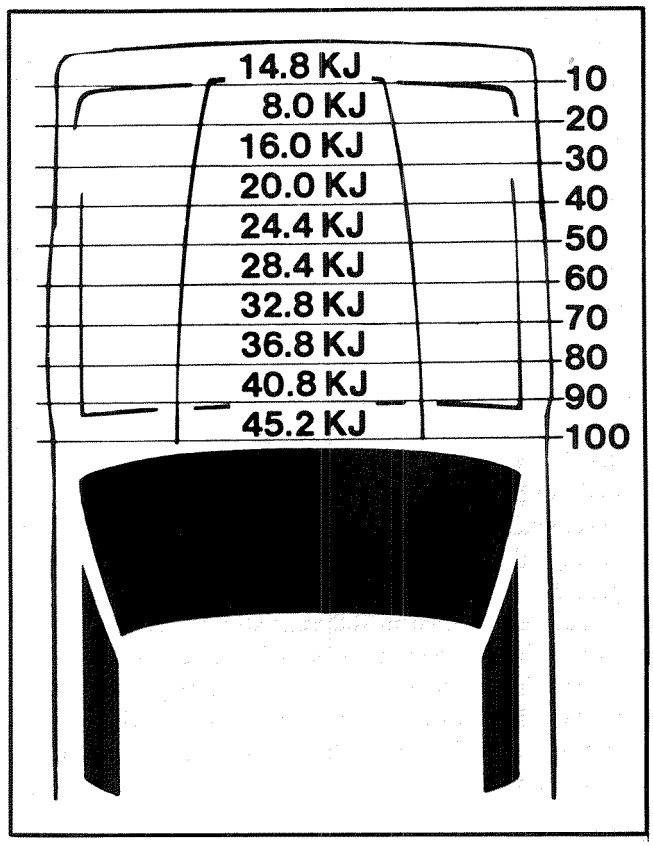


Figure 6. Energy absorption pattern for the Volvo 240.

and 760, have linear characteristics. This statement is discussed later in the paper.

The energy absorbed per unit of crush in the front was calculated. The Campbell assumption of even distribution of energy absorption over the width and height of the car was applied, and gave for the 240 car a frontal energy absorption pattern shown in Figure 6.

A package of computer programs was assembled to facilitate calculation of DV.

The energy matrix for any car is stored together with important data for that car, the length, the width, the curbweight and a few other things. The energy matrix for a car is calculated, if the equation of the line in the crush versus impact speed diagram is given.

When a DV is to be computed the program first asks for the type of car involved and fetches the stored data, including the energy matrix, for this car.

The deformation pattern is then asked for. It is given as an arbitrary number of coordinate pairs, the amount is decided by the investigator and depends on the complexity of the deformation pattern. Alternative patterns can be given. Based on the deformation pattern the absorbed energy is calculated.

To do the DV calculation according to the Campbell formula the characteristics of the various collision objects must be known.

The investigator can choose amongst three main types of collision objects.

1. Fixed rigid body —barrier
   —rock
   —pole, tree
2. Moveable rigid body —truck
3. Moveable deformable body—car

When the collision object is another car there will be a new loop of energy absorption calculation before the DV is computed.

When DV is computed and the investigator has decided on which alternative result to choose, this can be stored together with all other computer-stored information on that particular accident.

The application of this system to some selected traffic accidents soon showed that it had some major drawbacks which had to be dealt with

—The assumption that energy absorption was fairly even over the width of the car was not valid.
—Accidents involving poles had to be related to the actual packing of the engine compartment.
—Several of the distributed frontal collisions are partial underrides—a situation that doesn't engage the side members over the entire deformation phase.

As the existing method seemed to give good results in distributed frontal collisions where there was no underride it was decided to improve the Campbell method rather than choosing a new approach to the DV problem. Campbell himself (9) and Opel Co (10) have also written about these restrictions.

IMPROVEMENTS AND MODIFICATIONS

Firstly, we more thoroughly penetrated the statement that there is a linear relationship between velocity and remaining deformation.

Generally, the force F as function of deformation depth X, can be written

$$F(X) = K\,X^n$$

where K and n are constants.

For an ideal plastic impact we find that

$$\frac{1}{2}mV_o^2 = \int_o^c F(X)\,dX = K\int_o^c X^n\,dX = \frac{K}{n+1}\cdot c^{n+1}$$

where

m = the weight of the vehicle
V_o = the impact speed
c = crush distance

When n = 1 we have a linear relationship between V_o and $C \cdot V_o = \sqrt{\frac{K}{m}}\,c$

If $1 < n < \infty$ the force F (X) is described by the family of characteristics in Figure 7.

All these characteristics describe processes with different degrees of deformation hardening.

Barrier forces registered during tests indicate that n slightly greater than 1 could be possible, but as not enough tests have been carried out to prove it either way, the linearity seems to be an acceptable approximation of the relationship between velocity and deformation.

From the straight line in the crush versus velocity diagram the energy needed to create a certain deformation can be calculated.

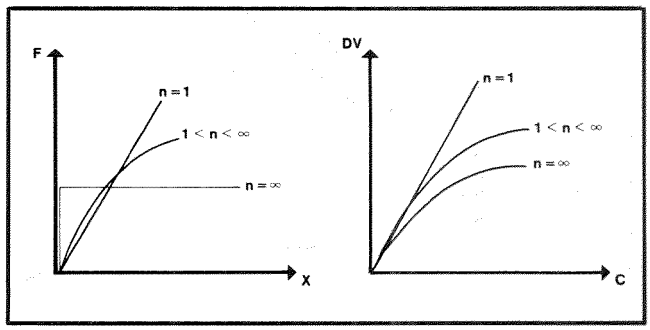


Figure 7. F (x) and DV (c) for different values of n.

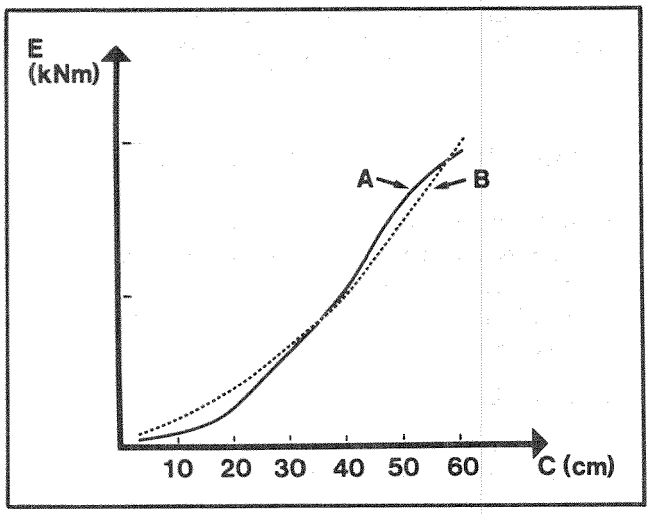


Figure 8. Comparison of energy vs. crush calculated in two different ways.

As a rule, energy as a function of deformation distance is always established in the full frontal barrier tests carried out in our laboratory. This is calculated by integration of the resultant force from the barrier.

The energy as a function of distance thus calculated (A) is in accordance with the energy versus distance curve we get from the "crush line" (B). This is shown in Figure 8.

By this comparison we are convinced that the Campbell method is valid for distributed collisions engaging the whole front.

The improvement should thus be based on the crush versus velocity characteristics, but with a certain carefulness in the low-speed part of the diagram (Figure 9).

The improvement was made along two parallel lines.

a) To arrive at a better representation of the energy distribution over the width of the car

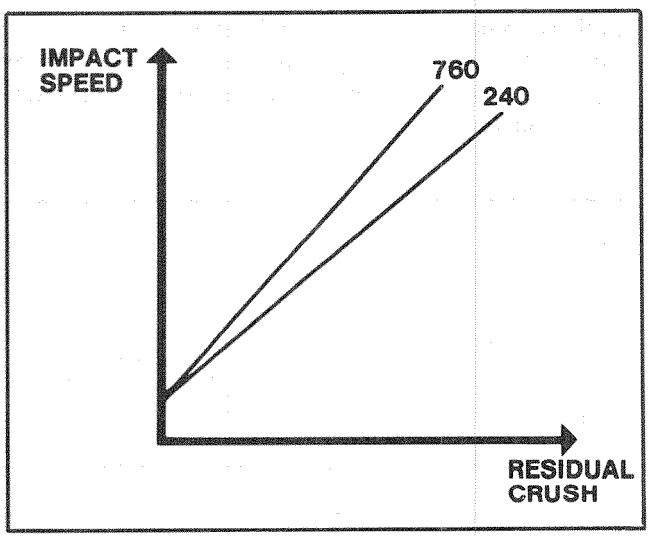


Figure 9. Crush vs. impact speed for the Volvo 240, 760.

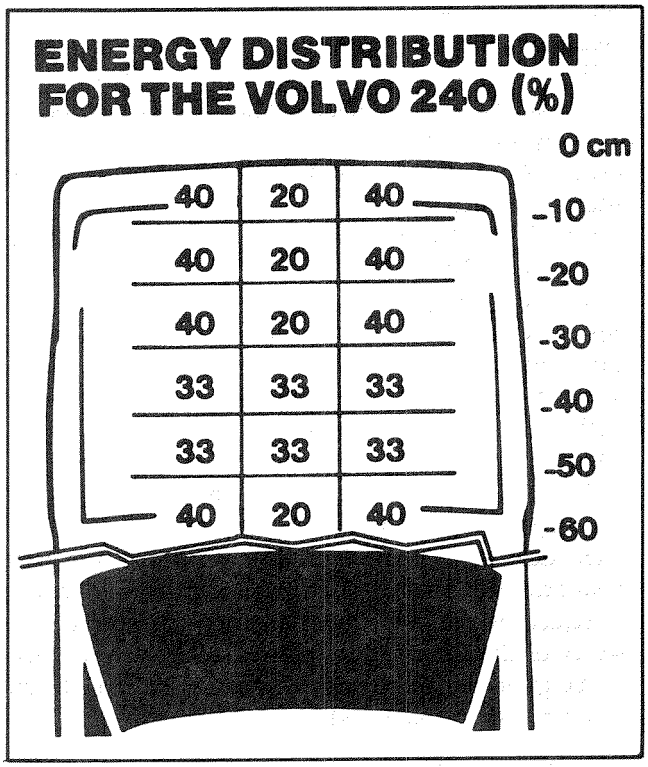


Figure 10. Energy distribution in the 240 front.

b) To arrive at the energy absorption when underride occurs.

From barrier forces recorded in full barrier 0° tests, the energy distribution over the width as a function of deformation distance was calculated.

It was shown that Volvo cars, with their symmetrical side members and longitudinal engine, are well represented by three segments with the outer parts of the fenders being completely neglected.

A typical distribution, for a 240, with the energy as a percentage of the total energy absorbed in that crush increment, is illustrated in Figure 10. It can be seen how the energy distribution alters when different parts in the engine compartment are engaged.

A similar analysis of full barrier tests can be performed to give the distribution of energy widthwise, in a plane above the side members.

It should be observed, however, that this only gives the distribution when the whole front is engaged as by the full barrier, and it cannot be used for the calculation of energy absorption when there has been a partial deformation of the front.

The next step was to analyse laboratory crashes not involving the whole front. This was done using half-barrier tests, both vertical and horizontal, and impacts with poles.

In the case both of the horizontal half barrier and impact with the pole between the side members, it can be seen that the reduction in speed is low until the engine

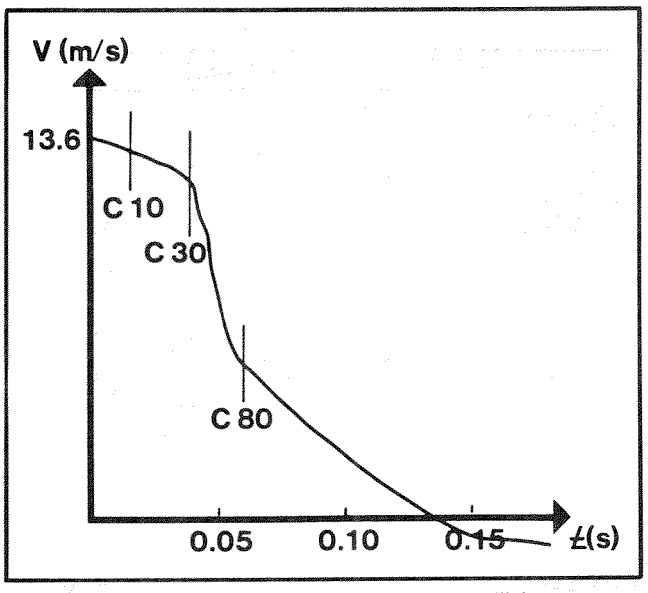


Figure 11. Typical V(t) curve for underride collision.

has been pushed close to the fire wall (Figure 11). Every collision type is "energy versus deformation" analysed, using the speed reduction as the input for the calculation of energy absorption.

The energy needed to deform a part of the front is then compared to the energy needed to achieve the same deformation distance in a full barrier crash.

In this way we find the relationship between the deformation work needed to deform a part of the front when the whole front is simultaneously deformed and the deformation work needed to deform the same part of the front when this part is the only part deformed.

In the case of impact with a pole between the side members, the energy absorbed is greater than the energy

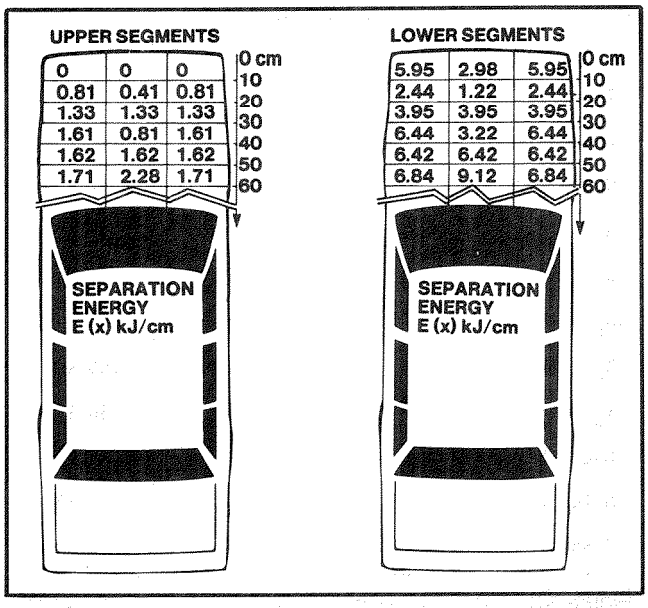


Figure 12. Typical energy matrix.

absorbed by the same segment in a full barrier impact. This is due to the energy needed to create the separation in the border zone between deformed and undeformed areas. This energy difference we call "separation energy".

The separation energy is always present in a deformation with deformation borders parallel to the longitudinal axis of the car. It is a function of deformation distance, just as the energy absorption is.

There is separation taking place also in the underride case, but as we only have two situations heightwise, either underride or total front engagement, it is practical to incorporate the separation energy in the upper energy matrix.

An analysis as above can be and should be made for the deformation work in the front of every car model, including different engines. Each car will have its own characteristical matrix of the type shown in Figure 12.

COMPARISON OF CASES

The evaluation of actual accidents has been performed for accidents in which our investigation team has had a good opportunity to gather information other than that used for the DV calculation. In this way we try to establish reference data for our DV-results.

For some accidents we have chosen to make mathematical simulations with the CRASH III program to obtain a comparison with this. The calculations have been carried out by Prof Warner, Collision Engineering Inc. who has experience of using the CRASH III program. In Table 1, calculations of DV are presented, for each case the results for the Campbell method (A), our modified version (B) and the CRASH III (C) are shown. It is compared to the estimated velocity change or laboratory recording.

The table shows that our modified version (B) provides a good correlation with what we have estimated to be the true facts. In the laboratory tests the error is less than 6% although the deformation has been measured in the same way as in the actual accidents. Other laboratory tests performed, but not shown in Table 1, also give errors less than 6%.

It is shown in Table 1, that for frontal distributed accidents without separation energy present, the Campbell method (A) and our modified version (B) give the same result, close to the "estimated DV". The CRASH III (C) calculation gives values which are too high.

For accidents against narrow obstacle, (A) gives a value which is too low, while CRASH III and (B) are close to each other and the "estimated DV". In the underride cases (A) and (C) give varying results depending on the interpretation the investigator has made of the damage pattern.

It is obvious that the modifications made to the Campbell method, nonuniform energy distribution widthwise and heightwise and introduction of separation-energy,

Table 1. DV calculation for some selected accidents.

	Obstacle	CDC-Code	DV km/h			
			est	A	B	C
1	Full barrier 0° (LAB)		48.3	48.8	47.8	—
2	Full barrier 30° (LAB)		56.9	52.5	53.3	—
3	Wall	12 FDEW2	25	23	24	28
4	Large stone	12 FLEW3	—	26	26	33
5	Half barrier 0° (LAB)		48.3	—	48.8	—
6	Large tree	01 FYEW3	—	49	49	60
7	Pole (LAB)		49.0	40.3	46.4	—
8	Pole	12 FCEN3	35	26	36	37
9	Underride (LAB)		49.0	—	48.6	—
10	Underride, partial	12 FYMW3	35	33	37	38
11	Car 340 (LAB)		44.6	43.6	43.5	52.3
12	Car 240 (LAB)		51.8	54.9	54.9	64.3
13	Car 240	12 FYEW3	35	34	30	38
14	Car 240	12 FYEW2	35	33	29	36

should give these differences between DV calculated by (A) and (B) respectively.

To understand the differences between (B) and (C) the CRASH III calculation must be explained.

CRASH III computes DV from energy absorbed in the impact, using the formula

$$E = \int_0^{\ell} \left(AC_1 + B\frac{C_1}{2}^2 + G\right) d\ell$$

where

li is the width increment engaged
C is the deformation distance
A, B, G are constants typical for a certain vehicle

The energy absorption is thus evenly distributed across the front, widthwise.

A, B, and G can either be set by the operator of the program or found in the manual to the program, which gives a choice of 11 different stiffness classes, 5 of which are cars. This table is shown in Figure 13 and you can find the Volvo in class 3. From laboratory tests we find that the A, B, and G values in class 3 are considerably higher than the actual values for the Volvo.

It is now understandable that for accidents where the force has been evenly distributed over the whole front, the higher stiffness of the CRASH III, will give a higher DV.

In accidents with narrow obstacles the higher stiffness may be balanced by the wrong assumption of an even energy absorption widthwise, adding up to something of the right order.

Slight differences between (B) and (C) are also due to different weight calculations and damage interpretations.

The weight of the car in (A) and (B) consists of curb weight plus passenger and cargo. The weight of unbelted occupants is not added and every belted occupant is counted as ⅓ of his real weight. The gas tank is assumed to be half filled. The CRASH III includes the total weight of every occupant.

ACCURACY

With what accuracy can DV then be determined using the modified model? The following is an attempt to estimate an overall error. This can no doubt be refined in future work. Let us assume that the DV computation of laboratory impacts will give us the maximum possible accuracy for this method.

This gives us, as mentioned above, a minimum error in the method, amounting to ± 6%.

PARAMETER	3
WHEELBASE (IN)	101.6-110.4
TRACK (IN)	58.9
LENGTH (IN)	196.2
WIDTH (IN)	72.6
a (IN)	51.3
b (IN)	55.5
X_F (IN)	89.8
X_R (IN)	-106.4
Y_S (IN)	36.3
RSQ (IN^2)	3324.
M ($LB\text{-}SEC^2/IN$)	9.18
CURB WT (LBS)	3247.

Figure 13. Table of car stiffnesses used in the CRASH III program.

The sources of errors are

A. inaccuracy in determining the speed versus crush line
B. inaccuracy in determining the deformation
   —depthwise
   —widthwise
   —heightwise
C. inaccuracy in determining the mass of the vehicles involved
D. inaccuracy in determining the energy absorption characteristics of the other vehicle involved

Error B above may, in turn, be broken down into inaccuracy due to investigator inexperience, and inaccuracy due to complicated deformation patterns, i.e., low quality of input data.

The Maximum Error

The maximum error can be calculated by the equation

$$DF\ max = \pm \left[\sum_{j=1}^{k} \left| \frac{\delta F}{\delta X_j} DX_j\ max \right| \right]$$

where $F(X_j) = dV(X_j)$

Thus DV is derived with regard to all its variables X_j, and DX_j is the estimated maximum error in that specific variable.

It is convenient to make the estimation of the maximum error in two steps. Step one concerns the error in the energy absorption determination of the case vehicle. This error can be estimated through an analysis of points A and B above. Step two concerns the error in the calculation of DV based on the knowledge from step one and the error contributions from points C and D above.

Thus, step one is performed as follows. The maximum error in the energy absorption depends on error sources A and B. Source A, the inaccuracy in determining the speed versus crush line, depends in its turn on the information from laboratory tests which the line is based on. A higher number of tests increases the confidence in the line being correct. We have earlier discussed the problem with determining the line, it might even be curved, and we know that the inaccuracy is higher at lower speeds. Instead of putting statistical confidence bands around our straight line we take a shortcut and assume that because the laboratory evaluation of the DV calculation method has a relative error of maximum 6%, this is also the maximum relative error arising from errors defined under point A.

Error source B, the error due to inaccurate measurements of the deformation, can also be estimated without doing the actual derivations. The maximum error arises when every measurement is erroneous in the same way, too high or too low. That situation actually indicates a systematic error which should be analyzed and eliminated. However, when this is the case we can, from the speed versus crush line, determine the error in energy due to a certain error in the crush measurement. The maximum error in deformation measurements can be held below 10% in all our accident investigations thus giving a maximum relative error of 9% in the energy determination.

Step two is done by derivating the DV formula from Figure 4 with respect to the variables, energy and mass. The simplest case is when the collision object is a rigid obstacle.

$$\text{We get } D(DV) = \frac{DV}{M} \cdot DM + \frac{DV}{2E} \cdot DE$$

The maximum relative error in DV can be calculated with the input from step one and the estimated maximum relative error in mass determination of 50 kg in the case vehicle. We find a maximum relative error amounting to 11%.

If the collision object is another car and not a fixed obstacle, the error in energy determination and mass estimation for that car must also be calculated. For our selected accidents the other vehicle has also been a Volvo where the errors are as discussed above. When the other vehicle is of some other make, we will have to make estimations of the energy absorption characteristics. At the best this could be done by assuming an even distribution of energy (as in the Campbell method) and base the straight line on data from a single standard compliance test. As is known from calculation in the CRASH program, this error can be quite large.

The Plausible Error

Hopefully, the maximum errors are not always adding up to their worst combination. If the errors are not systematic but random we can instead of adding the maximum error calculate the root-mean-square-value, RMS. This would give an RMS error of 6,5% if we apply it to both step one and two and an RMS error of 8,5% if it is applied directly on step two. It must be remembered that RMS errors are "typical", and are sometimes exceeded in unfavourable cases.

CONCLUSIONS

In accident analysis it is important to have a reliable parameter measuring the severity of the accident. The velocity change DV is such a parameter.

DV in frontal collisions can be established from post-crash data using the formula:

$$\Delta V_A = \frac{M_B}{M_A + M_B} \cdot \sqrt{\frac{(E_A + E_B)(M_A + M_B)}{M_A \cdot M_B}}$$

where EA and EB are the energies absorbed by the vehicles during the impact.

The accuracy of the DV calculation is dependent on the possibility to determine the energy absorption. It has been shown by Campbell (9) that the barrier impact speed as a function of remaining crush is a straight line. This seems to be an acceptable approximation for most cars. It is probable, though, that the straight line is curved in the extreme ends of the line.

Based on this, a simple energy absorption model can be derived, assuming even energy distribution across the whole front widthwise and heightwise. This model will work quite well for distributed collisions but give high errors in collisions involving narrow obstacles and underride.

By performing different laboratory tests a more complex energy absorption model of the front can be built. This model takes into consideration

—variation of energy distribution widthwise
—existence of separation energy when the front is partially deformed
—special deformation characteristics when the collision is of the partial underride type.

DV calculations based on this model for energy absorption give good accuracy for all types of frontal collisions within less than 30° from the longitudinal axis of the car and able to approximate as a plastic impact situation.

We find this model promising for our future work with our statistical accident investigation and believe that we by using this approach have sufficiently high accuracy in the DV calculation.

The main problem, however, is still the energy absorption characteristics of the other vehicle in the car-to-car impact cases.

* It is undoubtedly a major need of standardization of methods for determining DV. An international cooperation on this ought to be started.
* The error in the DV calculation will always be large as long as there is lack of knowledge of different car makes and models. It is important to establish ways of exchanging vehicle data to enable reliable calculations of DV and thus create a good basis for accident analysis.

REFERENCES

1. H. Norin, A. Nilsson-Ehle, C. Gustafsson, Volvo Traffic Accident Research System as a tool for side impact protection, evaluation and development, Ninth International Technical Conference on Experimental Safety Vehicles, Kyoto 1982.
2. Collision Deformation Classification—Technical Report—SAE J 224B.
3. The Abbreviated Injury Scale—presented on Eighteenth Conference of the American Association for Automotive Medicine.
4. C. Y. Warner, T. R. Perl, The accuracy and usefulness of SMAC, Twenty-second Stapp Car Crash Conference 1978.
5. Kenneth Campbell, Energy as a basics for accident severity, University of Wisconsin 1972
6. K. L. Campbell, Energy Basis for Collision Severity, Paper 740565 1974 SAE Conference.
7. J. Marquardt, Collision Severity—measured by DV, General Motors Corporation.
8. CRASH III, User's Manual.
9. G. C. Staughton, P. W. Jennings, Application of the Calspan Crash Program, under European Conditions. IRCOBI, Lyon 1978.
10. D. Schaper, Ist die Fahrzeugdeformation ein Mass für die Geschwindigkeitsänderung von Unfallfahrzeugen, Der Verkehrsunfall, the 17th annual volume, number 7/8, 1979.
11. K. Friedman, L. A. Klimko, Evaluating the Crashworthiness of Small Cars Using Accident Data, Eighth International Technical Conference on Experimental Safety Vehicles.
12. C. Tarrière, A. Fayon, F. Hartemann, The Contribution of Physical Analysis of Accident Towards Interpretation of Severe Traffic Trauma, 19th Stapp Car Crash Conference 1975.

Traffic Injuries in Göteborg—Registration of Accidents, Injuries, and Medical Costs

L. LINDSTRÜOM, Å. NYGREN,
D. STÅLHAMMAR and E. HOLMGREN
Department of Neurosurgery, Sahlgrens Hospital, University of Göteborg
B. ALDMAN
Department of Traffic Safety, Chalmers University of Technology, Göteborg
B. BRISMAR
Department of Surgery, Huddinge University Hospital, Huddinge
O. BUNKETORP and B. ROMANUS
Department of Orthopaedic Surgery, East Hospital, Göteborg
L. LINDSTRÖM
Lab for Clinical Neurophysiology, Sahlgrens Hospital, University of Göteborg
Å. NYGREN FOLKSAM
Insurance Company

ABSTRACT

Planning of accident prevention requires detailed information on accidents, injuries, costs for medical care, and other consequences for individual and society.

In Göteborg a system has been established for continuous registration of data on traffic accidents (cf Bunketorp and Romanus 1978). This system is now expanded to include collection of data on injuries and medical costs.

The aim of this report is to describe the methodology, difficulties and costs for data collection and also to discuss improvements of the system and exemplify the results obtained and their implications.

250 patients at "Östra sjukhuset" in Göteborg (traffic injuries) and "Huddinge sjukhus" (abdominal and thoracic injuries).

Data from the medical records have been collected by personnel with various qualifications: doctors, medical students and nurses. Types of information: individual, pretraumatic medical status, accident, injuries (type and severity according to the Abbreviated Injury Scale Classification), length and level of medical care, quantity of specific medical procedures (consultations, x-ray, lab tests, operations). The information has been structured into a form suitable for computer processing and entered via a terminal. Search for possible relations between trauma, costs, outcome, etc. has been made utilizing a specially developed program package.

The time required for data collection and entering into computer was successively reduced for 20-30 min/patient, still the errors encountered during these procedures seem to be less than 4%, varying with the type of data and the qualification and experience of the personnel. From the present experience we are able to optimize the process of data acquisition concerning the amount of information, degree of uncertainty and costs. In this retrospective study, based on hospital records, we found a large percentage of uncertain (0-20%) and missing data (0-50%) varying with the type of information.

In order to reduce these figures a prospective study must be carried out. It is concluded that the present method would be well suited for analysis of accident-injury relationships and cost-efficiency of medical care in a large scale multicenter study.

INTRODUCTION

The present study has been influenced by developments common to all countries of the industrialized world: altered distributions of age groups, growing unemployment and technological progress are factors that create new demands on society. In these radically changing circumstances we must analyse critically things that we have taken for granted in a welfare society, with a new awareness of costs and alternatives for all aspects of social care. With health care being the heaviest, and fastest growing cost in every modern society, all analyses of costs for medical care are of vital importance.

The planning of accident prevention and injury protection requires detailed information on accidents, injuries, costs for medical care, and other consequences for the individual and society. This information should be available continuously since important changes may occur over short periods of time.

In Sweden the following information is collected each year from most hospitals due to request from the Swedish Medical Council; the number of patients and their age, the length of hospital stay, diagnosis (according to the International Classification of Injuries, ICD, (4)), type of operation and cause of injury (ICD E-nr). It has been recognized, however, that the terminology on injuries and accidents in ICD, particularly in its present form (9th revision) is quite insufficient as a basis for a thorough analysis. Moreover, data on costs of medical care determining the resources available for the individual patient is in practice nonexistent.

Therefore we have started a study of the present situation with a long-term goal to contribute to the development of an appropriate system for continuous and relevant information from the hospitals regarding patients treated for injuries.

The aims of the present part of the project are:

—to elaborate a method to collect data from hospital records regarding the accident, the injuries and the consumption of medical resources for patients who have sustained impact injuries
—to assess the occurrence and the quality of the information in question
—to improve the quality of such information
—to test the usefulness of the method in a pilot study
—to exemplify the practical consequences

THE INFORMATION SYSTEM

General Considerations

In medical care no cases are alike. They differ with respect to background, trauma, diagnostic routines, therapy and outcome. Re-operations and repeated transfers between hospitals frequently occur which cause the same kind of data to appear iteratively. The information system therefore has to be very flexible indeed so that such data can be handled appropriately.

Medical data are often uncertain; diagnostic procedures and therapy seem to have occurred according to subsequent data but the specific events are not documented. Vague verbal statements in the patient files indicate the occurrence of actions taken but do not specifically state details.

In the search for combined causes and actions taken these uncertainties may or may not affect the statistical treatment depending on the combinations being inclusive or exclusive.

The practical information system has therefore been somewhat changed from what is normally used. In short it can be characterized as a set of labelled boxes containing the information and placed on the storage shelf in some not too rigorous scheme in contrast to the ordinary way in which each position on the shelf is assigned to a specific question. The system chosen allows a large variety of data to be contained in the same data pool.

The uncertainty in data is taken into account by a "quality label system" with three levels: data correct, data uncertain, and data missing.

The large variety of data has forced us to use different schemes of questions for different subgroups of patients and also to include the possibility to repeat the same questions on different occasions for the same patient. This has been implemented through the use of general input programs controlled by a set of text files containing different sets of questions which are brought into action in various combinations depending on the contents of previous data.

The statistical evaluation is performed by the formulation of a search profile containing the variables wanted as well as the contents of data pertaining to these variables. The procedure resembles the one used in scientific literature search although much more linking between questions and data contents is allowed. In particular, the use of so-called wild cards can be used in cases where certain aspects are to be neglected in the search. Also, a mathematical scheme for the logical combination of uncertain data has been included.

Specific Features

The information system is evolved to meet the following demands:

—the structure of the system is general

- basically the same system can be expanded for use within the areas of other diseases and injuries
- within the same system it is possible to freely add further variables of any category
- the data base created by this system is fully compatible with another data base with head injury patients (3)

—description of injuries, type and severity, allows for international comparison; ICD and AIS systems are used
—established codes (clinics & hospitals (7), geographical & mail codes (8), ICD-codes, codes within administrative and economic systems) are used for smooth communication with other databases
—reference to time and space (geographically and anatomically) is possible for any type of event
—data on consumption of medical resources is organized for automatic calculation of economic costs
—the system is designed to handle "soft", uncertain data
—the programs are designed for interactive working and their structure will after further elaboration allow for repeated data entering

Selection of Variables

The variables are arranged into groups according to Table 1.

In the Tables 2-7 are listed the variable names in the respective groups.

Table 1. Groups of variables with respect to information content.

individual
accident
injury
medical care—transportation
—hospital care—administration
—diagnostic procedures
—therapeutic procedures
—post hospital care

Table 2. Data on the individual.

* personal identification number
* age
* sex
* profession
* civil status
* social status
* pretraumatic medical status
  —specification of longterm diseases
  —occurrence of head injuries
  —abuse of alcohol (chronic and acute) and drugs

Table 3. Data on the accident.

* site
* date
* hour
* type of activity—work, leisure, play, sport, traffic, assault
* accident mechanics—fall (various kind), injured by object
* traffic accident—type of vehicle, collision and direction
* environment—in- and outdoor and other specified
* protective equipment
* status at scene of accident; unconsciousness

Table 4. Injury description.

* type of lesion—AIS 80-nomenclature (1)
* AIS-severity number (1)
* Injury Severity Score, ISS (1)
* anatomical code—body-region, AIS (1)
  —functional system, Nominae anat (5)
  —specific organ and part of organ (5)
* site of injury—sup-inf, ventr-post, right-left
* ICD-code (4)

Table 5. Transportation.

* date
* hour
* duration
* distance
* type of vehicle (4)
* status during transport
* treatment during transport

Sources of Information

Most of the data were collected from the hospital records and in addition some information was received from the health insurance office.

Table 6. Administrative data.

* data of arrival and discharge
* hospital-clinic code (7)
* discharged to
* registered diagnosis—ICD (4)
* registered cause of injury—ICD E-ser
* registered type of operation (9)

Table 7. Consumption of hospital medical resources.

* length of stay at hospital
* length of stay at intensive care unit
* surgical operations—organ operated
  —duration
  —type of anesthesia
  —type of operation
* consultations
* X-ray investigations
* dialysis
* intubation
* tracheostomy
* blood units
* drugs

Table 8. Medical data.

* status—arrival, discharge
* Complications—thrombo-embolic
  —infectious
  —pulmonary
  —cardiac
  —DIC

Table 9. Post hospital care.

* medical attendance
* length of sick leave
* status after 6-12 months
* status after 2 years
* status after 3 years

Collection and Entering of Data

The data were recorded on a form by personnel of various qualifications; a hospital nurse, a medical student, two registrars and an assistant professor (BB). The data were entered into the computer via a terminal by a technician and a student.

PATIENT MATERIAL

Patients from the following hospitals were included in the pilot study: Sahlgrens Hospital, East Hospital and

Childrens Hospital in Göteborg, Huddinge Hospital in Stockholm. See Table 10.

RESULTS

The Information System

Data collection. The form was primarily designed with a very spacious and simple layout. Annotations were made by simple markings. No figure codes were used in order to make the form filling as easy as possible and to minimize errors at data collection by personnel unacquainted with this type of work.

The time required for transfer of information from the records to the form varied considerably (15 min to 4 hours) according to:

—type and size of the medical record
—qualification and experience of the personnel
—type of data; most time-consuming were: lab-tests, drug consumption and injury coding

During the latter part of the study an out-patient record required 15-30 min and an in-patient record required 30-90 min.

Data entering. After successive improvements of the procedure it was possible to reduce the average time for data entering by a rather unexperienced person to 10-20 min per form.

Errors

Data collection. 120 completed forms were compared directly with the medical records by an assistant professor (BB) for most of the variables; totally about 4800.

—80 deviations were found (1.7%)
12 of these (0.3%) due to data entering errors
16 of these (0.3%) due to misinterpretation
52 of these (1.1%) misreading

Data entering. Two studies were made separately to control data entering errors.

1. For the first part of the study 4450 variables as appearing in the records were controlled by comparison against a list from the computer:

—43 deviations were found (1%)
12 of these (0.3%) errors regarding data quality
16 of these (0.4%) errors regarding figures
15 of these (0.3%) errors regarding other data

2. During the latter period of the study 2772 variables were controlled and totally 8 errors (0.3%) were found.

Data Quality

Due to the type of data and the type of patient, missing or uncertain information in the records is found in Table 11.

Findings in the Pilot Study

The details of this study will be presented elsewhere (cf 2). A general description of the material is given in Tables 12-15.

The correlations between the severity of injuries, expressed by ISS (1), and the consumption of specific medical resources for all in-patients presented in Figures 1 and 2.

Figure 3 presents the average total hospital costs for in-patients differing in degree of severity. Table 16 pre-

Table 10. Patient material in pilot study.

Selection criterion	No	Male	Female	Mean age
Traffic injuries, Göteborg			28	28
in-patients	71	43		
out-patients	136	85	51	30
Hudding Hospital			15	33
"abdominal inj," in-patients	63	48		
"thoracic inj"	61	42	19	43

Table 11. Data quality. The maximum percentage of missing and uncertain data occurring within a group of variables (cf Table 2-9).

Type of data	Indiv	Pretrauma	Accident	Injury Descr	Transp	Status arr/ dc	Surg op
In-pat							
uncert	0	10	5	0	3	0	3
missing	40	23	23	6	15	0	11
Out-pat							
uncert	0	20	7	0	5	0	—
missing	13	70	16	7	20	0	—

Table 12. Cause of accident.

	Traffic	Assault	Sport	Play	Other
Gbg, traffic, in-pat	69	0	0	1	2
Gbg, traffic, out-pat	136	—	—	—	—
HS, "abdominal inj"	23	25	1	—	20
HS, "thoracic inj"	21	20	2	—	30

Table 13. Distribution on various body-regions, according to AIS.

	Extern	Head	Neck	Thor	Abdom	Spine	Extrem
Gbg, traffic, in-pat	114	38	1	9	16	5	71
Gbg, traffic, out-pat	174	26	1	2	1	13	27
HS, "abdominal inj"	14	11	0	31	113	0	28
HS, "thoracic inj"	35	8	0	61	4	4	16

Table 14. Number of patients with various ISS.

	Göteborg Traffic		Huddinge	
ISS Range	In-pat	Out-pat	Abdominal Injuries	Thoracic Injuries
0- 5	30	131	8	0
-10	26	6	6	37
-15	5		1	19
-20	2		18	1
-25	2		13	1
-30	3		8	3
-35	2		7	
-40	0		1	
-45	1		1	

Table 15. Classification of injuries according to ICD, for 195 in-patients. Total number of registered diagnoses for official statistics and the total number of diagnoses found in the records in the present study.

ICD-nr		Official Reg	Our Study
800-829	Fracture	135	135
830-839	Dislocation		
840-848	Sprains and strains of joints and adjacent muscles	7	10
850-854	Intracranial injuries, excluding those with skull fractures	33	32
860-869	Internal injury of chest, abdomen and pelvis	146	159
870-879	Open wound of head, neck and trunk	14	41
880-887	Open wound of upper limb		
890-897	Open wound of lower limb	14	67
910-918	Superficial injury		
920-929	Contusion with intact skin surface crushing injury	15	53
950-959	Injury to nerves and spinal cord	2	2

Table 16. Consumption of medical resources for patients involved in motor-vehicle accidents. Numbers of X-ray investigations and blood units. Hospital costs in Swedish Crowns. Means and SEM.

	X-ray		Blood		Hospital Costs	
ISS-range	≤9	>9	≤9	>9	≤9	>9
Car-driver No (10+11)	4.5±1.7	11±3.5	0	7.3±4.7	10±4	56±27
MC-driver (5+7)	3.4±1.9	16±6	0.4±0.4	10±7.2	15±10	52±27
Pedestrian (6+11)	2±1	14±2.3	0	5±2.8	7±3	80±28

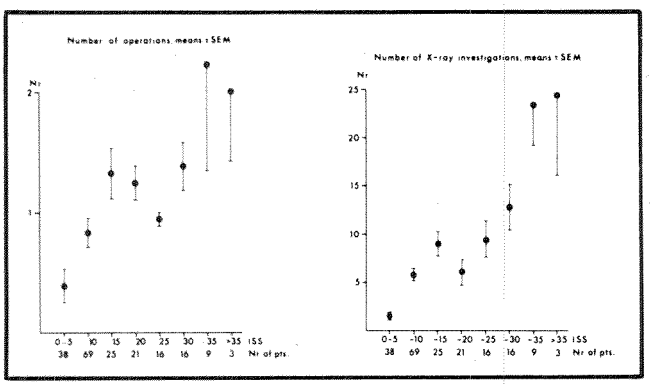


Figure 1. Number of surgical operations and X-ray investigations for groups of in-patients with injuries of different severity, ISS (1).

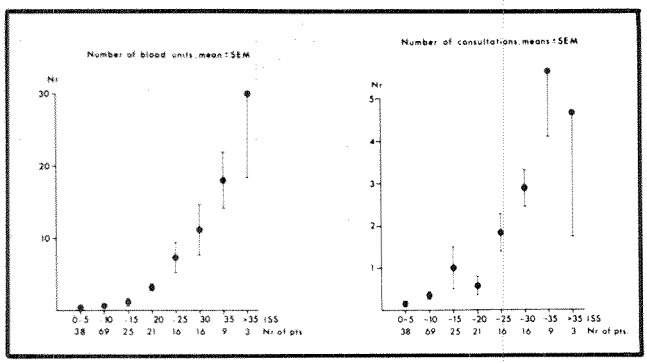


Figure 2. Number of blood units and consultations for groups of in-patients with injuries of different severity, ISS (1).

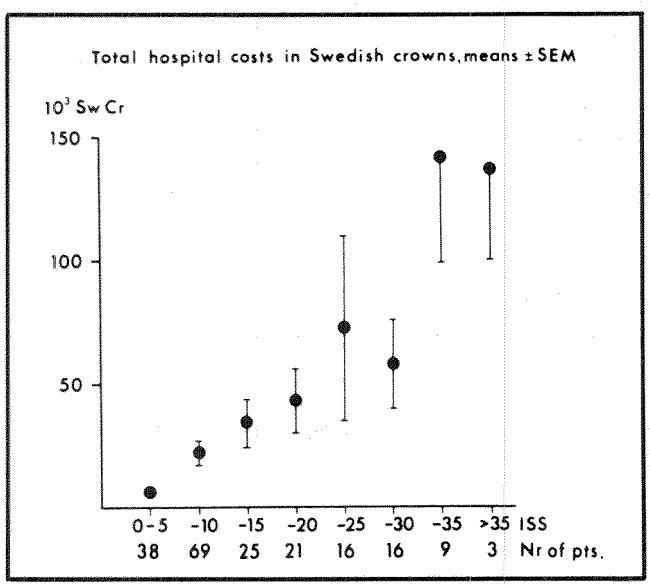


Figure 3. Total hospital costs for in-patients differing in degree of injury severity in terms of ISS (1). Means and SEM.

sents the hospital costs and consumption of specific medical resources for patients involved in certain types of motor vehicle accidents. The calculation of hospital costs is based on the number of days at an ordinary ward (1500 Sw Cr per day) and at an intensive care unit (6000 Sw Cr per day).

DISCUSSION

The present systems for classification and calculation of medical care costs for different types of injuries are considered unreliable and the figures available from official statistics may be misleading. Therefore, the aim with this project is to elaborate an instrument by which appropriate information could be collected for an analysis of the relationships between accident, injury and care. Information on pretraumatic circumstances and outcome should be included but we intend to focus particularly on classification of accidents of injuries and their prevention on one hand and on the other hand on assessment of consumption of resources in primary hospital care. The instrument should be designed for continuous use over a long period of time and information should be obtained from available medical records.

We have so far mainly devoted our efforts to methodological problems. The differences between the present official system and the system we have designed and tested regarding data on the accident, the injury and the costs for medical care are presented in Tables 3, 4 and 7.

The system has been tested in a pilot study as described above and the implications of practical application may be as follows.

In Sweden methods for assessment of costs for medical care are presently rudimentary as regards the individual patient and groups of patients. Officially and in research reports an average cost per patient day is calculated on the basis of the total annual costs for the clinic divided by the total number of patient days per year (cf 10).

The assessment of medical care costs used in the results presented above is based on measurement of the consumption of specific resources by the individual patient as described. However, staffing costs are shown to account for about 70-90% of total medical care costs and a further development is tested as well. By this method an estimate of the staffing costs has been derived on the basis of work load studies.

Table 17 shows the medical care costs per patient day;

Table 17. Medical care costs per patient day in two different clinics. The actual range according to our measurements and the official estimate.

	Actual Range	Official Estimate
Neurosurgery	1.1-3.4	2.5 Sw Cr 10^3
Intensive Care	3.5-13	6 Sw Cr 10^3

the actual costs per patient day may deviate twice from the official averages.

The example in Table 18 shows how severity grading and patient-based cost accounting will affect the estimate of total hospital costs for a specific type of patient-combination of injuries. Less severe injuries will be allocated to too high costs and the costs for patients with more severe injuries will be too low when the estimates are based on average clinical costs.

Table 19 shows the corresponding figures for a specific type of accident, i.e., pedestrians, and Table 20 shows the total hospital costs for 110 such patients with slight and severe injuries. The total costs for 110 pedestrians with slight and severe injuries will be about 2.7-.8 million Sw Cr. Our estimate will however reflect the actual allocation according to injury severity in a more accurate way.

Our experience points towards certain goals to aim for: an inclusive system for information must be formed, incorporating the following qualities: the information registered in the medical records must be complete, verifiable, easily and reliably registered. To fulfill these requirements we must construct forms which may be used by personnel of different qualifications. Emphasis must be put on the information and education of all personnel concerned.

Table 18. Example of specific patient type, combination of injuries, (brain concussion, AIS: 2-4 + fract of humerus, AIS 2-3 + skin abrasions, AIS 1-2) and total hospital costs.

	ISS-range		
	9-15	16-20	21-29
Study estimate	20	44	73 Sw Cr 10^3
Official estimate	26	34	35 Sw Cr 10^3

Table 19. The total hospital costs for pedestrian injuries of varying severity. Duration of hospital stay: 11-41 days.

	ISS range	
	4-9	31-35
Study estimate	13	140 Sw Cr 10^3
Official estimate	22	65 Sw Cr 10^3

Table 20. The total hospital costs for 110 pedestrian injuries of varying degree of severity according to our estimate and the official statistics respectively.

	ISS Range	Study Estimate	Official Estimate
100 slight injuries	4-9	1.3	2.2 mill Sw Cr
10 severe injuries	31-35	1.4	0.65 mill Sw Cr

Present classification systems which have proved inadequate must be revised for the present purpose. Similar attempts are currently carried out in the primary medical care in Sweden and have met with approval on all levels from politicians to patients.

Registration of information must thus be a firmly established routine. The next step will be to widen the perspective of health care to include further costs carried by society. One way will be to use the information registered by the insurance companies concerning sickness and accidents. The costs of post-medical care, pensions, etc., must be incorporated with costs of medical care on all levels in order to obtain figures of total costs to society, and non-medical costs should not be left out of economic considerations.

Costs for medical care must be strictly and consistently separated to form an adequate basis for cost-effect and cost-benefit analyses. All relevant costs must be attributed to each stage in the care of each individual patient. Bearing in mind that staff costs are the most important (70-90%), special efforts must be directed to measure these in a proper way by estimation of work load.

Consequently, the separation of costs is of utmost importance both in discussions of capital investments and organization of medical care as well as in debates concerning alternative methods of health care.

SUMMARY AND CONCLUSIONS

A method has been elaborated to collect and systematize information about persons who after having sustained impact injury have applied for hospital care. Hospital records, for in- and out-patients, constituted the main source of information which included data on the *accident,* the *injury* and the *consumption* of medical *resources.*

The percentage of errors at collection and entering of data was found to be low; about 1% and 0.4% respectively. The information system, although sophisticated and versatile, has yet proved possible to be smoothly run by rather unexperienced personnel.

It was shown that data on *pretraumatic* circumstances, on type of accident and on transportation were very often incomplete; missing for important variables in 15-70% and uncertain in 15-20%.

For the out-patients, there are no hospital statistics at all. For the in-patients only 73% of the injuries found in the study were officially registered.

For the in-patients, there was good correlation between the *injury severity,* as measured by ISS, and the consumption of medical resources.

In conclusion, our present official system for hospital statistics seems to be too insufficient and unreliable to produce an overall picture of the medical care of injured patients regarding medical as well as economic data.

By the method elaborated it will be possible to collect such data to a low cost—corresponding to less than 0.5% of the average hospital cost per admitted patient. However we consider it necessary to perform a prospective study to obtain more complete and valid data.

ACKNOWLEDGEMENTS

This study was supported by Swedish Medical Research Council Project nr B83-27X-06613-01, The Transport Research Delegation and the FOLKSAM Insurance Company. We are indebted to Mrs. Mall Stålhammar for valuable advice and translation into English.

REFERENCES

1. The Abbreviated Injury Scale 1980 Revision. American Association for Automotive Medicine, Morton Grove, IL 60053.
2. Brismar, B., B. Aldman, O. Bunketorp, E. Holmgren, B. Romanus, L. Lindstrom and D. Stålhammar: Injury Evaluation—Registration of Accidents, Injuries and Medical Consumption. Proceedings First Nordic Congress on Traffic Injuries, Linköping, Sweden, 1982.
3. Holmgren, E., C.-H. Nordström, D. Stålhammar: Head injuries in two Swedish regions during 1977. Acta Neurochirurgia, 1982 in press.
4. Manual of the International Statistical Classification of Diseases, Injuries, and Causes of Death. The 9th Revision, 1977. WHO, Geneva.
5. Nomina Anatomica. 3rd ed, 1972. Excerpta Medica.
6. Stålhammar, D., E. Holmgren, S. Lindgren and L. Lindström: Brain Injury Scaling. 1981 Proceedings 6th International IRCOBI Conference on the biomechanics of impact. 1982, in press.
7. Förteckning över Sjukvårdsanläggningar mm 1978, Socialstyrelsen. Liber.
8. Posthandboken, 1974. N A Bergforss, Malmö.
9. Klassifikation av operationer, 4:e uppl. Socialstyrelsen, Stockholm 1979.
10. Persson, Ulf: Vägtrafikolyckornas samhåsekonomiska kostnader. Report 1982:4. The Swedish Institute for Health Economics. Lund, Sweden.

Technical Session No. 5

Auto Safety Ratings

Mr. Kenichi Goto, Chairman, Japan

Aspects of the Passive Safety Motor Vehicles

B. RICHTER, R. ZOBEL
Research Division, Volkswagenwerk AG,
Wolfsburg, Germany

ABSTRACT

Repeated fears expressed in recent times hold that the increase in the market share held by smaller vehicles could lead to an alarming increase in traffic victims. Statements of this type are, for the most part, based on the Fatal Accident Reporting System (FARS).

At first glance these statistics would seem to confirm the fears mentioned above. However, more precise analysis shows that the relatively high proportion of traffic victims in small vehicles during vehicle-versus-vehicle collisions has been generated in the first instance by the mass aggressivity of the larger vehicles. An increased number of small vehicles in the future, accompanied by a simultaneous weight reduction in larger vehicles, would make it more likely that a reduction in the number of fatal injuries can be expected in this accident segment.

With respect to single vehicle accidents, the current statistical data picture is dominated by the fact that small vehicles are predominantly used by young drivers. If one assumes that an increasing market share for smaller vehicles must necessarily lead to a higher proportion of older drivers, then a relative reduction in traffic victims in small vehicles can also be expected.

One surprising result of this paper is the fact that occupants in vehicles of the mid-size range (1300-1500 kg) seem to be especially endangered.

INTRODUCTION

A steady increase in the United States of vehicles with smaller masses has fostered the concern that this may cause an alarming increase in the number of vehicle occupant fatalities. Specifically, it is feared that the expected broader mass distributions in passenger car to passenger car collisions could have particularly drastic effects.

The problem is then frequently reduced to a "large vehicle versus small vehicle" confrontation.

This results in statements like, for example, "Occupants of smaller vehicles (subcompact) are subject to hazards that are 8 times as great as those in larger vehicles (full size)."

This overlooks the fact that risks to the occupant of a subcompact vehicle are only 1.6 times greater than the corresponding collision probability, regardless of the significant mass relationship, while, at the same time, the occupants in the full size vehicle have lesser risks by a factor of 5 due to the lesser mass of the opposing vehicles (1).

This paper will attempt to show an analysis of the current accident situation in the United States: this analysis will address the fatalities in passenger car versus passenger car accidents as well as the fatalities in so-called "Non-Two Car Crashes", that in fact predominantly involve a single passenger car. The figures used are based on work by Evans (3), who compiled both the registration figures for 1978 and data regarding the driver age distribution in individual mass classes, along with FARS Statistics from 1978.

Several extrapolations (scenarios) were accomplished based on the current accident situation, and these allow estimation of the different mass-class related influences on the accident scenario of the future.

PASSENGER CAR VERSUS PASSENGER CAR ACCIDENTS ("TWO-CAR CRASHES")

Table 1 shows the distribution of occupant fatalities during passenger car versus passenger car collisions (FARS 1978), where passenger cars are divided into six classes from m_1 to m_6. Statements based solely on this table have limited applicability. On the other hand, they are admirably suited for building spectacular number relationships [3]. Thus, for example, only 12 occupant fatalities result in the largest mass-class vehicles, while 141 occupant fatalities occurred in the smallest mass-class vehicles during collisions involving vehicles from the smallest mass-class (m_1) versus vehicles from the largest mass-class (m_6). The factor of 141/12 = 11.75 derived from this corresponds to the factor 8* (based on FARS

* A direct, quantitative comparison is not possible, since formulation of the factor 11.75 is based on the distribution in six mass classes, while the factor of 8 was based on distribution in four mass classes (Subcompact, compact, mid-size, full size).

Table 1. The number of occupant fatalities in vehicles with mass m_i, when involved in collisions with vehicles of mass m_j (FARS 1978[3]).

		Car 1						
		m_1	m_2	m_3	m_4	m_5	m_6	Totals
car j	500- 900 m_1	7	11	13	17	10	12	70
	900-1100 m_2	32	19	11	26	23	22	133
	1100-1300 m_3	35	31	44	49	52	38	249
	1300-1500 m_4	96	97	131	178	169	150	821
	1500-1800 m_5	133	193	204	315	314	282	1441
	1800-2400 m_6	141	229	216	323	421	292	1622
Totals		444	580	619	908	989	769	4336

Table 2. Mass distribution of vehicles registered in the United States in 1978[3].

Symbol	Range kg	Average kg	Share %
m_1	500- 900	826	5.58
m_2	900-1100	991	8.78
m_3	1100-1300	1209	9.51
m_4	1300-1500	1403	13.36
m_5	1500-1800	1654	27.30
m_6	1800-2400	1992	35.47
	All	1594	100.00

Data for 1979), that was mentioned at the beginning with reference to its possibility for misinterpretation. We will come back to this issue later.

The disadvantage of Table 1 lies in the deficiency that it contains no information whether the number of occupant fatalities in a specific mass-class during collisions with vehicles from another mass can be expected or not. Therefore collision probability (exposure of the occupants) has to be taken into consideration. Collision probability is derived from the number of registrations through multiplication of the registration figures according to Table 2.**

The result is depicted in Table 3. This shows the individual probabilities for a collision by a vehicle in mass-class m_i with a vehicle of mass m_j. Sums in the columns and rows correspond to the proportion of registrations according to Table 2.***

If the number of occupant fatalities were exclusively a function of collision probability, and not dependent upon the specific properties of the individual mass-classes and/or combinations of mass-classes (mass ratio), then the total number of fatalities per Table 1 would have to break down according to the collision probability in Table 3 (4336 occupant fatalities = 100%). Table 4 shows this fictitious distribution.

It is a symmetrical distribution, meaning that the same number of occupant fatalities will occur in both vehicle classes during the collisions combination m_i with m_j. Therefore, for collisions of vehicles from mass-classes m_1 and m_6, 86 occupant fatalities in each of the two vehicle classes would result based on collision probability. Actually, 141 occupant fatalities were noted in class m_1, while only 12 occupant fatalities were noted in class m_6. This means that regardless of the extremely unfavorable mass ratio of 2.4, a fatality rate that is higher only by a factor of $141/86 = 1.64$, will result for the small vehicle, while the fatality rate in the larger vehicles is reduced by a factor of $86/12 = 7.12 = 1/0.140$. The product of both factors provides the previously mentioned ratio of $11.75 = 1.64 \times 7.17$.

Table 5 is produced by dividing each element in Table 3 by the corresponding element in Table 1.

This table indicates the factor by which deviation occurs between the number of occupant fatalities observed in FARS Statistics for 1978 and the number that is based on collision probability. Any factor greater than 1 means a higher proportion while factors less than 1 show a lesser proportion.

With the exception of the diagonal elements, there are still two influencing items within these factors. First there is the applicable mass relationship in each case. Here, the occupants in the lighter vehicle are fundamentally at a disadvantage for physical reasons. Second, major features of passive safety are naturally also expressed in these factors in the individual mass classes. This aspect can be examined independent of the influence of the mass relationship by using the diagonal elements, in which the vehicle classes with the same mass coincide, meaning that the physical advantages or disadvantages do not exist. Figure 1 shows the result.

This graph shows that the occupants in both of the smallest mass-classes, m_1 and m_2, as well as the occupants of the largest mass-class m_6, are clearly less endangered

** In this it is assumed that the yearly vehicle mileage is approximately the same for all vehicles and that the driving behavior does not significantly deviate between the different mass-classes.

*** Except for errors in rounding off numbers.

Table 3. Probability (%) of the collision of a vehicle m_i with a vehicle m_j, based on registration figures according to Table 2.

		Car 1						
		m_1	m_2	m_3	m_4	m_5	m_6	Totals
car j	500- 900 m_1	0.31	0.49	0.53	0.74	1.52	1.98	5.58
	900-1100 m_2	0.49	0.77	0.84	1.17	2.40	3.11	8.78
	1100-1300 m_3	0.53	0.84	0.91	1.27	2.60	3.38	9.52
	1300-1500 m_4	0.74	1.17	1.27	1.78	3.64	4.74	13.35
	1500-1800 m_5	1.52	2.40	2.60	3.64	7.45	9.68	27.30
	1800-2400 m_6	1.98	3.11	3.38	4.74	9.68	12.58	35.47
	Totals	5.58	8.78	9.52	13.35	27.30	35.47	100

Table 4. Number of occupant fatalities in vehicles with mass m_i during collisions with vehicles of mass m_j, if *only* the collision probability is the determinative factor.

		Car 1						
		m_1	m_2	m_3	m_4	m_5	m_6	Totals
car j	500- 900 m_1	13.50	21.24	23.03	32.30	66.05	85.12	241.95
	900-1100 m_2	21.24	33.43	36.24	50.82	103.93	135.04	380.70
	1100-1300 m_3	23.03	36.24	39.30	55.11	112.69	146.42	412.79
	1300-1500 m_4	32.30	50.82	55.11	77.28	158.03	205.32	578.86
	1500-1800 m_5	66.05	103.93	112.69	158.03	323.16	419.87	1183.73
	1800-2400 m_6	85.82	135.04	146.42	205.32	419.87	545.52	1537.98
	Totals	241.95	380.70	412.79	578.86	1183.73	1537.98	4336.00

Table 5. Relative risks of fatal injury for occupants of a vehicle with mass m_i during collisions with vehicles of mass m_j, as referenced to applicable collision probability.

		Car 1						
		m_1	m_2	m_3	m_4	m_5	m_6	Average
car j	500- 900 m_1	.518	.518	.564	.526	.151	.140	.289
	900-1100 m_2	1.506	.568	.304	.512	.221	.163	.349
	1100-1300 m_3	1.520	.855	1.120	.889	.461	.260	.603
	1300-1500 m_4	2.972	1.909	2.377	2.303	1.069	.731	1.418
	1500-1800 m_5	2.014	1.857	1.810	1.993	.972	.672	1.217
	1800-2400 m_6	1.643	1.696	1.475	1.573	1.003	.535	1.055
	Average	1.835	1.524	1.500	1.569	.836	.518	1.000

than their collision probability would indicate. As opposed to this, the risks for occupants in vehicles of mass-class m_4 are nearly twice as great as the collision probability would suggest.

A further distinction of mass-class m_4 can be derived from Table 5.

It could be expected that the relative risks for occupants in vehicle m_i would increase monotonically with the increasing mass m_j of the opposing vehicle. But, actually, a maximum for occupant risks is noted for *all* mass-classes (Line 4 of Table 5), if the opposing vehicle is from mass-class m_4, meaning vehicles in mass-class m_4 generate more fatal occupant injuries in all mass classes than the heavier vehicles in mass-classes m_5 and m_6.

SINGLE VEHICLE ACCIDENTS ("NON-TWO CAR CRASHES")

It is a fact frequently noted in literature that accident rates are strongly shaped by the age of the driver. This applies particularly for single vehicle accident in which, more frequently than in other accidents types, alcohol must be viewed as a contributing cause.

Table 6 shows the statistics for single vehicle accidents, broken down by mass-classes m_1 to m_6 as well as by driver age (3).

A relationship to collision probability is also necessary here. For this, the registration statistics must also be linked with a distribution by drivers' age (Table 7).

Table 6. Number of occupant fatalities during single vehicle accidents, broken down by vehicle mass and driver age (FARS 1978)[3].

Age, Years	Car Mass						Totals
	m_1	m_2	m_3	m_4	m_5	m_6	
16-24	581	817	967	1711	1861	897	6834
25-34	307	409	432	659	840	614	3261
≥ 35	263	433	517	948	1312	1603	5076
Totals	1151	1659	1916	3318	4013	3114	15171

Table 7. Age distribution (%) of the driver in the individual vehicle mass classes (Michigan, 1980[3]).

Age, Years	Car Mass					
	m_1	m_2	m_3	m_4	m_5	m_6
16-24	19.8	19.8	21.2	18.0	16.3	9.7
25-34	35.4	31.8	27.7	23.8	23.0	19.4
≥ 35	44.8	48.5	51.1	58.2	60.7	70.9
	100	100	100	100	100	100

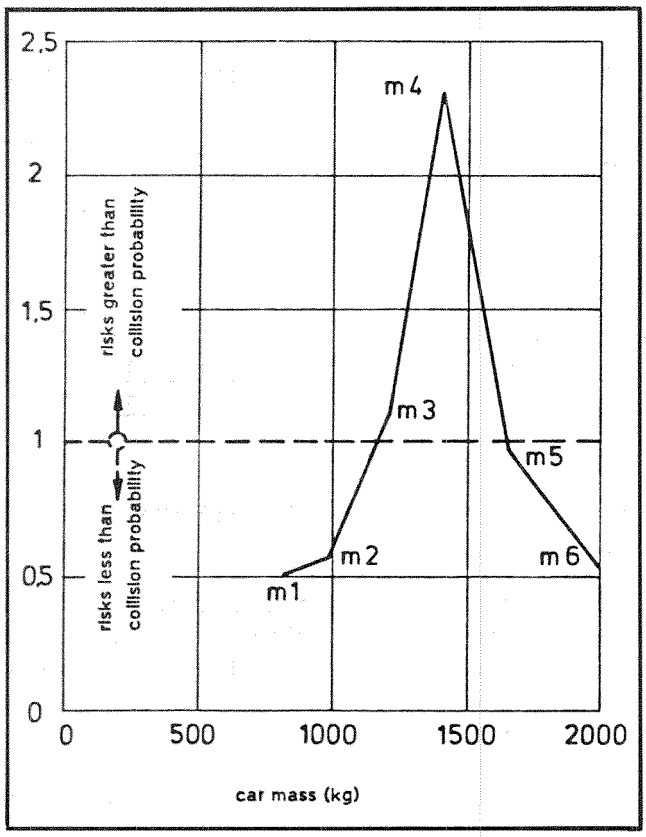


Figure 1. Relative risks of a fatal accident for occupants during collision of vehicles having the same mass, relative to the applicable collision probability.

Table 8 shows the resulting distribution (3).

Again if there were no particular influence due to vehicle mass and the age of the driver, the total number of occupants killed during single vehicle accidents (15,171) would have to break down in keeping with Table 8 (100% = 15,171 occupant fatalities). This fictitious distribution can be seen in Table 9. A comparison with Table 6 (FARS 1978) would, for example, state that only 167.6 occupant fatalities were to have been expected for mass m_1 in the age groups 16-24 years old: however, in actuality, 581 were registered. In keeping with this, the risks are 581/167.6 = 3.48 times as great as the expected value.

For drivers who are older than 35, the risks in the same mass-class m_1, with 263/379.3 = 0.69, are clearly under the expected value. If one uses this comparison for all mass classes and age groups, then Table 10 is obtained as a result.

Accordingly, all numbers greater than 1 mean a relative risk that lies above the expected value. The content of Table 10 is repeated in Figure 2. According to this, for the single vehicle accident area observations can be made as follows:

1. The relative risks for all mass classes lie significantly above the expected value for drivers between 16 and 25 years old.
2. If the driver is older than 35 years old, the relative risks in all mass classes are under the expected value.
3. Regardless of the driver's age, the occupants of mass-class m_4 (1300-1500 kg) are subject to the greatest hazards.

Table 8. Distribution (%) of registered vehicles in the United States, broken down by vehicle mass and driver's age (based on Table 2 and 7[3]).

Age, Years	Car Mass						Totals
	m_1	m_2	m_3	m_4	m_5	m_6	
16-24	1.10	1.74	2.02	2.41	4.44	3.44	15.15
25-34	1.98	2.79	2.64	3.17	6.28	6.87	23.73
≥35	2.50	4.25	4.86	7.77	16.58	25.16	61.12
Totals	5.58	8.78	9.51	13.36	27.30	35.47	100

Table 9. Number of occupant fatalities in single vehicle accidents, if *only* the collision probability is the determinative factor (by vehicle driver's age distribution and registration numbers for vehicles).

Age, Years	Car Mass						Totals
	m_1	m_2	m_3	m_4	m_5	m_6	
16-24	167.6	262.5	305.9	364.8	675.1	522.0	2298.4
25-34	299.7	423.6	399.6	482.4	952.6	1043.9	3600.1
≥35	379.3	646.0	737.3	1179.6	2514.0	3815.2	9272.5
Totals	846.5	1332.0	1442.8	2026.8	4141.7	5381.2	15171.0

Table 10. Relative risks of an occupant fatality in single vehicle accidents, relative to the applicable collision probability (elements of Table 6 divided by elements of Table 9).

Age, Years	Car Mass						Average
	m_1	m_2	m_3	m_4	m_5	m_6	
16-24	3.482	3.095	3.155	4.680	2.763	1.719	2.973
26-34	1.022	.966	1.079	1.370	.882	.589	.906
≥35	.693	.672	.701	.804	.522	.420	.547
Average	1.360	1.245	1.327	1.638	.969	.579	1.000

This last determination is noteworthy because the highest occupant risks also appeared within mass-class m_4 (Figure 1) for passenger car versus passenger car collisions.

If one compares Figures 1 and 2, the question arises as to why the favorable behavior of the smaller vehicles (m_1 and m_2) during passenger car to passenger car collisions is not also reflected during single vehicle accidents in the same degree. Namely, if the single car accidents consisted exclusively of collisions with flat, rigid obstacles, then these accidents would be comparable to a great extent to collisions between passenger cars having the same masses. Apparently there are obstacles involved in single car accidents that have different aggressive effects on smaller and larger vehicles. There are a number of possible explanations for this based on studies by the Office of Highway Safety (Bennet, FHWA [2]):

1. The posts used for a specific group of traffic signs are too rigid for small vehicles.
2. The exposed rigid base of posts with a defined breakaway point is too high for small vehicles due to their low ground clearance.
3. Guardrails are positioned too high for small vehicles, meaning that the front wheels of small vehicles catch on the guardrail posts while the large vehicles are deflected during such collisions.

These findings by FHWA have resulted in the fact that small vehicles will also be included in future studies to determine relevant safety fixtures along the road.*

* Examples from the FHWA Program [2]:
- Improved Performance of Small Sign Supports
- Guardrail and Median Barrier Terminals for Mini-Sized Cars
- Safety Modifications to Turn-Down Guardrails Terminals
- New Concepts in Traffic Barrier Systems.

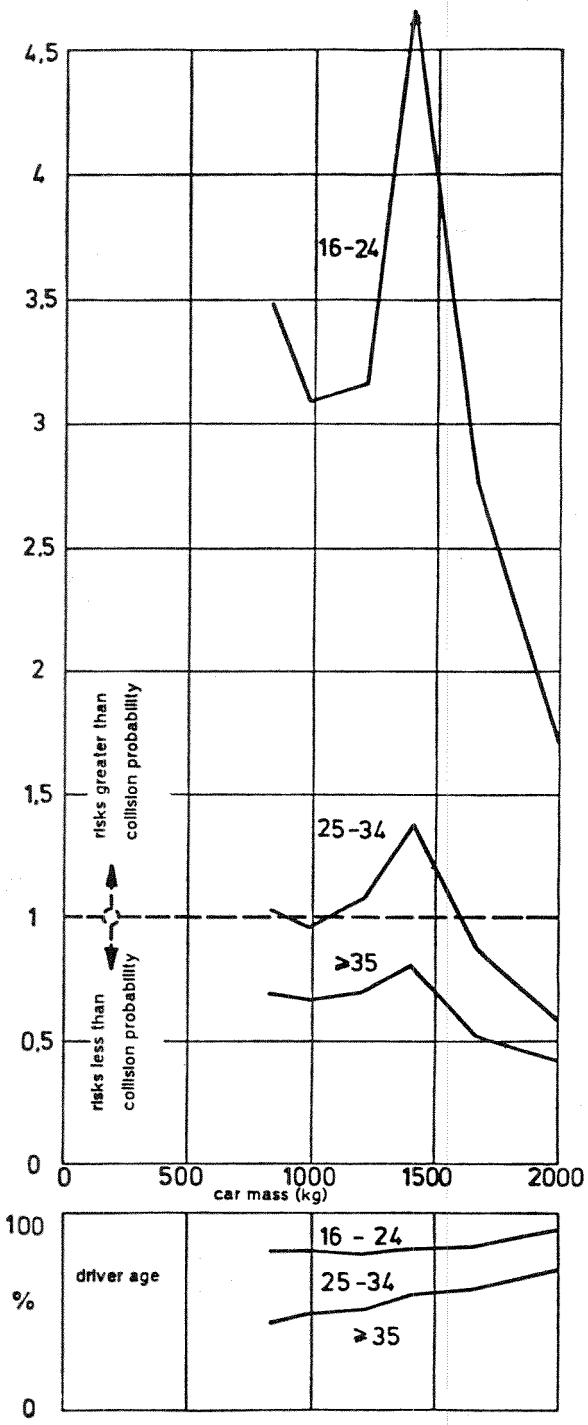


Figure 2. Relative risks of fatal injuries for occupants in single vehicle accidents ("non-two car crashes"), relative to the applicable collision probability.

SCENARIOS

The following will examine how the market share of the various mass classes affects the accident statistics for occupant fatalities. In order to better compare current statistics, this will assume that the total number of vehicles has not changed. Furthermore, it must be assured that the mean age structure is not modified during the extrapolation (16-24 years old: 15.15%, 25-34 years old: 23.73%, $\geq$ 35 years old: 61.12%). For example, this condition means that the age structure according to Table 5 will be retained during a doubling of the market share of one of the six mass classes, and that changes will only be made based on mean age distribution. Table 5 (Passenger Car Versus Passenger Car Accidents) and Table 10 (Single Passenger Car Accidents) are the basis for all extrapolations.

Eighteen different scenarios, as compared to current status, are depicted in Table 11. Scenarios 1 to 6 assume a doubling of the market share of one of the six mass classes with a simultaneous reduction in the market share of the other classes, consistent with prior distribution.

The other scenarios represent extreme changes. Only a single mass class is represented in each of the scenarios 7 to 12, and one mass class was completely eliminated in each case in scenarios 13 to 18.

It is surely no surprise that the largest mass classes (m_5 and m_6) leave the most favorable impression during consideration of all scenarios. In contrast, however, it is noteworthy that with the increase in the market share of the smallest mass classes (m_1 and m_2), the total number of occupant fatalities only slightly increased or was even reduced, contrary to some predictions. When its market share is doubled, the smallest mass class increases the number of occupant fatalities by only 0.4% while in mass class m_2 there is even a reduction of 0.2% with a doubling of the market share. Recall that, along with the physical disadvantage of the smaller masses during passenger car versus passenger car collisions, there is also the handicap of non-aligned traffic direction fixtures, as mentioned in Section 3. This fact is especially prominent in the types of scenarios in which only one mass class is represented. The number of occupant fatalities is reduced here for passenger car versus passenger car accidents to over 48% in the smallest mass class (m_1), while there is an increase of 10.1% for single vehicle accidents. A similar trend can be shown for the second smallest mass class (m_2).

In contrast, the sharpest rise in the number of occupant fatalities is characterized in mass-class m_4 by increasing its market share: put another way, elimination of this mass class would lead to the strongest reduction in the number of occupant fatalities.

SUMMARY

A detailed analysis of the FARS Statistics has shown that the current relatively high number of traffic victims in small vehicles during vehicle versus vehicle collisions can, in the first instance, be traced back to the mass

Table 11. Extrapolation of accident statistics for occupant fatalities with modified market shares by the six mass classes.

		Market share (%)						Number of occupant fatalities			Change (%)		
No.	Scenario	m_1	m_2	m_3	m_4	m_5	m_6	Car/ Car	Single Vehicle	Total	Car/ Car	Single Vehicle	Total
	Current Status												
	Double the market share of^{-1}												
0													
1	m_1	11.16	8.26	8.96	12.56	25.69	33.37	4359	15221	19580	0.5	0.3	0.4
2	m_2	5.04	17.56	8.60	12.07	24.67	32.06	4271	15192	19463	−1.5	0.1	−0.2
3	m_3	4.99	7.86	19.04	11.95	24.43	31.74	4384	15294	19678	1.1	0.8	0.9
4	m_4	4.72	7.43	8.05	26.70	23.09	30.01	5028	16271	21299	16.0	7.3	9.2
5	m_5	3.48	5.48	5.95	8.34	54.60	22.15	4372	14772	19144	0.8	−2.6	−1.9
6	m_6	2.51	3.95	4.29	6.01	12.29	70.94	3268	12241	15509	−24.6	−19.3	−20.5
	Vehicle population consists only of ...												
7	m_1	100	0	0	0	0	0	2248	18111	20359	−48.2	19.4	4.4
8	m_2	0	100	0	0	0	0	2465	16819	19284	−43.2	10.9	−1.1
9	m_3	0	0	100	0	0	0	4855	17637	22492	12.0	16.3	15.3
10	m_4	0	0	0	100	0	0	9988	23146	33134	130.4	52.6	69.9
11	m_5	0	0	0	0	100	0	4213	14361	18574	−2.8	−5.3	−4.8
12	m_6	0	0	0	0	0	100	2321	9965	12286	−46.5	−34.3	−37.0
	(Mass Class m_i) was removed from the vehicle population												
13	m_1	0	9.30	10.08	14.14	28.91	37.57	4295	14511	18806	−0.9	−4.4	−3.6
14	m_2	6.12	0	10.44	14.63	29.93	38.88	4377	14509	18886	0.9	−4.4	−3.2
15	m_3	6.17	9.70	0	14.75	30.17	39.20	4290	14404	18694	−1.1	−5.1	−4.2
16	m_4	6.44	10.13	10.99	0	31.51	40.93	3709	13412	17121	−14.5	−11.6	−12.2
17	m_5	7.68	12.08	13.09	18.36	0	48.79	4200	14843	19043	−3.1	−2.2	−2.4
18	m_6	8.65	13.61	14.75	20.69	42.31	0	5307	17320	22628	22.4	14.2	16.0

aggressivity of the larger vehicles. In a collision involving only smaller vehicles, the fatality risk is clearly less than the expected value. It is more so the case that after a slight increase in the total number of occupant fatalities during an increase in the market share of smaller vehicles, further increasing the market share can lead to expectations of a decrease in the total number of occupant fatalities. This trend will surely be even further reinforced by the simultaneous reduction in the weight of larger vehicles (to reduce fuel consumption rates).

When one considers the area of single vehicle accidents, the current statistics are in part highlighted by the fact that small vehicles are predominantly used by younger drivers, whose behavior leads to an increased accident risk. Beyond this, there is the indication that the Roadside Barriers and Structures available at this time are not adapted to the exterior dimensions of the smaller vehicles.

If one assumes that an increasing market share for smaller vehicles necessarily leads to a higher proportion of older drivers of these vehicles, and that the programs that have been instituted to improve Roadside Barriers and Structures will have an effect during the course of the year, then a decrease in the number of traffic victims in small vehicles can also be expected in single vehicle accidents.

A surprising result of the analysis is the fact that occupants in vehicles of the mid-class (1300-1500 kg) appear to be over-involved.

REFERENCES

1. W. Dreyer, B. Richter, R. Zobel: Handling, Braking, and Crash Compatibility Aspects of Small, Front Wheel Drive Vehicles. SAE Paper 810792, June 1981.
2. R. C. Bennet: The Small Car and the Forgiving Highway. Office of Highway Safety, Federal Highway Administration, SAE Passenger Car Meeting, June 1981.
3. L. Evans: Car Mass and Likelihood of Occupant Fatality. SAE Paper 820807, June 1982.

The Increase in the Risk of Injury in Traffic Accidents as a Result of Higher Test Impact Speeds

DR. WALTER SCHMID
Daimler-Benz AG, Sindelfingen

THE PROBLEM

Extensive investigations of actual road accidents for a number of years have already led to the result that vehicle manufacturers are testing the safety of their newly constructed vehicles by means of an impact test while selecting a test speed of 50 km/h for this purpose.

It seems rather obvious at first to expect the safety value of a vehicle tested at a higher testing speed also to be higher. Such a thought may very well also have been the basis of a draft with pertinent regulations issued by NHTSA authorities who would like to arrange the various vehicles in the order of their highest permissible test impact speed.

However, such an intention will heighten the problem of compatibility during a vehicle impact.

More recent investigations have additionally shown that an aggravation of test conditions may not just reduce the risk of an injury, but may even increase such a risk. Evaluating the results of actual accidents can in fact be applied to show that with regard to the risk of injuries during front end accidents the present vehicle population is optimally attuned and that any change may result in a change for the worse.

A careful analysis of the possibilities for obtaining an additional reduction of the risk of injuries by making changes on the vehicle is presented below.

INJURY SEVERITY AND CRASH SEVERITY

R & D engineers of the automobile industry have always been entertaining the up to now unfortunately unfulfilled wish of finding physical, measurable characteristics on vehicle, which have a positive connection with the respective accident or permit at least significant correlations.

A change of speed or an equivalent test impact speed is considered to represent such a characteristic, even though it is well known, that at pertinently smooth braking given changes in speed are free of risk for human beings.

Consequently, acceleration (deceleration) of the passenger compartment provides a physically meaningful characteristic, since the acceleration of the occupants is causatively dependent therefrom, since the acceleration of the occupants requires forces, which may cause injuries when biomechanical boundary values are exceeded.

A completely different mechanism with regard to injuries may result in crush injuries (bruises) if deformations of the cell surrounding the occupants are excessive.

Only the "not causative" dependence of the change in speed with regard to acceleration and intrusion on real vehicles permitted to consider these alone "temporarily" as a characteristic for the severity of an accident.

Characteristics of the Severity of an Accident

Even though, therefore, many injuries to the occupants of a vehicle have a causative relationship with the acceleration of the vehicle, this characteristic is too hard to handle to characterize the seriousness of an accident because of its considerable versatility as a continuous sequence with regard to time. Only a few numerical data should be required to describe what is essential.

Such essential figures are the acceleration level, the duration of the effect and perhaps data concerning the shape of the acceleration sequence, such as triangular, sinusoidal and saw-tooth shaped. The change in speed is the integral via the acceleration-time curve. The deformation path is also quite considerably dependent on the shape of the acceleration sequence.

The change in speed Δv which can be interpreted further down always as a barrier impact speed, the mean acceleration a and its deformation path s are therefore containing all the essential information of an acceleration-time characteristic, adequate for many observations. Because the intrusion depends on the deformation, these three characteristics are also containing the cause for crush injuries.

It is unfortunately not permitted to estimate the influence of these three characteristics with regard to the seriousness of an injury from a major number of real accidents. The three characteristics are not independent in relation to each other. The relation named in equation (1) which is obtained directly from energy observations, applies

$$s = \frac{\Delta v^2}{2a} \qquad (1)$$

Figure 1 shows a section of this relation which is of interest for the passive safety of vehicles. Now, for example, the change in speed could be determined from (1) and only the mean acceleration and the deformation could be considered characteristics for the seriousness of the accident. Unfortunately, on real vehicles, these two characteristics are also not independent of each other. It is therefore better, to find new, independent characteristics

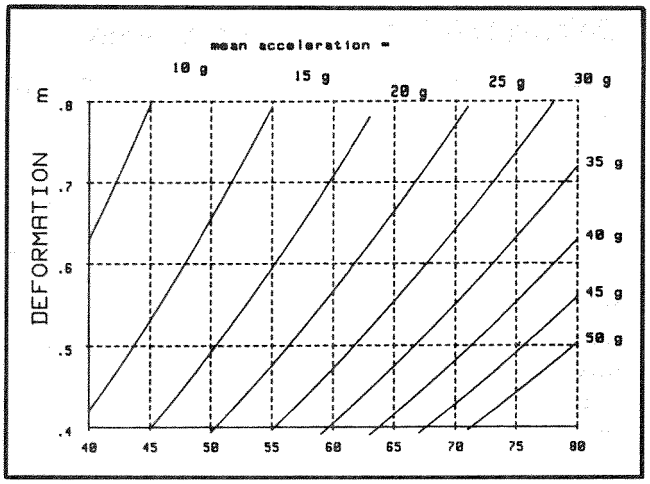


Figure 1. Impact velocity mean acceleration intrusion (deform.).

with the assistance of factor analysis, which are in addition also demonstratively interpretable. We have extracted two new characteristics and are calling them "crash severity" and "car front softness".

Crash Severity and Car Front Softness

We have investigated three different kinds of data quantities. Two basic quantities are coming from real accidents, where the change in speed, the intrusion and the mean acceleration could be measured, estimated or missing data could be determined by simulation with mathematical models in a most versatile number of ways. The third data quantity comes from a major number of experimental investigations, in which real vehicles crashed with fixed barriers. The desired output data could be measured directly. All types of crashes (collisions) were included in which essential deformations of the car front occurred.

A factor analysis provides for all basic quantities a first factor "crash severity Is", equation (2), which is shown as a sum of the influences of the three characteristics of change in speed, mean acceleration and intrusion. The second factor with a little less informative content (Figure 2) can be interpreted either as a difference (equation (3)) or even as a quotient from intrusion and mean acceleration. This factor has been called "car front softness" Fs.

$$\begin{aligned} Is &= c_v \cdot \Delta v + c_a \cdot \bar{a} + c_i \cdot i \\ c_v &= .4645 \,/\, 11.18 \text{ km/h} \\ c_a &= .3833 \,/\, 3.637 \text{ g} \\ c_i &= .3572 \,/\, 185.2 \text{ mm} \end{aligned} \tag{2}$$

$$\begin{aligned} Fs &= e_a \cdot \bar{a} + e_i \cdot i \\ e_a &= -0.7502 \,/\, 3.637 \text{ g} \\ e_i &= .8489 \,/\, 185.2 \text{ mm} \end{aligned} \tag{3}$$

$$i = \begin{cases} 0 & s < s_o \\ s - s_o & s > s_o \end{cases} \tag{4}$$

The front end of a vehicle generally permits a deformation path s_o without intrusion of passenger cell. If deformations are larger, intrusion and deformation path are linked to each other according to equation (4).

Crash severity and car front softness are two characteristics which are independent of each other and are particularly suited for statistical analyses.

Injury Severity

For the two basic quantities of the investigated road accidents the injury severity of the vehicle occupants was known and, as generally customary now, indicated in numerical values of the Abbreviated Injury Scale (AIS).

Figure 3 shows the result of a statistical analysis. In contrast to many another investigation, the results permit meaningful interpretations.

As usual in statistics, the abscissa values are recorded in standardized form. The numeral 0 represents the medium value and the numeral 1 a deviation from mean value according to standard deviation of a normal distribution.

The lefthand diagram in Figure 3 shows that the injury severity is widely determined by the crash severity. Because of the closed AIS scale, the curve bends in upward direction.

The righthand side of Figure 3 shows the influence of the car front softness. If it is too stiff, if the softness is too low, the injury severity increases due to unnecessarily

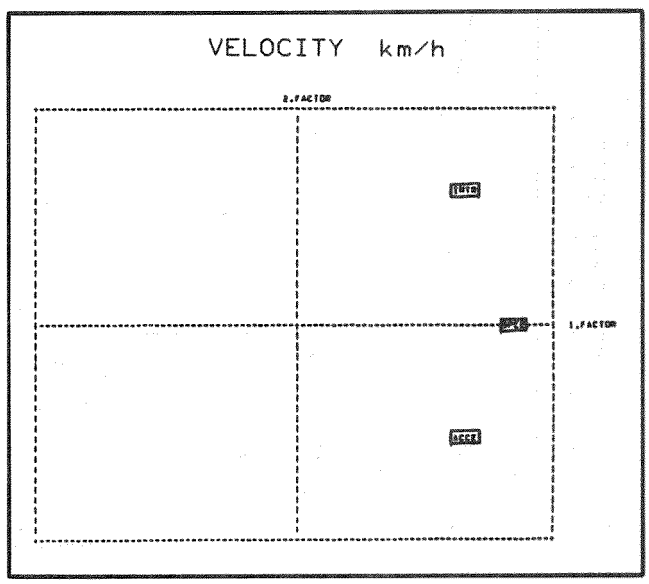


Figure 2. A factorial analyse.

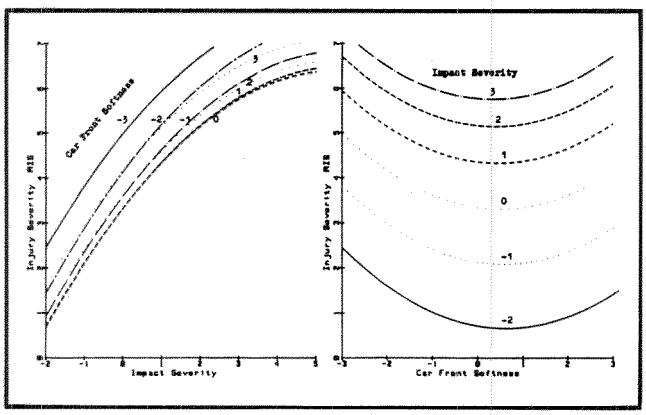


Figure 3. Statistical analysis injury severity impact severity and car front softness.

high accelerations. If, on the other hand, it is too soft, increased intrusion will cause injuries which are more severe. In-between is a minimum, to which vehicles now operated in Europe are obviously adapted and averaged.

POSSIBILITIES FOR INFLUENCING THE RISK OF INJURIES

As shown, the car front softness of our vehicle population has been averaged optimally to the smallest possible risk of injuries. Distinct changes of this softness can therefore cause only minor increases of the risk. For this reason, we shall devote our efforts particularly to the possibilities for influencing crash severity by means of structural measures.

Deformation Path and Crash Severity

According to equation (2) the crash severity comprises the sum of the influences of the three characteristics "change of speed", "mean acceleration" and "intrusion". At a preset change in speed the first characteristic is constant (parallel to abscissa in Fig. 4). According to equation (1) the mean acceleration drops hyperbolically with the increasing deformation path, with increasing softness. If the deformation path exceeds the intrusion-free path s_o, the intrusion increases with the increasing deformation path.

Following an initially heavy reduction of the accident severity under influence of longer deformation paths at similar change in speed, the latter will again increase if the deformation paths are too long and has its smallest value at s_{opt}.

With a small s_o, this smallest value is a minimum in the mathematical meaning and s_{opt} is larger than s_o. In such cases, when adapting to the selected change in speed, a given intrusion is permitted to obtain the benefit of the smallest possible crash and thereby injury severity.

In the event of larger s_o values which, for example, due to the need for the lightest possible vehicle and the finite length of parking lots, parking gaps and garages, can unfortunately often not be realized, the deformation characteristic is selected in such a manner that the mean acceleration is as low as possible, but that no intrusion will as yet occur. In such cases, the smallest risk is in the sharp bend of the crash severity curve, as shown in Figure 5.

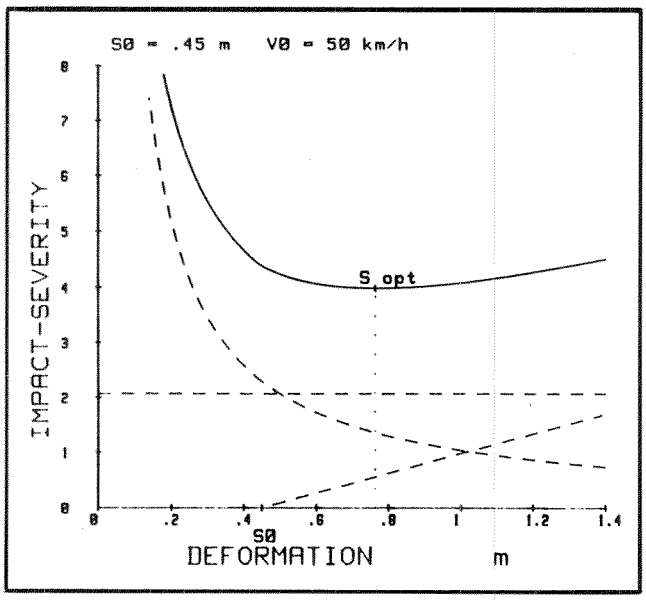


Figure 4.

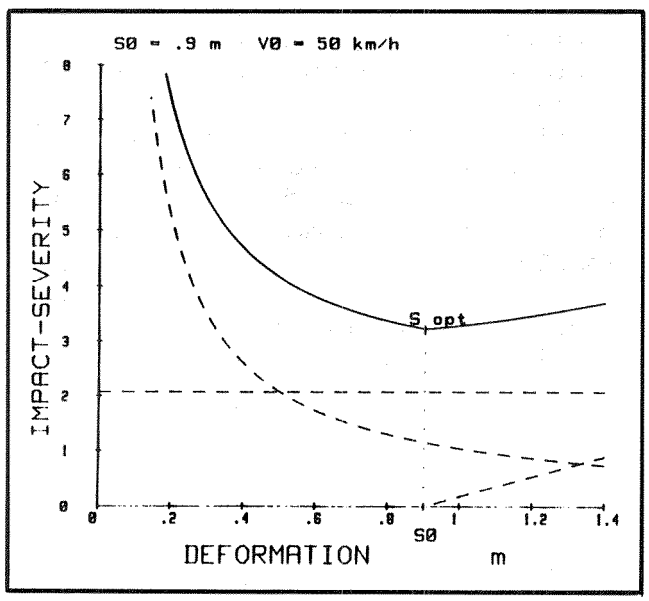


Figure 5.

s_{opt} is based on equation (5)

$$s_{opt} = \begin{cases} \Delta v \sqrt{\frac{c_a}{2c_i}} \quad \forall \; s_{opt} > s_o \\ (c_a \text{ from } c_i \text{ from equation (2)!}) \\ S_o \quad \text{in the other cases} \end{cases} \qquad (5)$$

The result will be all the points of optimal adaptation to a given change in speed Δv at various deformation lengths s_o shown in Figure 6. Figure 7, on the other hand, shows the deformation path s_o with a varied change in speed Δv.

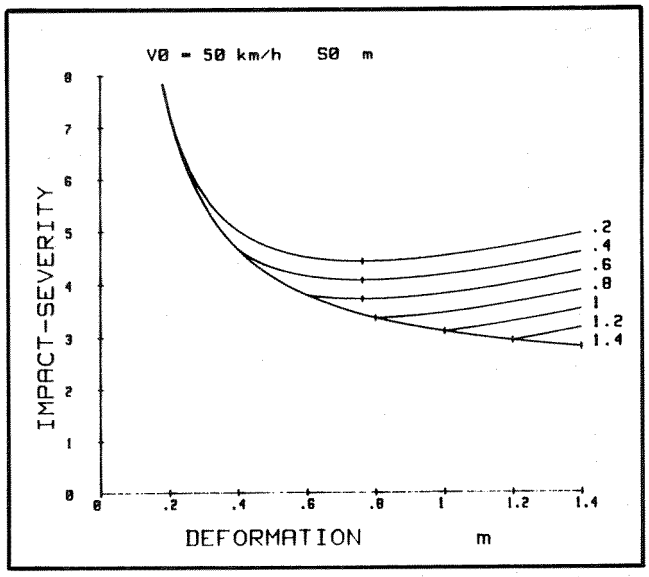


Figure 6.

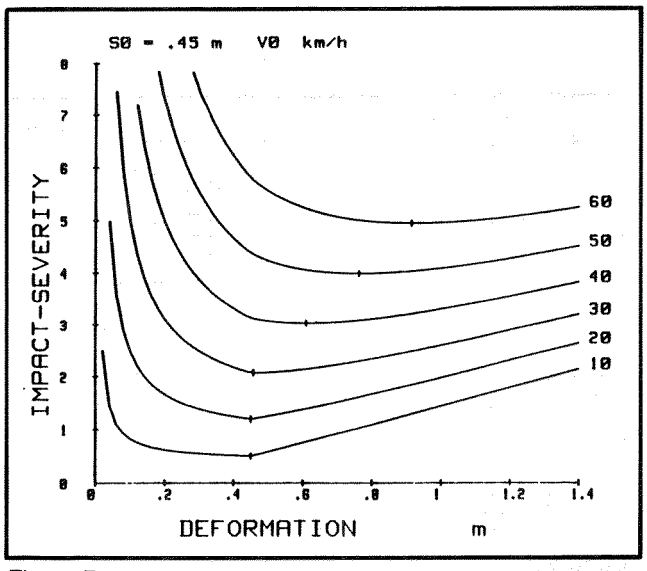


Figure 7.

At a specified test impact speed v_o, which corresponds widely to the change in speed Δv, the vehicles are adapted to this speed, that is, set more or less accurately to s_{opt} at mostly constructively preset s_o.

If, then, during an accident a change in speed Δv occurs which is different from the test impact speed v_o, the vehicle is of course generally also not accurately and optimally set to this Δv as an equivalent test impact speed. To what extent the injury risk will thereby be made slightly higher depends among others also on the force-path characteristic of the car front end.

Deformation Characteristics

Ordinarily, the deformation behavior of a vehicle front end is characterized by the force-path curve. For a survey, often a general statement concerning the shape of such a curve is enough. Starting from the assumption that the mean force F_{opt} fitting a mean type of acceleration and the deformation path s_{opt} at a given change in speed Δv is known, we are interested above all in the curve path in the direct environment of the point (s_{opt}, F_{opt}), which is drawn with an asterisk in Figure 8.

Let us now approximate the force-path curve of a vehicle with a function according to equation (6)

$$F(s) = \frac{2}{2 - æ} \; F_{opt}\left(\frac{s}{s_{opt}}\right)^{\frac{æ}{2 - æ}} \qquad (6)$$

in the environment of (s_{opt}, F_{opt}), we can read on exponent α (in Figure 8 designated Exp) whether the deformation characteristic is linear ($æ = 1$), underlinear ($æ < 1$) or overlinear ($æ > 1$). Three typical cases are drawn in Figure 8.

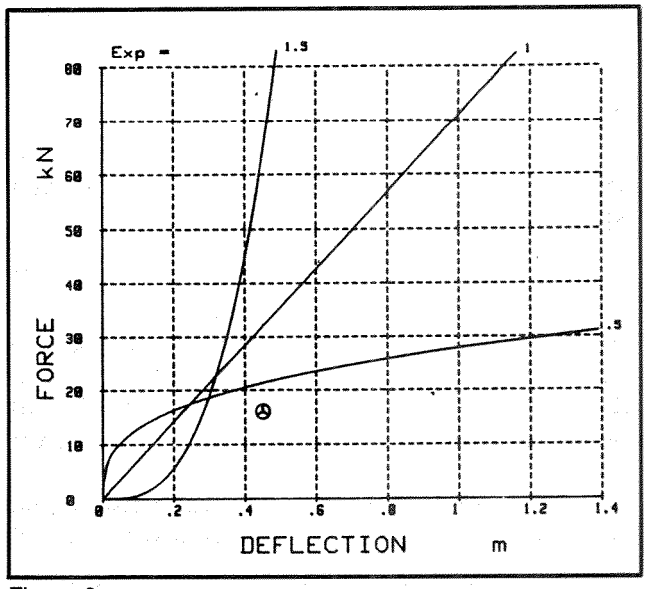


Figure 8.

Simple conversions permit changing relation (6) into equation (7), which we shall need below.

$$a = a_{opt} \left(\frac{v}{v_o} \right)^{\alpha} \qquad (7)$$

INJURY RISK AND TEST IMPACT SPEED

Let the test impact speed specified, for example, by a lawmaker for a given front end impact procedure be v_o. The vehicles participating in the traffic and for this reason tested will also be optimally set up for this test case and the crash severity will be set to the minimum value possible in this case according to equation (2).

Crash Severity and Equivalent Test Impact Speed

In the event of an accident the occurring equivalent test impact speed v (ETS) will be different from v_o. The resulting injury risk can now be estimated by using equations (7), (1), (4) and (2). Figure 9 shows the progress of the crash severity for $s_o = 0.45$ and $\alpha = 0.5$ for different test impact speeds v_o over equivalent test impact speed v (ETS) of real accident.

The frequency distribution of the equivalent test impact speeds of real accidents shown pointed in Figure 9 is characteristic for European conditions.

Figure 9 shows clearly that the crash severity in each case is the lowest for test impact speed v_o, but for other ETS higher than the lowest possible there.

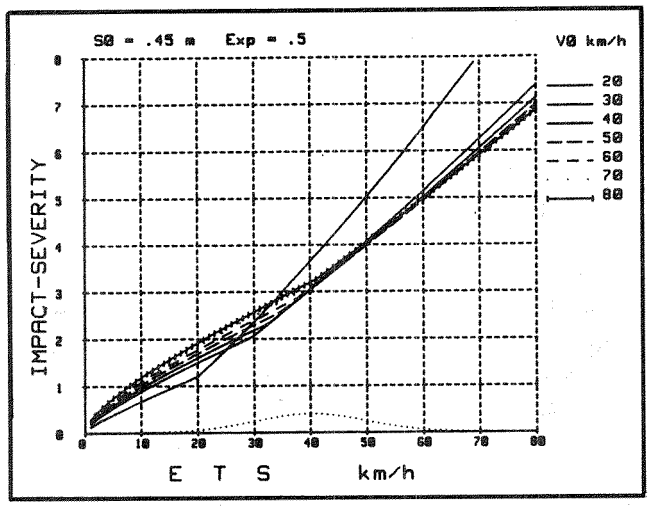


Figure 9.

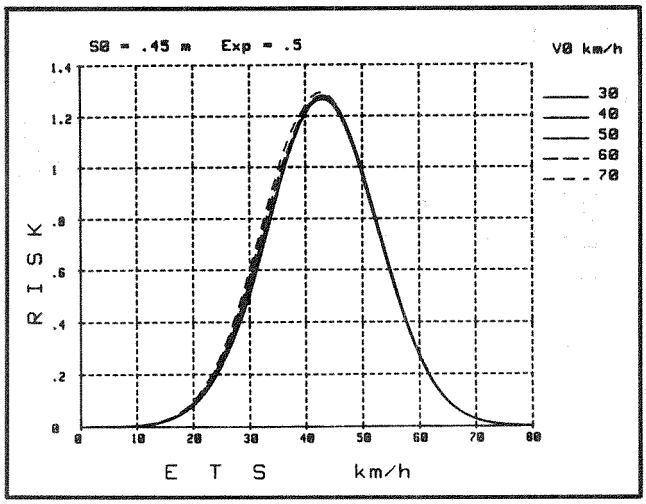


Figure 10.

Injury Risk and Test Impact Speed

In safety science, the risk is calculated from severity S and probability W of an unfavorable event according to equation (8).

$$R = S \cdot W \qquad (8)$$

Let us therefore multiply in Figure 9 the frequency with the severity of an accident and the result will be the crash risk in dependence of the equivalent test speed v (ETS) with test impact speed v_o as parameter (Fig. 10). According to Figure 3 this risk is closely coupled with the injury risk.

We can now estimate the entire traffic risk by integrating the curves shown in Figure 10 and are then obtaining a function which will then still depend from test impact speed v_o only. This is shown in Figure 11 for æ = 0.5 and various intrusion-free deformation paths s_o.

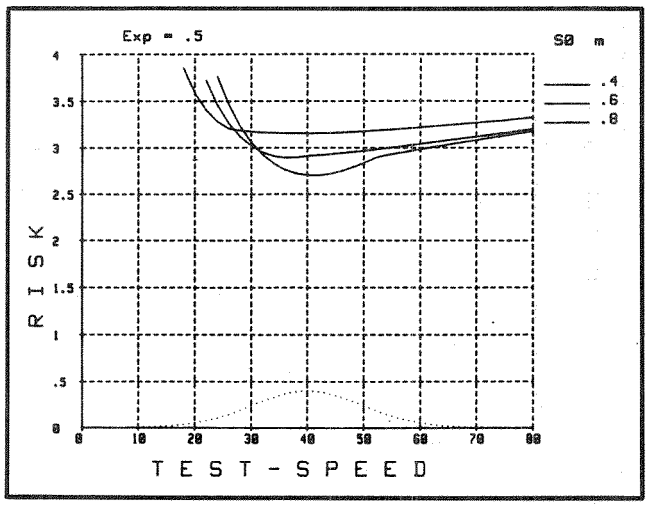


Figure 11.

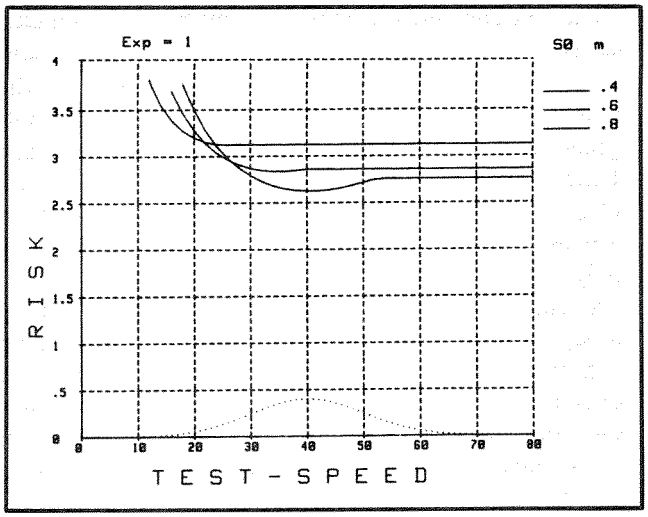


Figure 12.

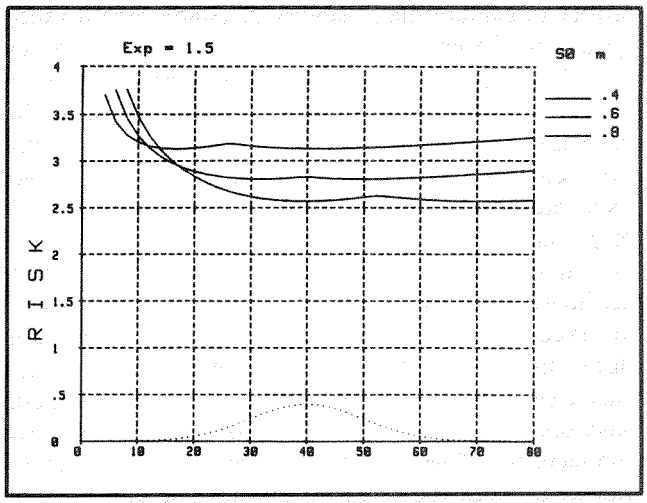


Figure 13.

The selections shown in Figures 12 and 13 are æ = 1 and æ = 1.5.

Independent of form (æ) of force-path curve of vehicle front end and independent of intrusion-free deformation path s_o Figures 11 to 13 show that an increase of the test impact speed cannot contribute to a desired reduction of the injury risk, but will generally even increase this risk.

SUMMARY

A careful analysis of data concerning real accidents shows connections which are opening possibilities to estimate the influence of different adaptations of deformation behavior of vehicle front ends to injury risk in an observed traffic procedure.

Here, the test impact speed at specified test procedures plays an important part. It is shown that the extent of this test impact speed cannot be selected at will, if only to make sure that the injury risk is not unnecessarily increased.

As shown in Figures 11 to 13, the impact speed of 50 km/h provided for the 90° barrier test is already too large for European conditions and European vehicles are therefore already now provided with an unnecessarily high force level. A test speed of 40 km/h would be better. The order of precedence of motor vehicles in accordance with their highest permissible test impact speed as proposed by NHTSA is therefore not promoting safety. As a matter of fact, exactly the opposite might be obtained and traffic on public roads might become worse!

Data Integrity Assessment of the New Car Assessment Program Crash Tests

WILLIAM THOMAS HOLLLOWELL
National Highway Traffic Safety Administration

RUDY H. ARENDT
MGA Research Corporation

ABSTRACT

In 1979, the National Highway Traffic Safety Administration initiated a program from which to rate the comparative crashworthiness of automobiles. Entitled the New Car Assessment Program, this project continues today and involves subjecting passenger vehicles to various modes of crash testing. This paper presents the findings to date from an ongoing assessment for investigating the integrity of the crash test data. Additionally, the method utilized for determining the accuracy of a crash facility data acquisition system is presented.

INTRODUCTION

In 1979, the Office of Automotive Ratings of the National Highway Traffic Safety Administration began a

project to explore the feasibility of establishing a rating system on the comparative crashworthiness of automobiles. Its purpose was to generate these ratings before or sufficiently early in the model year to provide useful information to new car purchasers. This project, entitled the New Car Assessment Program (NCAP), continues today and involves subjecting various makes and models of passenger vehicles to frontal fixed barrier and rear moving barrier impacts at speeds of thirty-five (35) miles per hour. In these tests, extensive instrumentation is used to develop both structural and occupant (Part 572 Anthropomorphic Test Devices) response data. To date, tests have been conducted at four different crash facilities and have been used to compare the performance among the complete set of test vehicles. These data have been reviewed by both the NHTSA and an independent organization (1). During this process, it became evident that differences in test equipment and/or practices among the facilities might have an important effect on the ability to make detailed comparisons of the overall test results. Similarly, the occupant response data for a given test were processed and reported without an evaluation made of the quality of the reduced data. For these reasons, a study has been initiated to provide a rigorous assessment of the data integrity. The study consists of two distinct efforts. The first is a test site instrumentation study. The second is an in-depth analysis of the integrity of the occupant response data acquired from the crash tests. This paper is written to present the findings to date of these efforts.

TEST SITE INSTRUMENTATION STUDY

As mentioned, differences among test facilities might have an important effect on the ability to make detailed comparisons of crash test results. Even though the NHTSA has been contracting for testing at various organizations for many years, a method has not been established for evaluating the differences among test facilities. Contractual requirements simply specified that the data acquisition procedures must conform to the Society of Automotive Engineers Recommended Practice J211B, entitled "Instrumentation for Impact Tests." As shall be demonstrated later in this paper, conformance to the requirements of J211B does not necessarily ensure that facilities-related differences are insignificant, particularly with respect to measures of occupant injury criteria. Hence a study was initiated to investigate the data acquisition and reduction practices of NHTSA crash and sled testing contractor facilities. Also, the study was to identify differences in procedures or practices which may cause problems in comparing test results, and recommend guidelines which will minimize the effect of these differences. The effort was conducted by MGA Research Corporation under Contract DOT-HS-8-01936, entitled "Test Site Instrumentation Study."

The test site instrumentation study has been divided into two phases. The first phase has been completed and consists of the following activities: (1) a survey of the crash and sled test facilities, (2) the design and development of a signal wave generator, (3) site visits to each of the facilities to inject waveforms from the newly developed signal wave generator into the data acquisition systems, and (4) processing of the recorded data and the analysis of the resulting data [2].

As stated, the first activity of Phase I was the facility survey. A questionnaire was developed and sent to all participating facilities. See Table 1. The survey was to provide a summary of the facilities' equipment and characteristics and was intended to serve two purposes. First, the assimilation of such data would provide a basis for a general assessment of the range of facility characteristics. Secondly, such information was necessary to ensure that the signal generator outputs were compatible with all of the facility data acquisition systems.

Information relative to the topics shown in Table 2 was requested. As can be seen, the general topics include the accelerometer sensors, the instrumentation amplifiers, time zero systems, data calibration, tape recorders, impact velocity measurement systems, and tow system characteristics.

The second activity of Phase I was the design and development of a signal wave generator. The test site instrumentation study was dependent upon having essentially the same signals injected into the data acquisition systems at each facility. For this purpose, a unique solid state, digital based signal wave generator was designed and developed. Shown in figure 1 is the device used in Phase I. Six different waveforms were defined and stored in Erasable Programmable Read-only Memory (EPROM). The waveforms are read from the EPROMs and then converted to analog signals. The use of EPROMs for waveform storage assured constant signal conditions at all facilities. The generator provided for three simultaneous outputs of analog signals which may be injected into the facility data channels. In addition, a high level analog signal, which bypassed the facility signal condi-

Table 1. Participating facilities in the test site instrumentation study.

General Motors Corporation
Approved Engineering Test Laboratories
Calspan
Motor Vehicle Test Centre
Wayne State University
Highway Safety Research Institute
Transportation Research Center of Ohio
Dynamic Science
Minicars
Mobility Systems and Equipment Co.
Physical Sciences Laboratory
Southwest Research Institute

Table 2. Facility survey topics.

Accelerometer Sensors
Output impedance
Sensitivity
Rated excitation
Natural frequency
Damping ratios
Wiring diagram
Sensor connector
Instrumentation Amplifier
Differential input
Approximate input impedance
Typical gain range
Data channel input
Time Zero System
Type of sensor
Wiring diagram
Data Calibration
Pre test
Post test
Amplitude
Calibrate pulse time properties
Tape Recorder
Input impedance
Input voltage amplitude range
Impact Velocity Measurement System
Operating principle
Redundant measurement
Measurement accuracy
Tow System Characteristics
Impact speed control
Impact speed repeatability

tioning system, could be recorded directly. Hence, a preliminary check of instrumentation response characteristics was available at the facility immediately after recording the signal. Depending upon the waveform, a signal was deleted on one of the three instrumentation channels. This combination of signal inputs permitted the determination of the system noise from the deleted channel response and a comparison of response characteristics between two channels under identical input conditions.

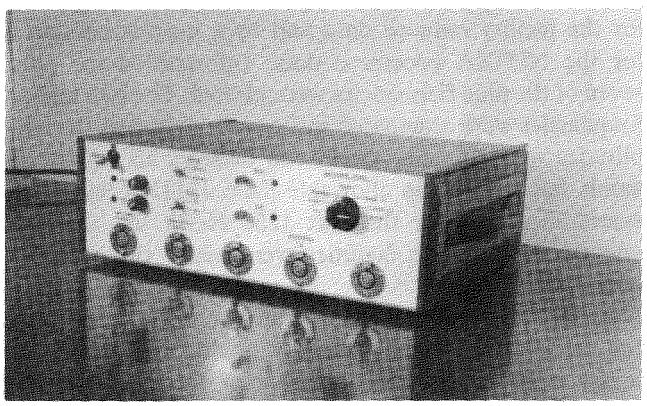


Figure 1. First generation signal waveform generator.

As mentioned, six waveforms were stored in the EPROMs. (See Figure 2.) The first waveform was a burst of sine waves having nine different frequencies which range from 25 Hertz to over 12000 Hertz. This pulse provided a means from which to assess filter attenuation as a function of frequency response.

The second waveform consisted of a continuous series of seven triangular shaped waveforms that had successive reductions in their period. This pulse provides a means to determine attenuation and time shift of a triangular response as a function of period.

The third waveform consisted of a series of nine rectangular segments having various time duration and each separated by a five millisecond interval. The attenuation and time shifts may be determined under a range of input rectangular shapes.

The fourth waveform was selected to represent a severe dummy head impact condition. The waveform was the resultant acceleration of a head response recorded in a passenger dummy during a 35 mph frontal barrier crash test. The waveform is characterized by a very high, short-duration spike.

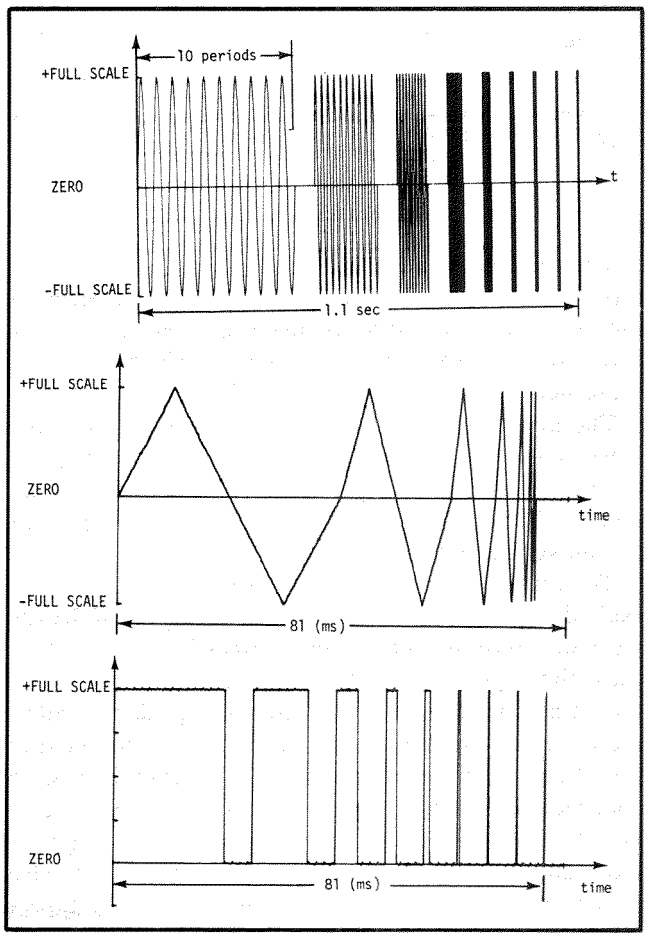


Figure 2. Waveforms injected during Phase I test site instrumentation study.

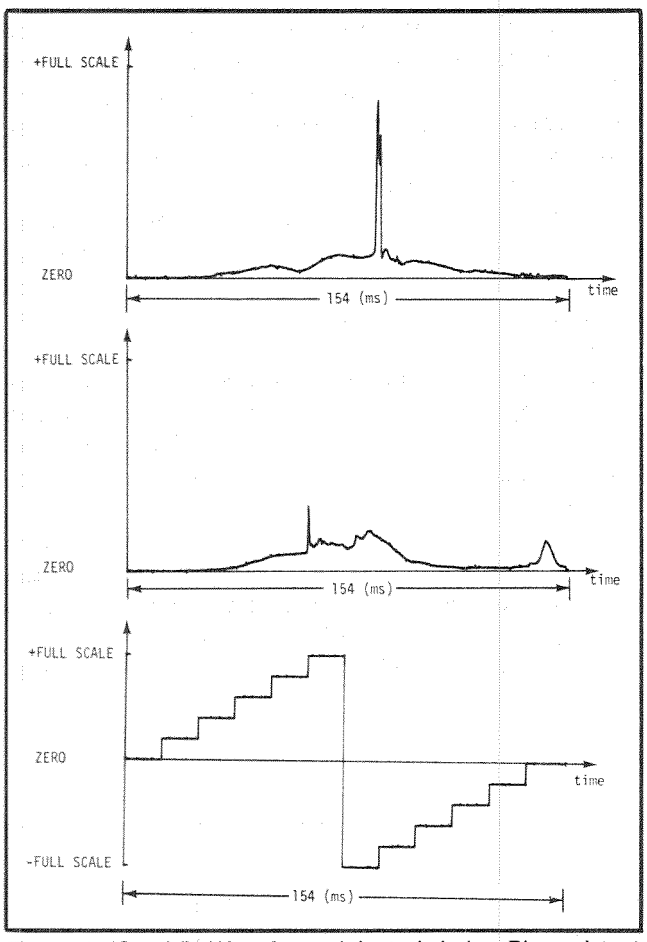


Figure 2 (Cont'd). Waveforms injected during Phase I test site instrumentation study.

The fifth waveform was selected to represent a more typical dummy head impact condition. The waveform is the resultant acceleration of the head response for the driver in the same crash test from which the previous crash pulse was taken.

The sixth and final waveform was a staircase pulse where input full scale attenuation ranged from negative to positive one hundred percent in increments of twenty percent. This pulse provides a means for assessing the overall system linearity.

The third activity of Phase I was to make site visits to each of the participating facilities. The purpose of the site visits was to review the collected survey information with the facility operators and to inject the six waveforms into the data acquisition systems. To accomplish the latter, the waveform generator output cables were connected to the signal conditioning amplifiers. The amplifiers were connected to the data recording system through an umbilical cable (See Figure 3). The signal waveform generator time zero and high level output cables were also connected to the data recording system. These by-passed the facility signal conditioning amplifiers, but in some cases were connected to the recording system through the

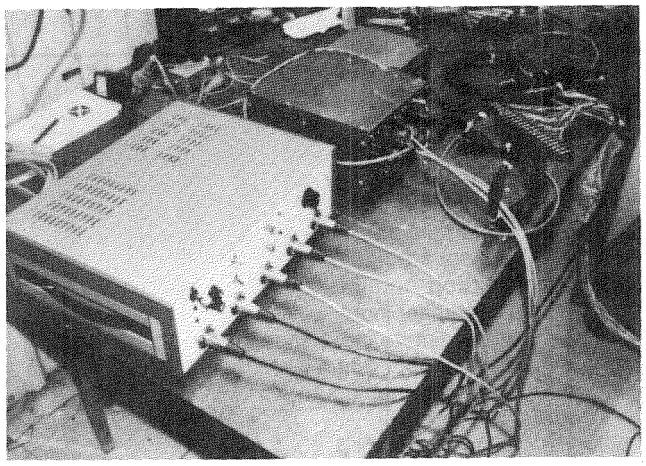


Figure 3. Setup of Phase I signal waveform generator.

umbilical cable. After a verification of the overall system, continuity and voltage levels, the waveforms were recorded. This was done by playing in sequence a calibrate waveform followed by the six test waveforms. The process was repeated to provide redundant data for subsequent processing.

The next activity was the data processing and data analysis. The data recorded during the playing of the six waveforms were digitized by each facility and the resulting digital data were processed by the facility through its data reduction software. Each facility was requested to process the data through their SAE Class filters (Class 60, 180, 600, and 1000). Additionally, the facilities computed the head injury criteria (HIC) for the two head pulses. The data were also processed by the NHTSA through its crash test data base system.

The first analysis undertaken was to determine the frequency response of each facility data acquisition system. This was accomplished by determining the amplitude of the nine different frequencies of the injected sine bursts. These amplitudes were in turn contrasted to the known input values. Shown in Figure 4 are the results obtained for the Class 1000 data. The amplitude variations for the given test frequencies are designated by a wide banded I for the facility reduced data and by a narrow banded I for the NHTSA processed data. Information for only seven of the nine frequencies were plotted. The two higher frequencies were attenuated sufficiently such that the amplitudes were unreadable. As can be seen, all amplitude bands fall within the allowable SAE J211B Class 1000 corridors except for those at 1250 Hertz. At this frequency, some of the facilities were below the accepted boundary.

At this point, no statement could be made concerning the accuracy to which a facility could provide for the injury measures. A determination of the frequency response from the dummy responses would first be neces-

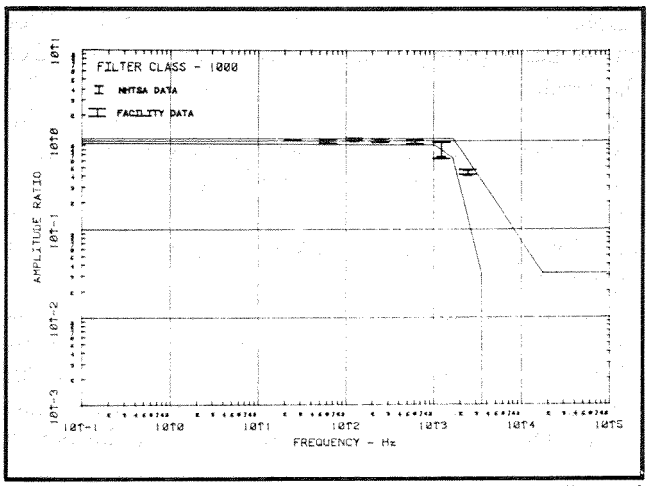


Figure 4. Comparison of frequency response for facility and NHTSA data.

sary. However, a more direct approach is available through the determination of a facility's time accuracy and amplitude accuracy.

The results of the time accuracy was obtained by measuring and contrasting to the known values the time of occurrence of the leading edges of the repetitive rectangular pulses. The known input times for the pulses ranged from zero to approximately seventy-five milliseconds. This provided a check for the time zero accuracy as well as the measure of the time linearity. Shown in Figure 5 are the results for the time accuracy. The time zero accuracy was bounded by a 1.6 millisecond band for the facility processed data and bounded by a 2.5 millisecond band for the NHTSA processed data. The time linearity over the seventy-five millisecond duration resulted in errors as large as ten percent. The errors included both time expansion and time contraction. However, the maximum time contraction was approximately four milliseconds as compared to a maximum time expansion of eight milliseconds. The effects of the time accuracy on the injury measures are varied. For example, the severity indices calculation errors would be directly related to the time linearity errors. That is, a ten percent error in time linearity would result in a ten percent error in a severity index (Head Injury Criterion or Chest Severity Index). A more subtle error would be derived from a modified frequency content that would result from time linearity errors. Slight differences in amplitudes would result from the filtering of data through a Class 1000 filter in which the time linearity of the data has been modified. This type of error would be minimal when the head response is characterized by low frequency contents, but would increase as higher frequency components are excited. Such excitation could be caused by the head striking a steering column or dashboard.

The amplitude accuracy of the data acquisition systems was determined by measuring the amplitudes for the known but varying levels of the staircase waveforms. The results of the amplitude linearity analysis are shown in Figure 6. The error, in percent of full scale, was determined for each amplitude level. The peak error for the facility reduced data was twenty percent as compared to the eight percent error determined from the NHTSA reduced data. Amplitude errors have a more substantial effect on injury measures than the time accuracy errors. Rather than having a linear effect on the severity indices, the error would be raised to the two and one-half power. For example, an amplitude error of six percent (1.06 times the known value) would result in a severity index error of 15 percent. The above analyses are the results of the extreme values found from the combination of the data from all the participating facilities.

The following analysis is more representative of what minimum errors are found in the injury measures. This analysis involved the calculation of the HIC for the previously described Crash I and Crash II waveform. Shown

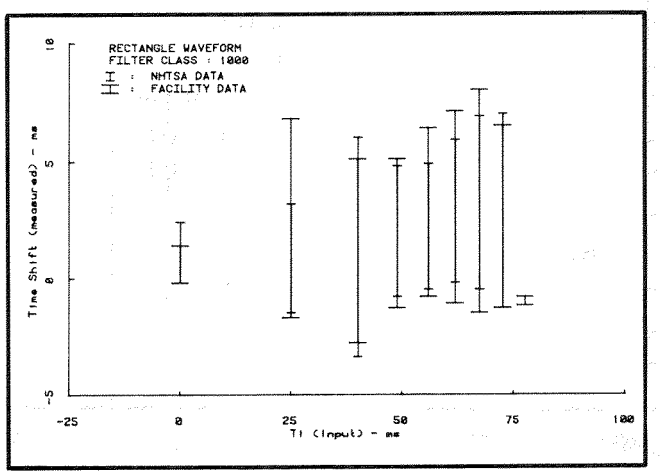


Figure 5. Comparison of time accuracy for facility and NHTSA data.

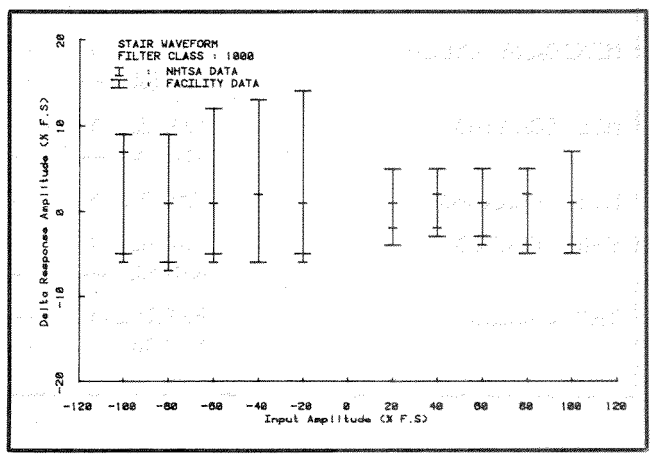


Figure 6. Comparison of amplitude accuracy for facility and NHTSA data.

in Figure 7 are the results for the Crash I waveform. The dash lines in the figure indicate levels that are ±5 and ±10 percent deviation from the known values. As shown, the deviations are as large as thirty-five percent for the facility calculated HIC values. The maximum deviation calculated using the NHTSA HIC software was ten percent. In reviewing the software used by the facilities for the HIC calculation, a number of strategies were found in which the intended purpose was to minimize the computer run time. It was determined that these strategies often failed to provide a maximum HIC value. Hence, the NHTSA test contractors were advised to use software provided by the NHTSA.

Shown in Figure 8 are the results for the Crash II waveform. The maximum deviation for the facility calculated HIC for this waveform was seventeen percent. The corresponding deviation for the NHTSA calculated HIC values was twenty-two percent. Again, it should be emphasized that the above errors were those found for all the participating crash and sled testing facilities. For the crash test contractors participating in the New Car Assessment Program, the maximum deviation was ultimately determined to be ten percent. This determination was made after one facility resubmitted a data tape to the NHTSA. The facility's self analysis of their data led to their correcting a playback problem with an analog tape recorder.

The aforementioned studies concluded the effort of Phase I of the Test Site Instrumentation Study. The use of the waveform generator was determined to be a viable approach through which to systematically evaluate data acquisition systems. Its limitation was that the output signals numbered three low level signals and one high level signal. This is a substantial drawback in that an average of seventy channels of data is collected for a typical crash test conducted for the NHTSA. Hence, a

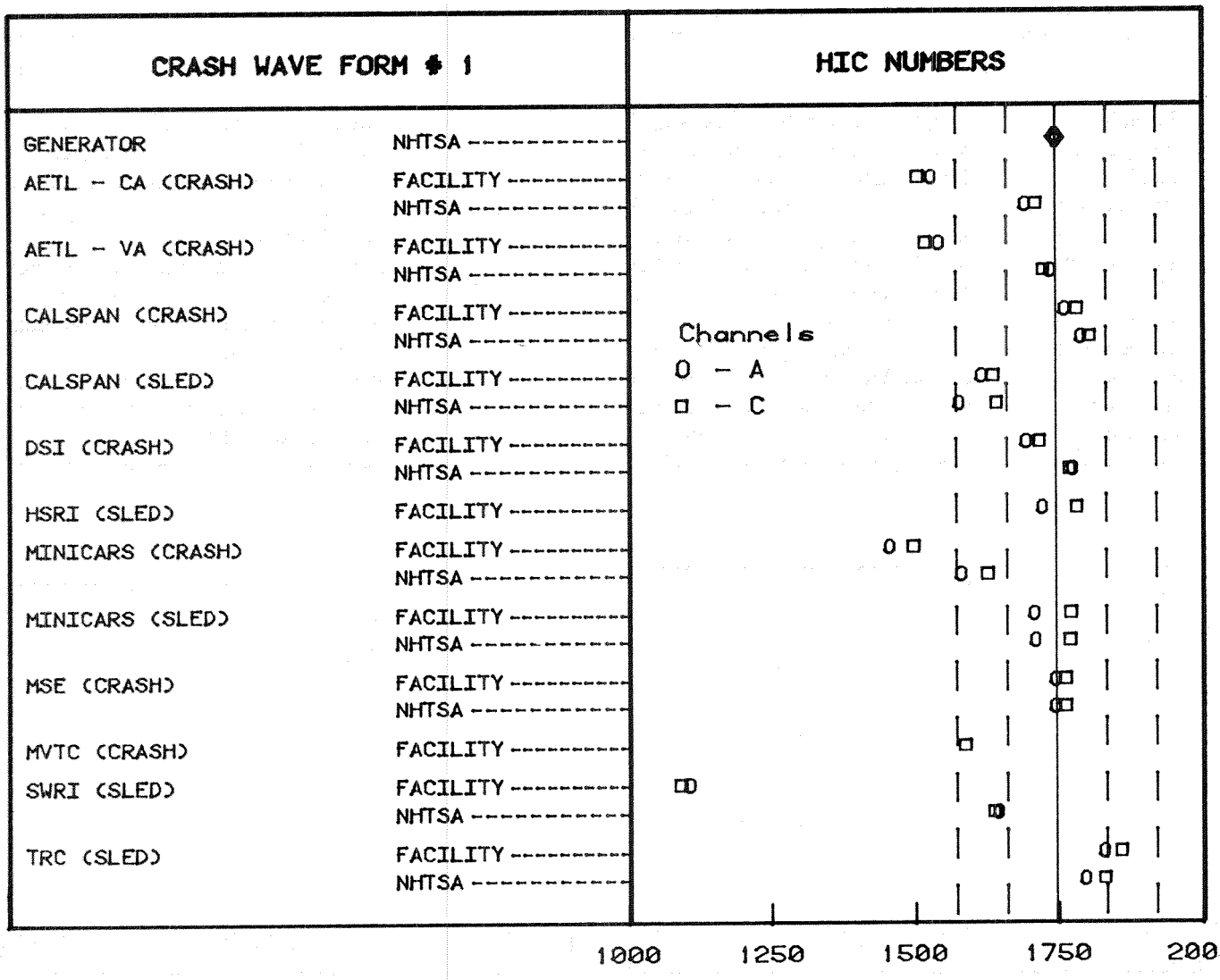


Figure 7. HIC numbers for Crash 1 waveform.

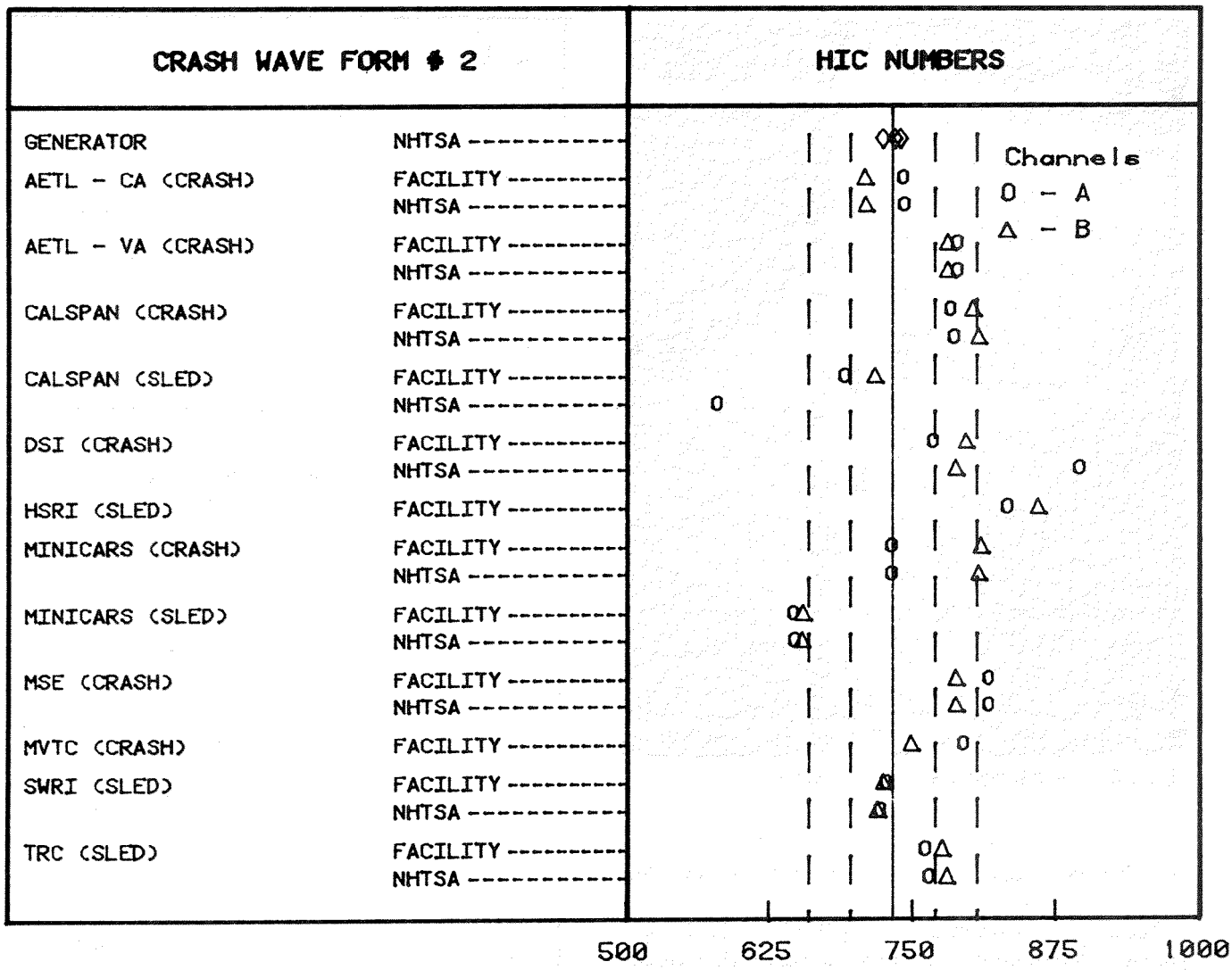


Figure 8. HIC numbers for Crash 2 waveform.

Phase II effort was initiated. The purpose of Phase II was to refine the design of the signal waveform generator such that a more rigorous analysis of a data acquisition system could be accomplished. Furthermore, the Phase II effort was to provide recommended performance specifications to which the data acquisition system must conform. The specifications are intended to minimize the differences observed among the various facilities.

Shown in Figure 9 is the second generation signal waveform generator. Its salient features include the following. It is a small, portable, and self-contained instrument that can operate with a 115 volt, 60 Hertz power source or a 220 volt, 50 Hertz power source. The instrument utilizes an Intel 8085A microprocessor for its control. There are three self-testing features to assure the proper functioning of the device. These include self tests on the stored waveforms, tests on the output voltage amplitude, and tests on the time accuracy. The waveform accuracy is accomplished by summing the waveform data bits contained in the EPROMs and comparing to a value stored elsewhere in the device. The voltage outputs are evaluated by performing an analog to digital conversion of an output signal and comparing the peak value to a quantity stored in memory. The time accuracy check is accomplished through comparisons of redundant crystal clocks. The signal waveform generator has sixteen low level output data channels and two high level output data channels. The low levels signals may be selected to simulate a piezoresitive or a strain gage type transducer.

The output signals are composed of various waveforms. These include rectangular and staircase waveforms, waveforms that represent the x, y, and z components of a typical crash pulse, waveforms that are half sine pulses and summed sine waves, and a waveform consisting of white noise.

Shown in Figure 10 is the rectangular waveform. Its objectives are to determine channel time accuracy (time zero and time linearity), to determine channel overshoot

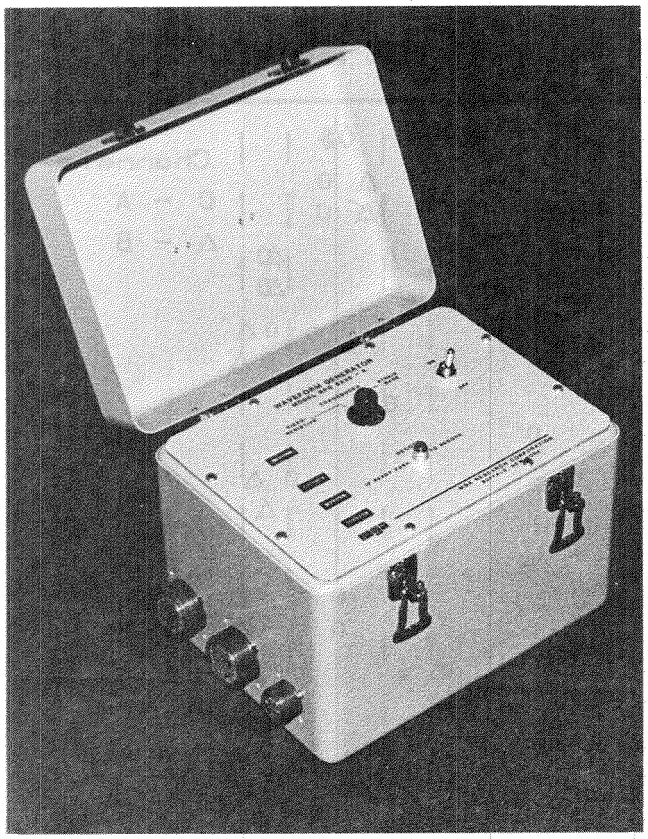


Figure 9. Phase II signal waveform generator.

and risetime response, and to determine the time shift from channel to channel.

The staircase waveform is shown in Figure 11. Its purpose is to determine channel amplitude response accuracy and channel time response accuracy.

The waveforms for the typical crash pulse are shown in Figure 12. The y-component has been set to zero to

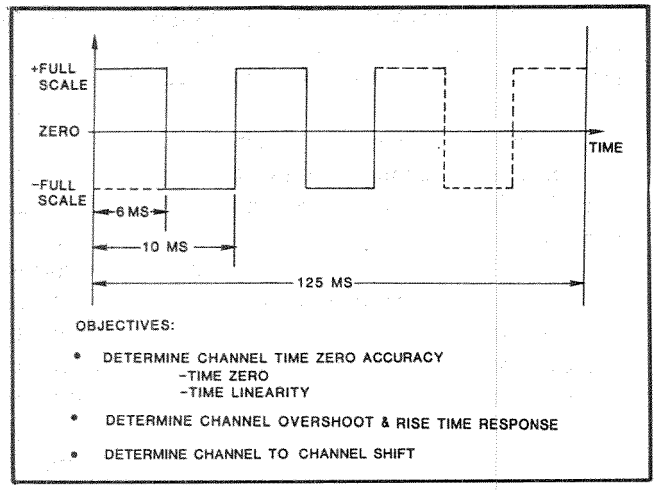


Figure 10. Phase II signal waveform generator rectangular pulse.

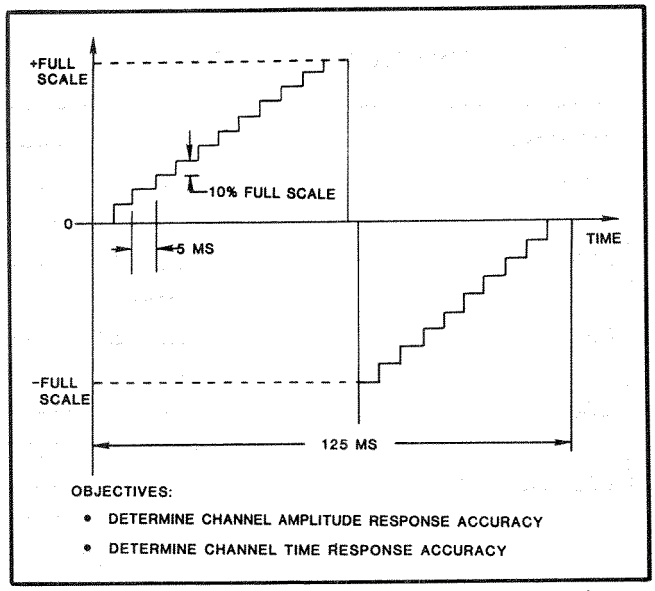


Figure 11. Phase II signal waveform generator staircase pulse.

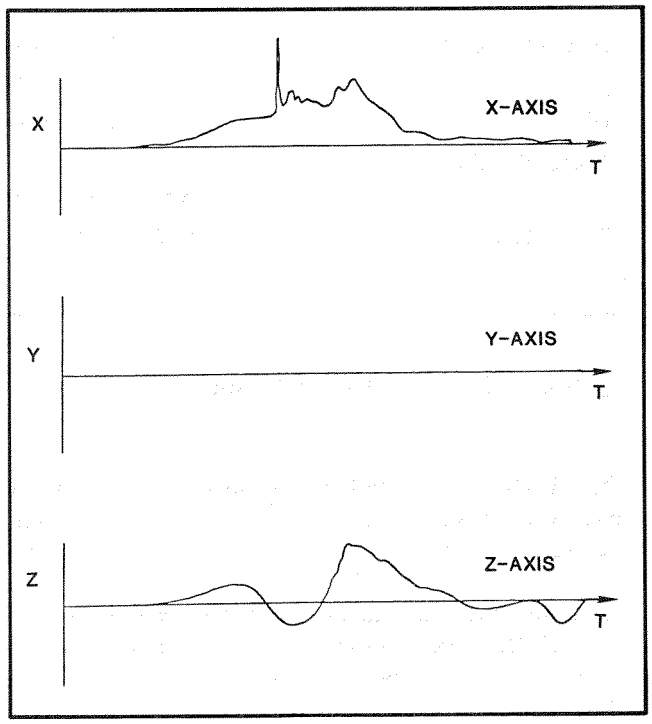


Figure 12. Phase II signal waveform generator typical crash pulse.

provide a basis for determining the level of noise in the system. The resultant of the components will be utilized to determine the accuracy of a low HIC value.

The waveform consisting of the summation of the sine waves is shown in Figure 13. Its purpose is to determine the channel frequency response for discrete frequencies. For this analysis, a fast fourier transform shall be used that employs windowing techniques.

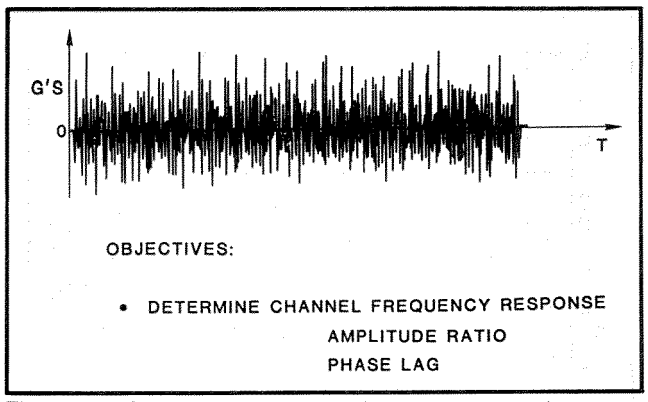


Figure 13. Phase II signal waveform generator sine summation pulse.

The half sine pulses are shown in Figure 14. These are prescribed to simulate a demanding crash pulse. The waveform shall be used to determine the accuracy of a high HIC value and to determine the channel to channel time shift.

The final waveform is shown in Figure 15. It consists of a white noise signal that is to be used to determine a continuous spectrum frequency and phase response. This analysis is to be accomplished by using a fast fourier transform along with random sampling techniques.

The signal wave generator was completed in September 1982. To date, the device has been deployed at the Motor Industry Research Association (Nuneaton, England), the Organisme National de Securité Routière (Lyon, France), and at Volkswagenwerk AG (Wolfsburg, Germany). It shall be deployed at the United States facilities beginning in October, 1982. The results obtained from the deployment shall be evaluated to determine the merit of the recommended data acquisition performance specifications.

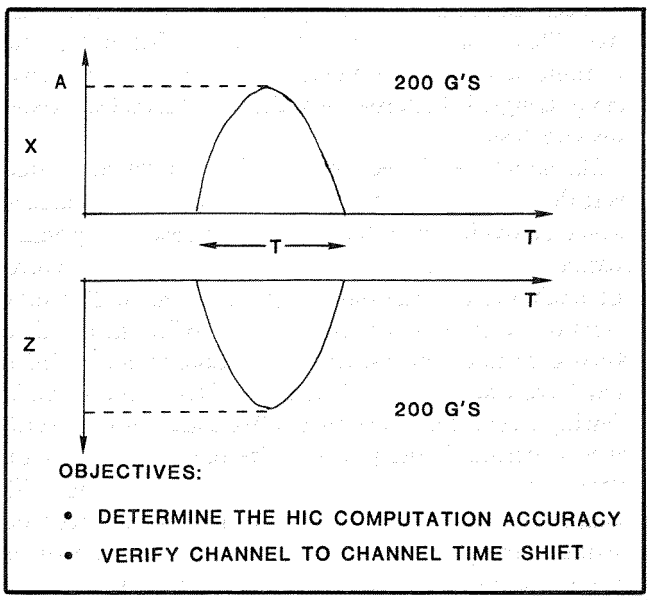


Figure 14. Phase II signal waveform generator demand crash (half sine) pulse.

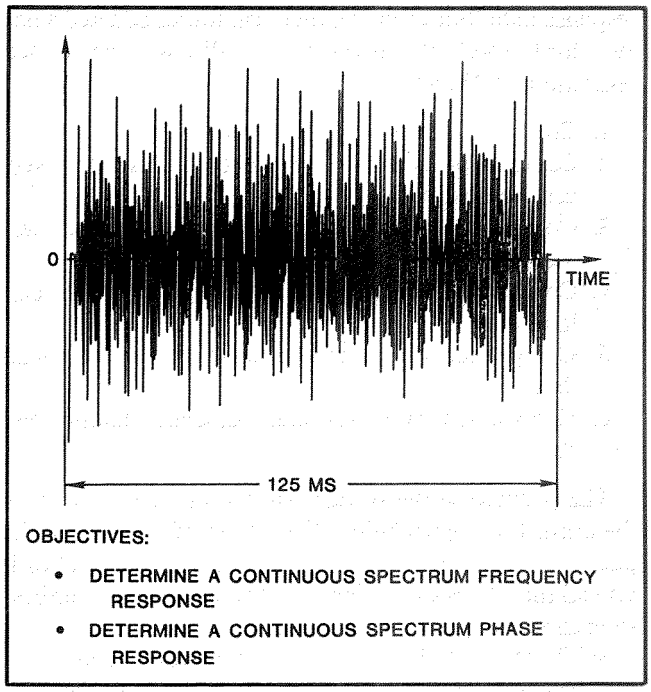


Figure 15. Phase II signal waveform generator white noise pulse.

The recommendations include both performance specifications as well as recommended practices. Relative to the performance specifications, the recommendations essentially adopt the International Standards Organizations standard 6487, "Road Vehicles-Techniques of Measurement in Impact Tests-Instrumentation". In particular, the amplitude accuracy of a data acquisition system is recommended to be within a ± 2.5 percent deviation range. The time linearity of the data acquisition is recommended to be better than 1 percent, time synchronization less than one millisecond, and the time of contact accuracy to be within ± 1 millisecond. For those channels that are used to compute resultants, the relative delay between such are not to exceed 0.1 milliseconds.

The recommended data acquisition practices include those of the SAE J211B. In particular, the minimum sampling rate is specified to be 8000 Hertz. Also, the filter characteristics are defined for the Class 1000 data. Another recommendation included the recording of the time reference signal. The final recommendation was that the zero and calibrate signals be recorded for pre- and post-test.

IN-DEPTH DATA ANALYSIS

The second effort initiated for the assessment of the data integrity was an in-depth analysis of the occupant

response data. For each frontal crash test conducted since 1981 for the NCAP, the following studies were conducted in-house at NHTSA:

1. Comparison of injury calculations.
2. Comparison of driver and passenger resultant head acceleration data.
3. Comparison of driver and passenger resultant chest acceleration data.
4. Comparison of driver and passenger shoulder belt load data.
5. Comparison of driver and passenger lap belt load data.
6. Comparison of driver and passenger femur load data.

The purpose of the studies was to provide a review of the crash test results before the release of the data to the public. The attention the NCAP has received makes it crucial that the results from each test be closely examined to ensure the quality of the data.

While the test site instrumentation study focused on the accuracy of the data acquisition system, the data comparisons focused on the sensor (accelerometer and load cell) outputs. In particular, attention was focused on the data from time zero until dummy contact. During this time period, the response of the driver and passenger dummies should be identical under the assumption that the vehicle related parameters do not vary.

Shown in Figure 16 is an overlay of the head resultant acceleration data for a test conducted in 1982. As can be seen, the response for the two dummies are closely matched up to the point of contact. Shown in Figure 17 is an overlay in which there is a noticeable difference in the traces. In determining the quality of these data, it is necessary to review the remaining sensor outputs. In particular, the chest resultant acceleration and shoulder belt loads receive close examination. Here, the assumption is made that if the head data are valid, the same trend will be observed in the chest acceleration and shoulder belt load cell data. As seen in Figures 18 and 19, this is the case. This is a test in which it is concluded that the restraint system performance varied between the driver and passenger belt. A review of the test films substantiated this conclusion.

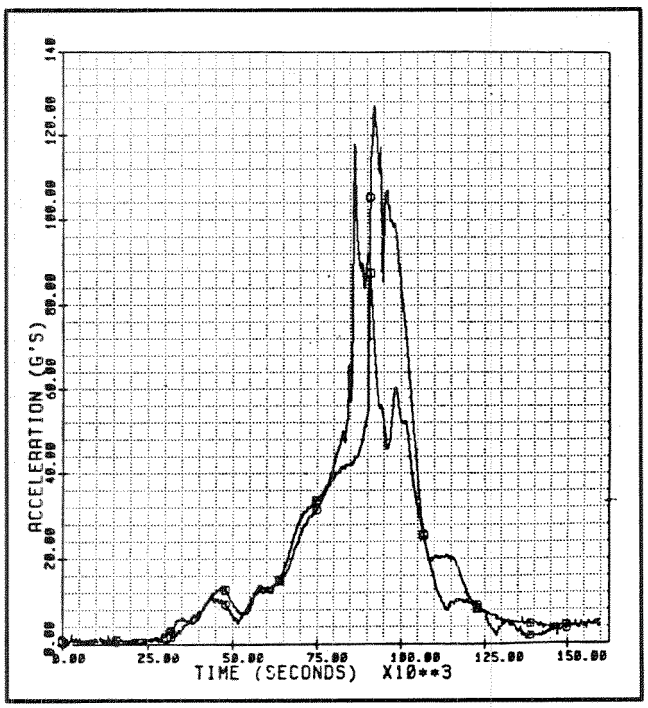


Figure 16. Comparison of driver and passenger head resultant acceleration close agreement.

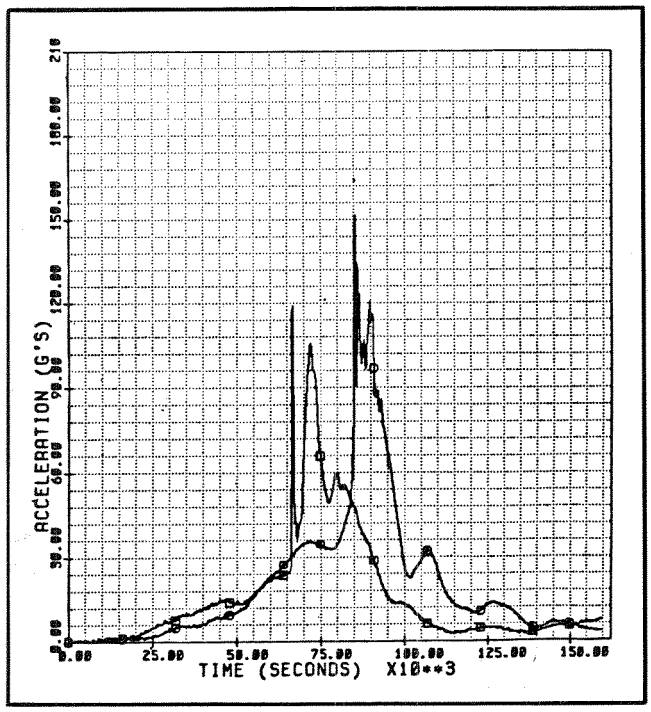


Figure 17. Comparison of driver and passenger resultant head acceleration noticeable deviation.

The above mentioned cases are those in which the data were determined to be acceptable. Occasionally, data have been received in which this was not the case. The primary reason accounting for an unacceptable data set involves the calibration of the data to physical units. The most common error is that there is a zero offset in the data. According to the character of the response, a zero offset may have a substantial effect on the HIC calculation. In viewing a resultant trace, these effects are not necessarily easy to detect. Large peaks in the data often mask the offsets when viewing the data on hard copy plots. To compensate for this masking, a technique has been developed through which better judgments can be made as to the quality of the data. An algorithm was developed which computes the mean of the driver and passenger head acceleration up to the point of head contact. A new

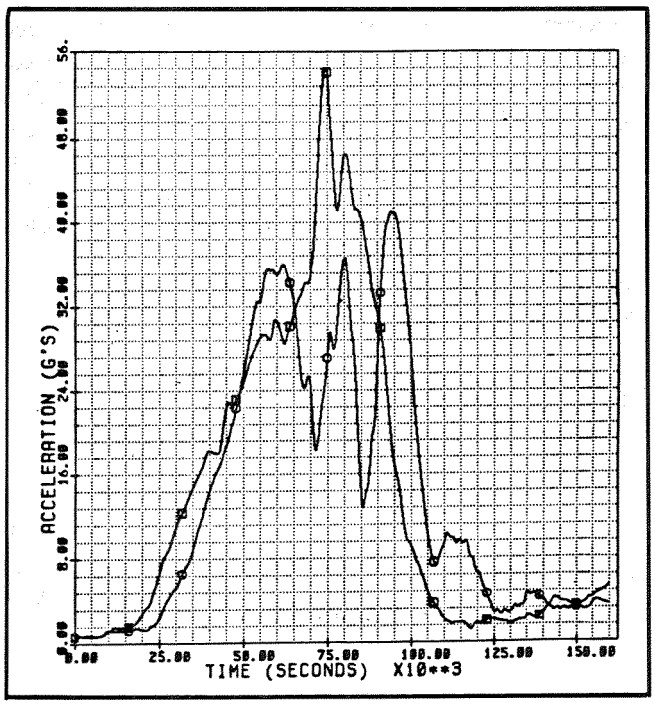


Figure 18. Comparison of driver and passenger chest resultant acceleration.

data set is then generated by subtracting the computed mean from the driver data set and dividing the resulting data by the average value of the mean data set. This process is repeated for the chest data using the time of contact determined from the head data. In comparing the newly generated data sets, it is possible to make better judgments concerning data quality and zero offsets. Figure 20 provides an example that demonstrates consistency between head and chest response. Figure 21 provides an example in which a zero offset is clearly visible. In such a case, a contractor is required to re-examine his data reduction in order to provide a better data set.

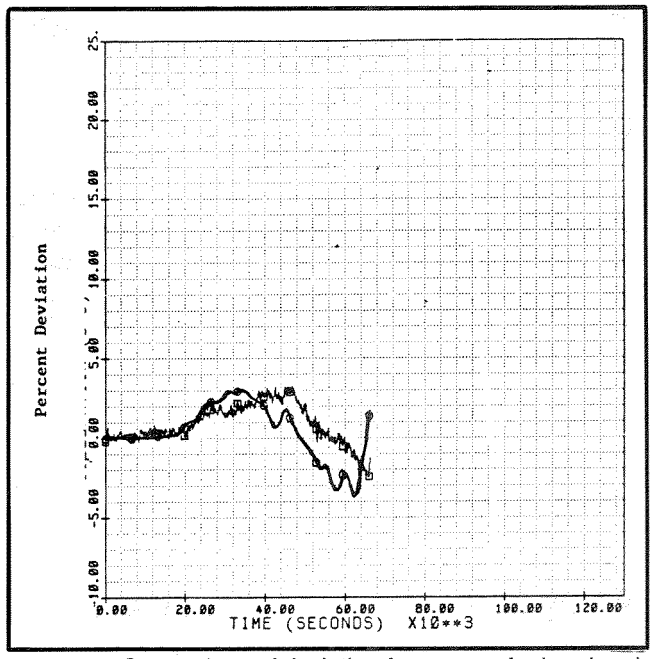


Figure 20. Comparison of deviation from mean for head and chest acceleration.

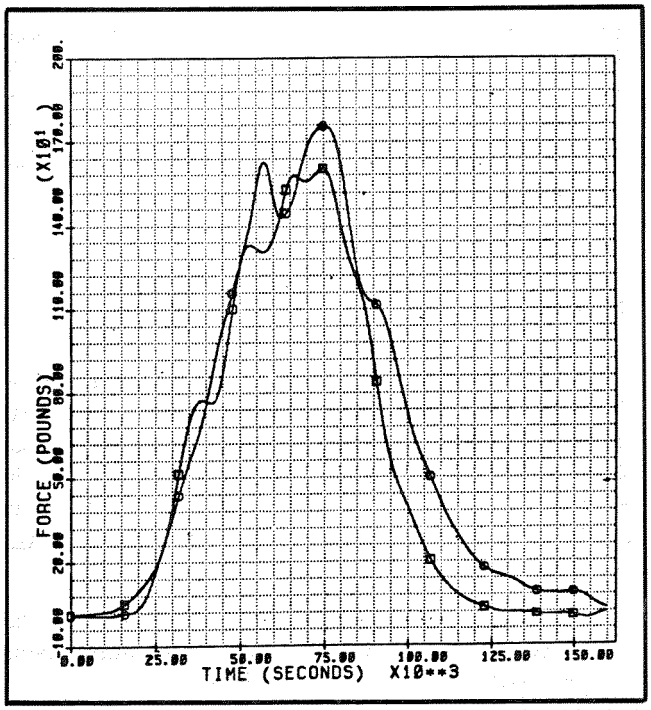


Figure 19. Comparison of driver and passenger shoulder belt load.

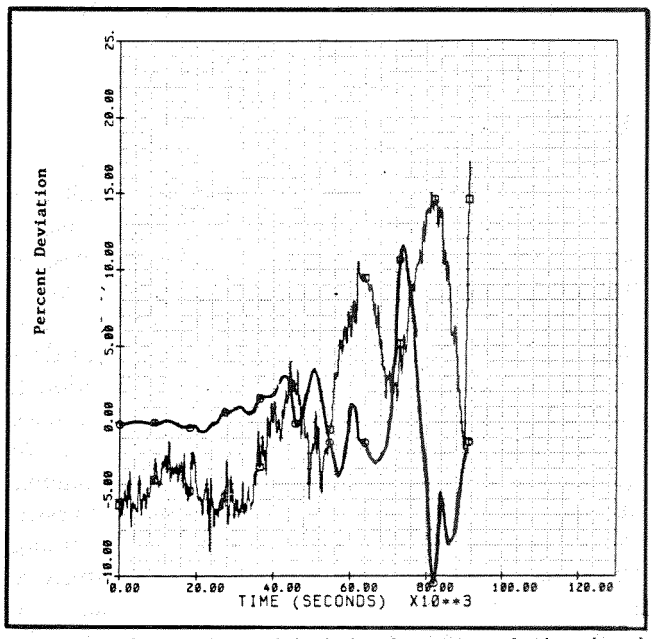


Figure 21. Comparison of deviation from mean for head and chest acceleration zero offset.

As demonstrated, the determination of data quality is largely subjective. This judgment often requires substantial man hours before determining the disposition of a data set. It is anticipated that an automated means for assisting in the determination of the data quality will soon be available. The aforementioned algorithm provides a step in this direction.

Other studies are under way to evaluate the injury measures as a function of dummy kinematics and interactions. Trends have already been realized. The results of these studies shall be available in early 1983.

CONCLUSIONS

This study is the first of an exhaustive effort to determine and improve the quality of the data collected for the NCAP crash tests. The signal waveform generator developed for this study provides a viable means for measuring the accuracy of a data acquisition system. It is anticipated that this device will be used to determine conformance to performance specifications for data acquisition systems. The instrumentation study indicates that the severity indices are at best accurate to within ten percent. This accuracy will be improved to six percent if the recommended specifications are adopted. Exhaustive studies are made to determine the quality of the data collected. Ongoing efforts are directed toward replacing these largely subjective evaluations with automated procedures.

REFERENCES

1. Miller and Rydzynski, "Analysis of Frontal Impact Test Data—New Car Assessment Program," DOT HS-805-395, February 1980.
2. Arendt and Miller, "Test Site Instrumentation Study," DOT HS-805-979, June 1981.

Analysis of 35 mph Barrier Crash Test Data

THOMAS F. MACLAUGHLIN
ROGER A. SAUL
National Highway Traffic Safety Administration
Vehicle Research and Test Center
East Liberty, Ohio

ABSTRACT

An analysis of 29 35 mph frontal barrier crash tests was performed for the purposes of determining degree and variability of crashsurvivability among vehicles, determining general reasons for good (or poor) crashworthiness, and providing general recommendations regarding selection of vehicles to be modified to demonstrate enhanced occupant protection. In addition to head injury criterion (HIC) values and maximum chest accelerations, obtained from dummy measurements, required internal occupant stroking distance calculations and occupant/airbag modeling results were used to assess the occupant protection capability of the vehicles' frontal structures. The crash responses of vehicles identified as potentially offering unusually good or poor crashsurvivability were examined, in hopes of identifying features correlated with level of occupant protection.

Conclusions are presented regarding the relationship of occupant protection potential to vehicle weight, maximum dynamic crush, and specific features of the occupant compartment acceleration response. Recommendations are given on the type of crash response a vehicle should exhibit in order to be selected for modification to demonstrate enhanced occupant protection performance. Finally, a relationship between crashworthiness and structural aggressiveness is observed and discussed.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) has been conducting 35 mph frontal crash tests under the New Car Assessment Program for the purpose of developing an automobile crashworthiness rating methodology. Reported in this paper are the results of an additional analysis of the test data, conducted for the following purposes:

1. to determine the degree and variability of frontal crashsurvivability of cars in all weight classes using Restraint Survival Distance (RSD) calculations and occupant/airbag simulations (using the ABAG model) to supplement dummy measurements,

2. to attempt to find general reasons for enhanced crashworthiness exhibited by some of the vehicles by looking at such factors as the shape of the vehicle acceleration-time pulse, and
3. to provide general recommendations regarding the selection of vehicles to be modified as future demonstration vehicles.

This analysis was not conducted to determine rating information or crashworthiness comparisons among vehicles; therefore, the names of the vehicles have been omitted, and they have been identified only by a letter or number designation.

DATA PROCESSING

The data analyzed in this study were obtained from digital magnetic computer tapes and reports of New Car Assessment and Standards Enforcement Indicant Tests conducted by three contractors. The vehicles included in the study are primarily 1979 model cars. The data obtained from the crash tests included occupant responses and vehicle accelerations.

The longitudinal compartment acceleration data were obtained from accelerometers located below the front seat, below the rear seat, or at the vehicle center of gravity. All compartment acceleration data were digitally processed at the NHTSA's Vehicle Research and Test Center (VRTC) through a phaseless, low pass Butterworth filter with a 40 Hz cutoff frequency and −40 dB attenuation at a stop band frequency of 127 Hz. By experimenting with filters having different cutoff frequencies, it was judged that the 40 hz filter, by eliminating extraneous high frequencies and preserving the fundamental features of the crash pulse, facilitated the job of identifying and comparing features which could be correlated with "good" or "poor" occupant protection. Unfortunately, however, the analog filtering of the data at the contractor sites was not uniform (although conforming to SAE J211 recommended filtering practice) for all crash tests, resulting in errors for the indicated time zero for some tests. For each of those tests, the acceleration pulse was shifted prior to digital filtering to allow the initial rise in acceleration to correspond to time zero. The acceleration pulse was then examined to ensure that the velocity change for the test was within reason.

Summarized in Table 1 are the differences in dynamic crush which resulted from the detailed compartment pulse examination described above. Static crush values were not used in this analysis due to uncertainties which were encountered in extracting these values from the test reports (see the Appendix).

Table 1. Comparison of contractor and VRTC dynamic crush data.

Vehicle			VRTC Channel Selected	Test Contractor	Dynamic Crush—in.	
Class	Year	Symbol			VRTC	Contractor
Mini-Compact	1979	A	Front	Calspan	25.7	24.5
	1979	B	Rear	Dynamic Science	31.5	32.5
	1979	C	Rear	Calspan	29.5	28.1
	1979	D	Rear	Dynamic Science	28.7	31.0
Sub-Compact	1979	E	Rear	Dynamic Science	28.6	32.4
	1979	F	Rear	Calspan	28.8	27.3
	1979	G	Rear	Calspan	31.0	28.5
	1979	H	Rear	Dynamic Science	37.3	34.8
	1979	I	Front	Dynamic Science	35.8	35.6
Intermediate	1979	J	Rear	Dynamic Science	26.7	31.0
	1979	K	Front	Calspan	30.7	29.7
	1980	L	Front	Calspan	31.6	30.6
	1979	M	Front	Calspan	29.7	30.0
	1979	N	Front	MSE	30.3	31.1
	1980	O	Rear	Calspan	23.8	22.8
	1979	P	Rear	Calspan	31.5	30.7
	1979	Q	Rear	Dynamic Science	34.8	38.0
Standard	1979	R	Rear	Dynamic Science	35.1	41.2
	1979	S	Rear	Calspan	31.5	38.8
	1979	T	Front	Calspan	31.0	31.2
	1979	U	Rear	Dynamic Science	27.9	32.7
	1979	V	Front	Dynamic Science	38.4	38.3
	1979	W	Front	Calspan	35.7	34.2
	1979	X	Rear	Calspan	33.6	33.0
	1979	Y	Rear	Dynamic Science	32.8	37.4
	1979	Z	Front	Dynamic Science	32.7	34.4
	1979	2	Rear	Dynamic Science	33.5	37.9
	1979	3	Front	Dynamic Science	39.2	39.9
	1979	4	Rear	Dynamic Science	41.1	39.4

MEASUREMENT OF OCCUPANT PROTECTION

Three methods were used in this study for determining occupant protection: dummy measurements, Restraint Survival Distance (RSD) calculations and advanced restraint system modeling with the ABAG computer model. Dummy responses provide a measure of "actual" crashworthiness, while the other two methods give a good indication of "potential" crashworthiness (i.e., occupant protection that theoretically would be provided by the vehicle if it contained a more nearly ideal restraint system).

The use of dummy measurements is the most direct method of determining occupant crash survival. Occupant injury severity indicators derived from dummy measurements are dependent upon the crash pulse (crash severity), compartment integrity, and performance of the occupant restraint and containment system. They are, however, subject to some degree of variation due to variables such as placement of the surrogate within the restraint system, positioning of the seat, etc. And, because they are dependent upon the restraint system, dummy measurements do not allow determination of the potential for occupant protection that would exist in a particular vehicle structure if a different restraint system were installed in the vehicle.

Restraint Survival Distance (RSD) is a useful indicator of the potential for occupant crash survival. The RSD is the occupant stroking distance remaining after the crash, and is defined as

$$RSD = AID - (D_p - D_c), \qquad (1)$$

where:

AID is the Available Internal Distance (i.e., the distance between occupant and interior vehicle surfaces); and

D_p and D_c are the distances represented by the areas under the dashed and solid curves, respectively, in the interval between t_o and t^*, of Figure 1.

The quantity $D_p - D_c$ can be thought of as the minimum amount of internal distance *required* to safely bring the occupant's velocity down to the vehicle's velocity. Defined as the Required Internal Distance (RID), it is represented by the shaded area in Figure 1. Beyond t^*, it is assumed that the occupant can safely ride down the vehicle for the remainder of the crash. It is clear from equation [1] that minimizing the RID (i.e., the quantity $D_p - D_c$) serves to maximize the RSD. If the computed RSD is a positive number, it indicates that the *available* internal distance exceeded the *required* internal distance. If negative, it indicates that the *available* distance was not sufficient to adequately protect the occupant. The derivation of RSD is contained in Reference 1.

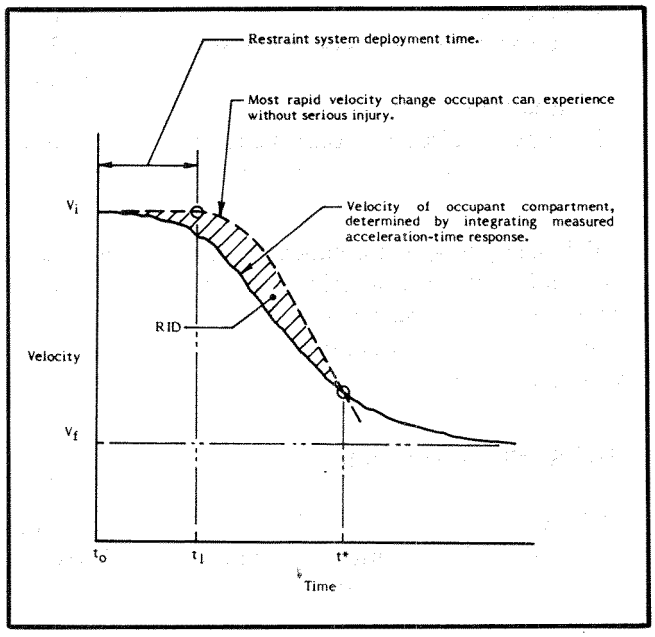


Figure 1. Velocity-time responses of vehicle and occupant.

The parameters needed to define the occupant's velocity-time response (the dashed line of Figure 1) are restraint system deployment time, maximum tolerable acceleration rate and maximum tolerable acceleration level. For this study, the values used were 30 milliseconds, 3000 g's/second and 60 g's, respectively.

The ABAG computer model provides prediction of the degree of occupant crash survival that would result from equipping the vehicle with an airbag restraint system. The model is a one-dimensional program which simulate the cushioning of an occupant's torso with an airbag that is being simultaneously inflated and vented. The program utilizes the vehicle crash pulse to produce occupant acceleration, velocity, and displacement time histories. Unfortunately, the model does not account for compartment integrity and, therefore, occupant injury which might result from intrusion.

The approach in this study was to utilize the ABAG program to differentiate between different crash pulses (i.e., different vehicles) by simulating "standard" driver and passenger air cushion restraint systems. No effort was made to optimize the ABAG parameters for each individual vehicle. In a previous analysis, ABAG model parameters were selected and the ability of the model to simulate 35 mph barrier crash tests of airbag equipped vehicles was confirmed (2)[1].

An advantage of the RSD calculation and the ABAG simulation is that they allow determination and comparison of the potential for occupant protection provided by different vehicle structures, all containing the same "idealized" restraint system.

Table 2. Weight categories.

Number	Classification	Weight
1	Mini-Compact	Below 2,150 pounds
2	Sub-Compact	2,150 to 2,650 pounds
3	Intermediate	2,651 to 3,350 pounds
4	Standard	Above 3,350 pounds

RESULTS

The analysis results are presented and discussed according to the vehicle weight category. The vehicles were categorized by curb weights as shown in Table 2.

Dummy Measurements

The crash test parameters and dummy measurements are summarized in Table 3. Driver and passenger HIC measurements and peak chest accelerations are presented in Figures 2-5. Each vehicle is represented by a symbol (letter or number) which corresponds to that in Table 3. A least squares line has been fit to the data in each figure. Three observations are immediately apparent:

1) There is a very large amount of variability among vehicles, especially in HIC.
2) There is a slight trend of improved occupant protection in the larger vehicles.
3) There are a large number of vehicles in which occupant injury criteria were exceeded. (In fact, the

Table 3. Crash test parameter and dummy measurement summary

VEHICLE			Curb Wt. (lbs)	Test Wt. (lbs)	Crash Vel. (mph)	Dynamic Crush (in)	DRIVER				PASSENGER			
Class	Year	Symbol					Head Acc. (g)	HIC	Chest Acc. (g)	Femur Loads	Head Acc. (g)	HIC	Chest Acc. (g)	Femur Loads
Mini-Compact	1979	A	1690	2180	34.8	25.7	116.0	2029.6	92.6	1080/838	142.0	2093.3	46.0	1520/1460
	1979	B	1830	2313	35.3	31.5	127.1	1270.2	72.1	893/435	207.0	1919.4	66.3	686/561
	1979	C	1860	2600	34.8	29.5	90.0	1023.9	67.0	1170/630	47.0	428.8	33.0	937/1460
	1979	D	1960	2425	35.1	28.7	122.4	1358.0	68.9	-1536	183.7	1745.0	59.4	781/2183
Sub-Compact	1979	E	2206	2661	34.9	28.6	91.9	652.7	51.6	974/708	69.9	780.4	38.2	580/657
	1979	F	2240	2720	34.8	28.8	118.0	871.4	47.0	1280/1600	88.0	858.6	45.0	990/1400
	1979	G	2510	3025	34.8	31.0	94.0	848.8	61.0	2920/435	158.0	1862.0	59.0	400/520
	1979	H	2515	2943	34.7	37.3	122.0	818.6	41.1	221/946	73.0	567.1	33.1	781/376
	1979	I	2629	3067	35.0	35.8	NA	NA	NA	1322/NA	131.3	770.2	44.3	676/397
Intermediate	1979	J	2707	2998	35.1	26.7	58.8	723.3	64.2	463/1343	247.4	1877.5	51.4	741/571
	1979	K	2730	3240	35.1	30.7	103.0	1107.6	42.0	580/400	87.0	1032.6	41.0	600/325
	1980	L	2750	3260	35.0	31.6	79.0	845.0	48.0	560/760	64.0	623.0	34.5	1040/350
	1979	M	2820	3300	35.4	29.7	102.0	939.4	54.0	825/1155	94.0	1583.2	85.0	1245/600
	1979	N	2890	3374	35.0	30.3	79.0	1782.0	52.0	320/900	168.0	1889.0	61.0	700/320
	1980	O	3130	3700	34.7	23.8	94.0	1077.8	61.0	1300/910	79.0	1457.2	39.0	375/337
	1979	P	3260	3820	35.0	31.5	74.0	724.2	40.0	1000/1000	200.0	1677.2	40.0	1200/570
	1979	Q	3298	3799	34.8	34.8	71.1	694.6	41.5	1130/2082	50.3	500.5	39.7	567/562
Standard	1979	R	3390	3908	35.2	35.1	74.2	964.5	42.2	582/472	74.4	1297.0	46.8	503/717
	1979	S	3490	3950	34.6	31.5	110.0	1441.6	61.0	1750/350	99.0	1278.6	56.0	390/570
	1979	T	3600	4160	35.0	31.0	235.0	2402.4	45.0	740/300	102.0	1070.8	39.0	420/440
	1979	U	3659	4179	35.2	27.9	240.7	1277.0	61.8	580/804	123.2	1254.0	51.1	670/391
	1979	V	3695	4224	35.4	38.4	158.2	1204.4	60.8	368/802	90.0	868.2	42.4	378/---
	1979	W	3790	4370	35.4	35.7	143.0	1452.4	38.0	750/180	93.0	616.0	34.0	510/360
	1979	X	3880	4440	35.3	33.6	58.0	645.5	39.0	250/725	58.0	730.7	44.0	360/170
	1979	Y	3935	4457	35.0	32.8	133.6	1908.5	66.7	832/531	102.2	NA	50.3	647/588
	1979	Z	3941	4440	35.3	32.7	104.4	541.0	42.2	943/892	60.4	782.1	39.0	137/---
	1979	2	4187	4709	35.0	33.5	113.3	909.8	59.4	774/534	165.1	1734.2	53.5	370/439
	1979	3	4283	4815	34.9	39.2	150.0	1088.0	61.4	1062/2775	134.0	781.0	40.2	584/429
	1979	4	4846	5362	35.0	41.1	138.7	520.5	44.6	335/393	117.8	919.0	52.5	577/981

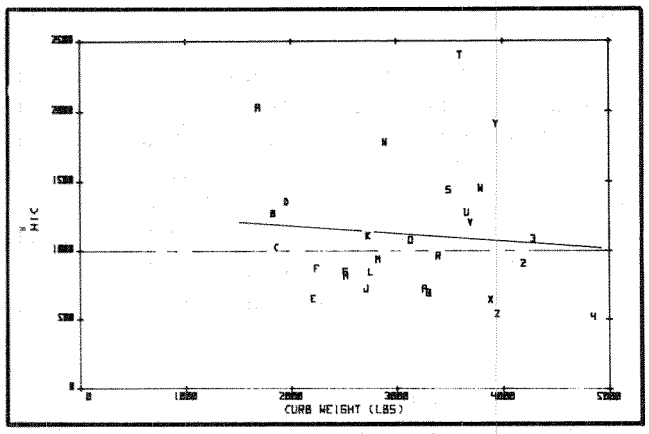


Figure 2. Head injury criterion values determined from dummy measurements—driver.

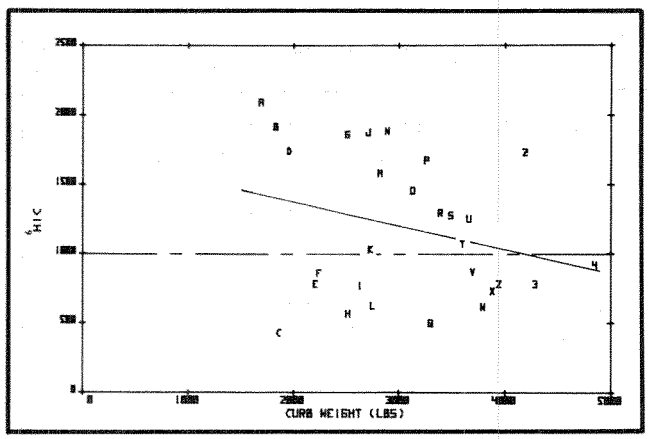


Figure 3. Head injury criterion values determined from dummy measurements—passenger.

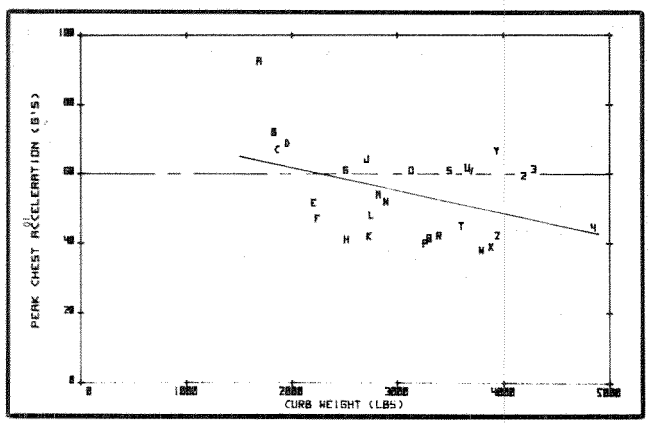


Figure 4. Maximum chest accelerations determined from dummy measurements—driver.

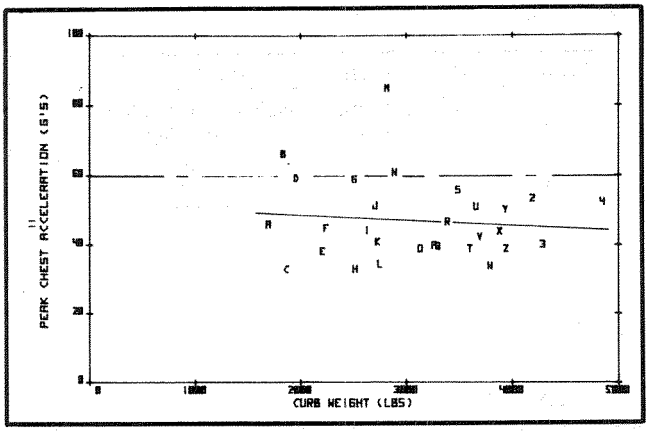


Figure 5. Maximum chest accelerations determined from dummy measurements—passenger.

least squares lines for HIC for both occupants are higher than 1000 over most of the weight range.)

An attempt was made to identify the "best" and the "worst" vehicles in terms of occupant head and chest protection, and to determine whether or not good and poor occupant protection could be correlated with any occupant compartment response characteristics. In each of Figures 2-5, the five vehicles whose injury measures were the farthest distances above the least squares line were singled out. Similarly, the five vehicles whose injury measures were the farthest distances below the least squares line were identified. Then those vehicles appearing more than once among the "best five" (or the "worst five") were listed. The result of this exercise is shown in Table 4. Although admittedly arbitrary, this scheme should identify two distinctly different groups of vehicles in terms of measured occupant protection.

The crash responses of these ten vehicles were then examined, in hopes of identifying features which appeared to correlate with good or poor protection.

Table 5 shows average dynamic crush values for the two groups of vehicles, along with the overall average for

Table 4. Identification of "Best" and "Worst" vehicles in terms of measured occupant protection.

Dummy Measurement	"Best Five" Vehicles	"Worst Five" Vehicles
Driver HIC	E J X Z 4	A N T W Y
Passenger HIC	C E H L Q	A G J N 2
Driver Peak Chest Accel.	F H K P W	A U Y 2 3
Passenger Peak Chest Accel.	C E H L W	B D G M N
Vehicles appearing more than once among the "Best Five": C E H L W		
Vehicles appearing more than once among the "Worst Five": A G N Y 2		

Table 5. Dynamic crush values of vehicles determined to be "Best" and "Worst" by dummy measurements.

	Average Curb Weight (pounds)	Average Dynamic Crush (inches)
"Best Five" Vehicles	2624	32.54
"Worst Five" Vehicles	3042	30.66
All Vehicles	3094	32.02

all vehicles. It is seen that the "best five" vehicles had a slightly greater average crush than did the "worst five" vehicles, even though they averaged a lighter weight. This would indicate, not unexpectedly, that a softer front structure (resulting in greater crush) is correlated with enhanced occupant protection in a 35 mph barrier collision.

Occupant compartment acceleration- and velocity-time responses for the 10 vehicles are shown in Figures 6-13.

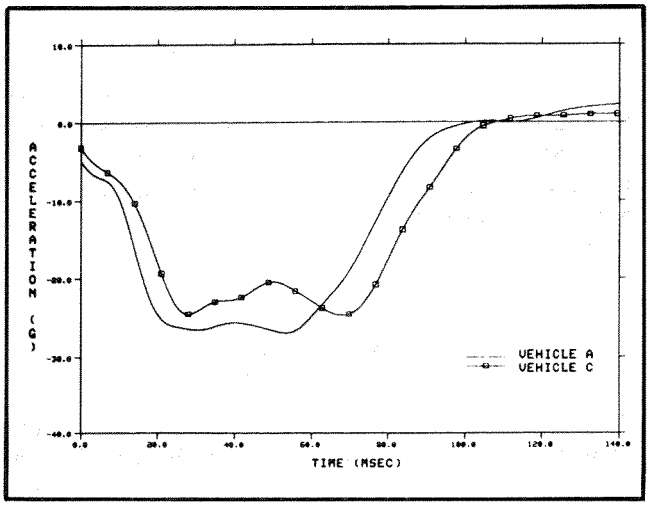


Figure 6. Mini-compact vehicle accelerations (dummy measurement criteria).

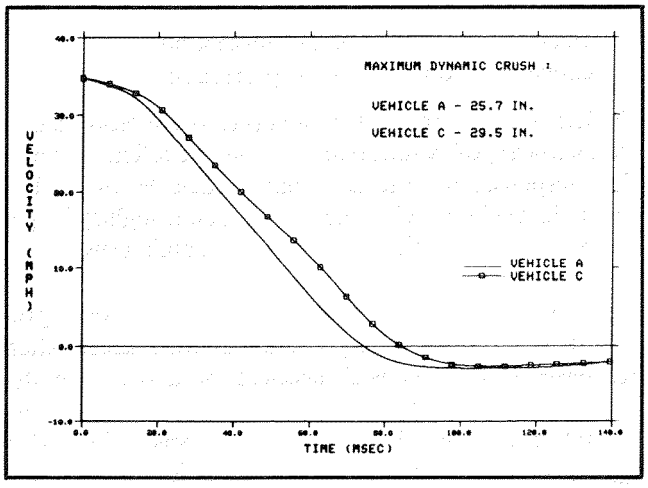


Figure 7. Mini-compact vehicle velocities (dummy measurement criteria).

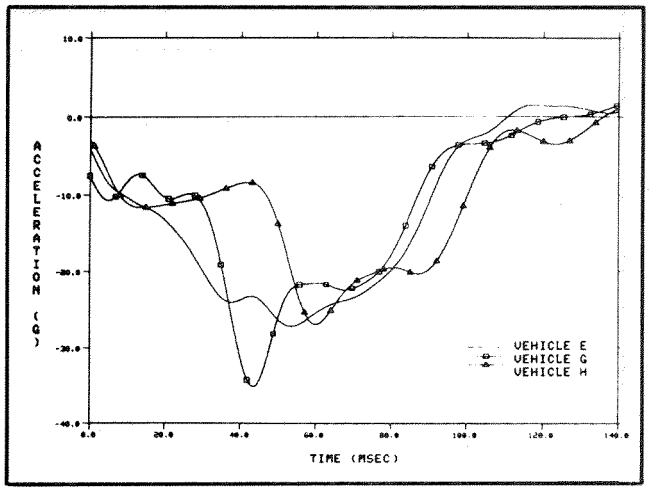


Figure 8. Sub-compact vehicle accelerations (dummy measurement criteria).

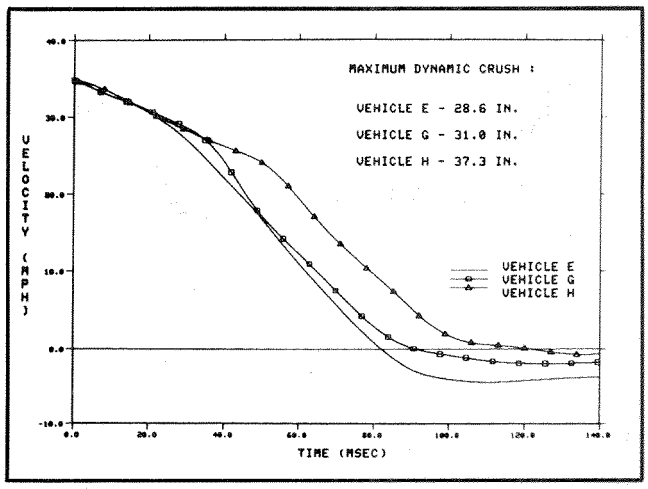


Figure 9. Sub-compact vehicle velocities (dummy measurement criteria).

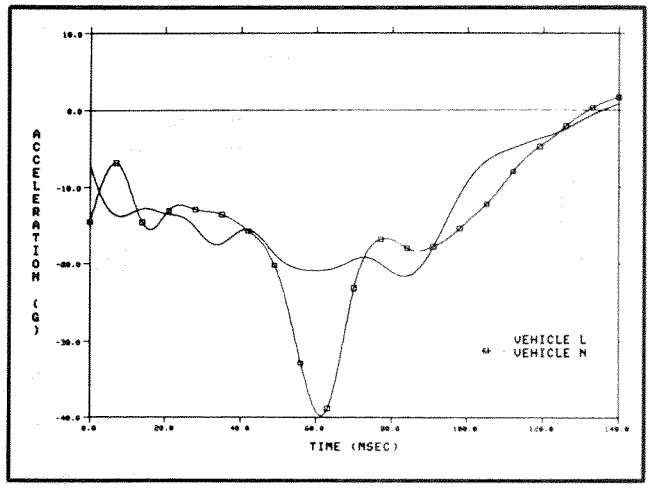


Figure 10. Intermediate vehicle accelerations (dummy measurement criteria).

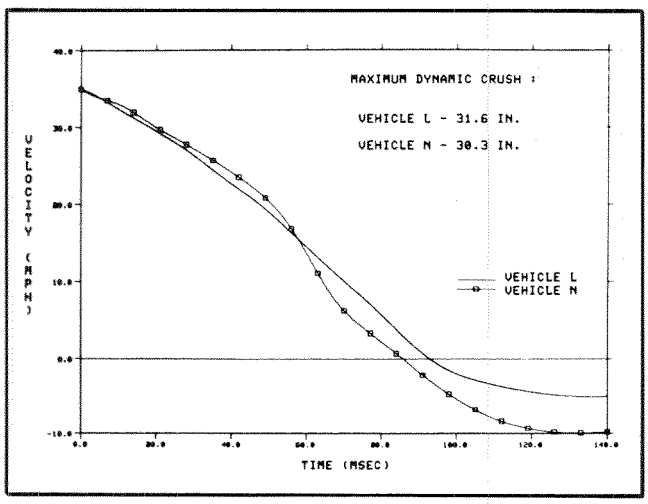


Figure 11. Intermediate vehicle velocities (dummy measurement criteria).

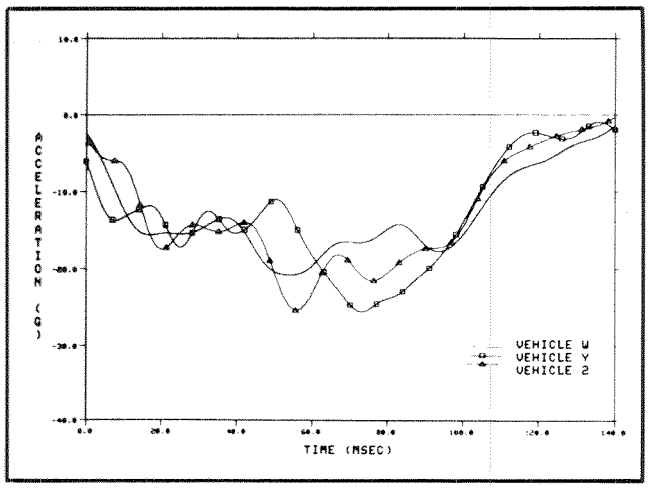


Figure 12. Standard vehicle accelerations (dummy measurement criteria).

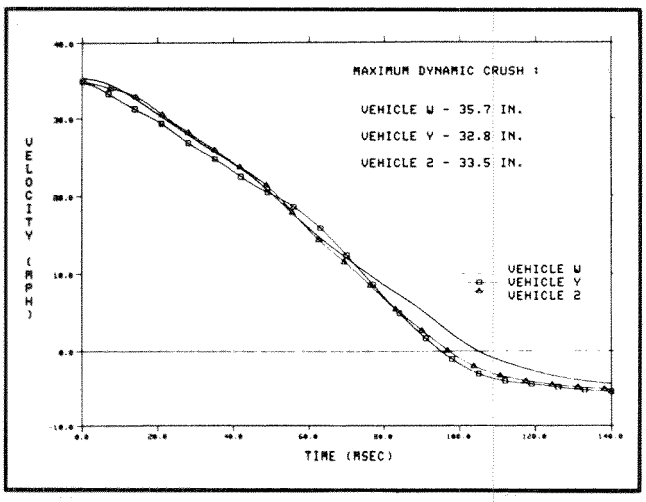


Figure 13. Standard vehicle velocities (dummy measurement criteria).

Each figure contains the responses of the two or three vehicles within a given weight category. It turned out that each category contained both "good" and "poor" vehicles. The vehicle responses were filtered at 40 Hz to emphasize the basic response shapes, which are felt to be more directly correlated with occupant response than are the higher frequency components of the responses. Observations were made within each weight category, as follows:

Mini-Compact:

Vehicle A—"poor" occupant protection.
Vehicle C—"good" occupant protection.

Vehicle responses were similar in shape, but Vehicle C had a slightly lower peak acceleration, a longer pulse duration, and considerably greater dynamic crush.

Sub-Compact:

Vehicle E—"good" occupant protection.
Vehicle G—"poor" occupant protection.
Vehicle H—"good" occupant protection.

Acceleration responses were quite different in shape. Vehicle G had a considerably higher peak acceleration than the other two cars, and it occurred earlier. Vehicle E had the shortest pulse duration, the smallest dynamic crush, and the smoothest acceleration and velocity response shape.

Intermediate:

Vehicle L—"good" occupant protection.
Vehicle N—"poor" occupant protection.

Acceleration pulse shapes and durations were similar, with the notable exception of the very high peak acceleration for Vehicle N. Vehicle L had slightly greater dynamic crush.

Standard:

Vehicle W—"good" occupant protection.
Vehicle Y—"poor" occupant protection.
Vehicle 2—"poor" occupant protection.

Vehicle W had a somewhat smoother acceleration pulse, with a lower peak value, than the other cars. The velocity-time responses were similar, but Vehicle W had a less rapid change in velocity after 75 ms, and a slightly longer pulse duration, resulting in greater dynamic crush.

In summary, vehicles offering "good" occupant protection generally had longer and smoother acceleration responses with lower peak acceleration and greater dynamic crush values than did vehicles offering "poor" occupant protection. The only exception was Vehicle E, a "good" vehicle, which had a shorter pulse duration and smaller dynamic crush than the "poor" vehicles in its weight category.

Restraint Survival Distance Calculations

A problem was encountered in the data analysis which prevented the calculation of the RSD. It was found that there was no uniform way to determine a value for the AID from the test reports. Calspan Corporation provided two measurements which were suitable for AID: CD (dummy chest to dash) and HW (dummy head to windshield). According to the figure provided in their reports, HW was measured from the dummy's forehead. Dynamic Science, Inc. (DSI), presented a table listing two suitable measurements: chest to instrument panel and nose to windshield. Unfortunately, the chest to instrument panel measurement was not recorded in all of the DSI reports; and DSI's nose to windshield measurement was obviously different from Calspan's forehead to windshield measurement.

Consequently, only the RID (which is the second term of equation 1) is presented in this analysis. The calculation summary is presented in Table 6, and RID is plotted in Figure 14 for each vehicle. A least squares line has been fit to the data.

It was expected that the variability of RID among vehicles would be much less than that observed for the dummy measurements, since experimental variability inherent in obtaining dummy data, and variability due to different belt restraint systems and different occupant compartment geometry among the vehicles are not factors in the determination of RID. However, it is seen that a large amount of variability does exist in RID, indicating that the potential occupant protection capability is very

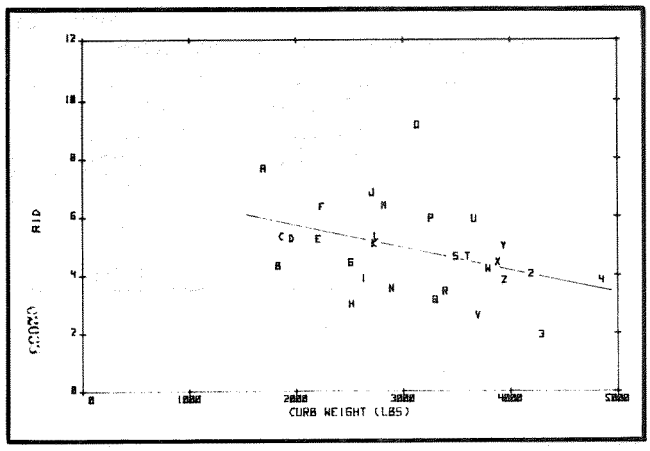


Figure 14. Required internal distance calculations.

Table 6. Calculation summary for minimum required internal distance (RID).

Vehicle			T*	DC	DP	RID
Class	Year	Symbol	(Sec)	(in.)	(in.)	(in.)
Mini-Compact	1979	A	0.0625	24.35	32.03	7.68
	1979	B	0.0539	26.52	30.87	4.35
	1979	C	0.0564	25.68	31.03	5.35
	1979	D	0.0567	26.21	31.50	5.29
Sub-Compact	1979	E	0.0573	26.08	31.34	5.26
	1979	F	0.0596	25.30	31.66	6.36
	1979	G	0.0552	26.30	30.75	4.45
	1979	H	0.0473	24.87	27.90	3.03
	1979	I	0.0486	24.77	28.68	3.91
Intermediate	1979	J	0.0601	25.22	32.06	6.84
	1979	K	0.0586	26.70	31.80	5.10
	1980	L	0.0536	25.14	30.48	5.34
	1979	M	0.0577	25.53	31.93	6.40
	1979	N	0.0518	25.33	28.89	3.56
	1980	O	0.0641	22.86	32.03	9.17
	1979	P	0.0530	24.34	30.30	5.96
	1979	Q	0.0483	25.22	28.39	3.17
Standard	1979	R	0.0492	25.75	29.21	3.46
	1979	S	0.0545	25.72	30.37	4.65
	1979	T	0.0555	26.37	31.02	4.65
	1979	U	0.0576	25.77	31.70	5.93
	1979	V	0.0465	25.48	28.10	2.62
	1979	W	0.0521	26.15	30.38	4.23
	1979	X	0.0518	25.72	30.18	4.46
	1979	Y	0.0515	24.70	29.71	5.01
	1979	Z	0.0528	26.69	30.53	3.84
	1979	2	0.0503	25.23	29.29	4.06
	1979	3	0.0447	24.90	26.86	1.96
	1979	4	0.0490	25.11	28.95	3.84

Table 7. Dynamic crush values of vehicle determined to be "Best" and "Worst" by RID calculations.

	Average Curb Weight (pounds)	Average Dynamic Crush (inches)
"Best Five" Vehicles	3124	36.24
"Worst Five" Vehicles	2801	26.76
All Vehicles	3094	32.02

sensitive to the structural response of the vehicle. Also, a definite trend of improved protection capability with increasing vehicle weight can be observed.

As was done with the dummy data, the "best five" and "worst five" vehicles were identified (those vehicles whose RID calculations were farthest from the least squares line). The "best five" vehicles were B, H, Q, V and 3; the "worst five" were A, J, M, O and U. It is interesting that only one vehicle (H) appears in the "best five" based on both criteria (dummy measurements and RID calculation); and only one vehicle (A) appears in the "worst five" based on both criteria.

Table 7 shows average dynamic crush values for the two groups of vehicles, compared with the average for all vehicles. The "best five" vehicles average significantly greater crush values than the "worst five", a similar (but more pronounced) trend as was observed in Table 5 for the dummy measurement criteria.

Occupant compartment responses (filtered at 40 Hz) for the ten vehicles are shown in Figures 15-22. There was only one vehicle (H) in the Sub-Compact weight category, and four (J, M, O and Q) in the Intermediate category. Therefore, for ease of comparison, the Sub-Compact vehicle was plotted with the two lightest Inter-

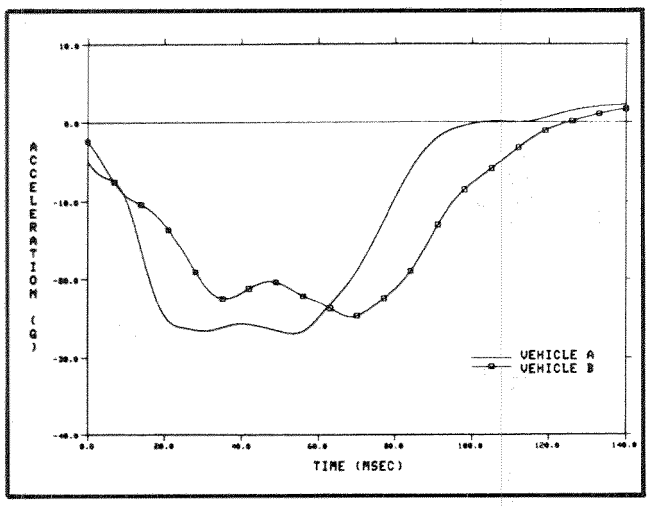


Figure 15. Mini-compact vehicle accelerations (RID criterion).

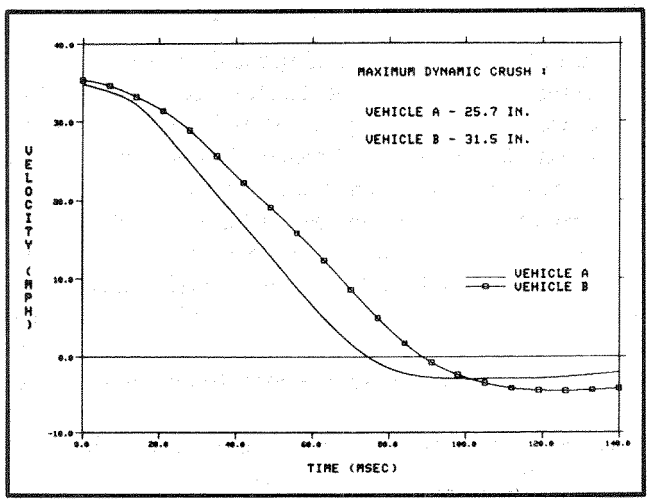


Figure 16. Mini-compact vehicle velocities (RID criterion).

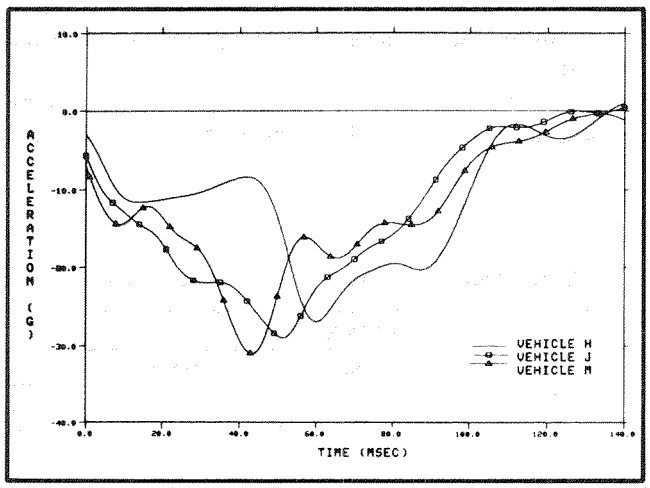


Figure 17. Sub-compact and light intermediate vehicle (<3000 lbs) accelerations (RID criterion).

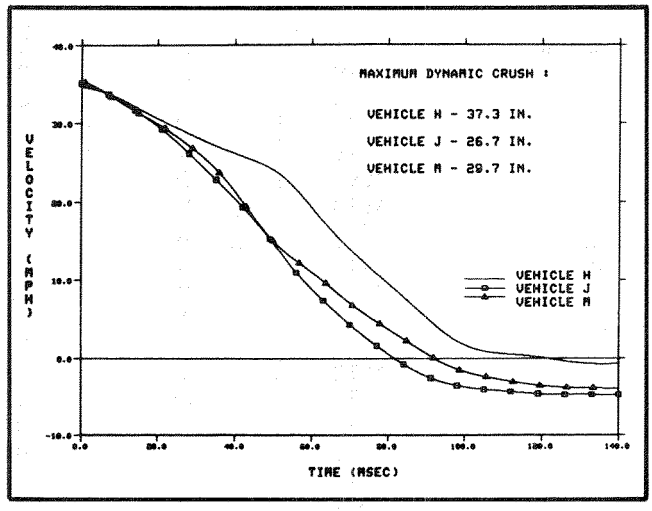


Figure 18. Sub-compact and light intermediate vehicle (<3000 lbs) velocities (RID criterion).

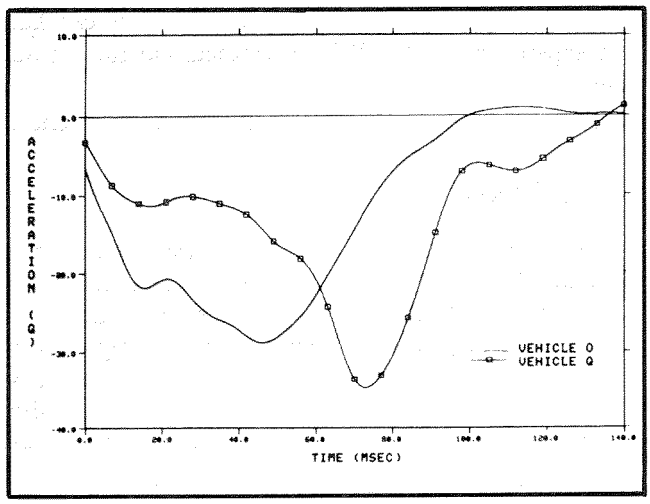


Figure 19. Heavy intermediate vehicle (> 3000 lbs) accelerations (RID criterion).

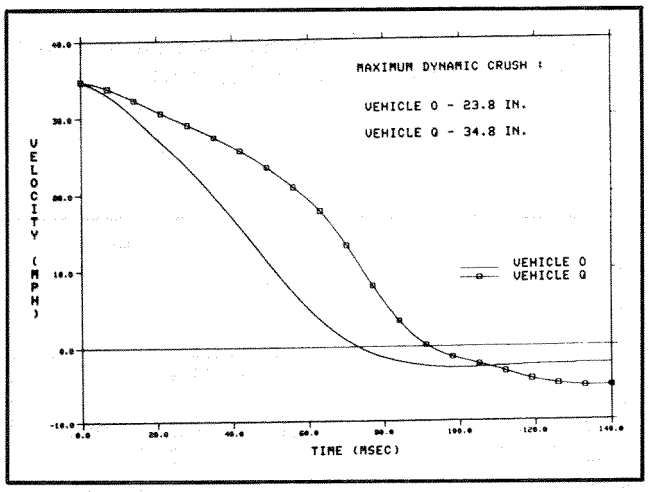


Figure 20. Heavy intermediate vehicle (> 3000 lbs) velocities (RID criterion).

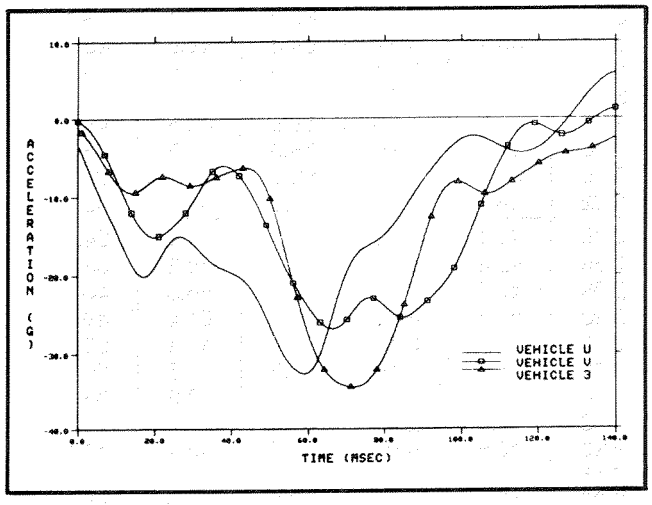


Figure 21. Standard vehicle accelerations (RID criterion).

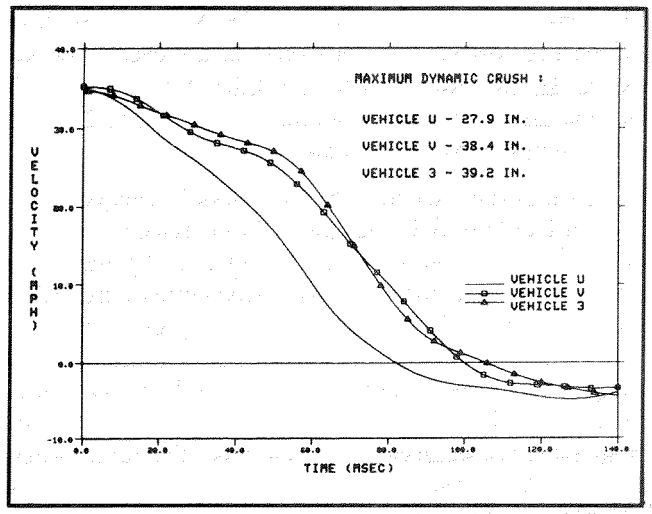


Figure 22. Standard vehicle velocities (RID criterion).

mediates (Figures 17 and 18), and the two heaviest Intermediates were plotted together in Figures 19 and 20. Observations within these groups are as follows:

Mini-Compact:

Vehicle A—"poor" occupant protection.
Vehicle B—"good" occupant protection.

Acceleration pulse shapes were similar, but Vehicle B had a slightly lower peak acceleration, a longer pulse duration and much greater dynamic crush. (Note the similarity of this comparison with that of Vehicles A and C, for the dummy measurement criterion.)

Sub-Compact and Light Intermediate:

Vehicle H—"good" occupant protection.
Vehicle J—"poor" occupant protection.
Vehicle M—"poor" occupant protection.

Acceleration pulse shapes were similar for Vehicles J and M. For Vehicle H, however, the shape was noticeably different, with a very low acceleration early in the event and a later peak. Also, the dynamic crush of Vehicle H was much greater.

Heavy Intermediate:

Vehicle O—"poor" occupant protection.
Vehicle Q—"good" occupant protection.

Differences are very pronounced. Vehicle O developed high accelerations very early in the event, and had a very short pulse duration. Vehicle Q had a very late peak acceleration and much greater dynamic crush.

Standard:

Vehicle U—"poor" occupant protection.
Vehicle V—"good" occupant protection.
Vehicle 3—"good" occupant protection.

Responses were similar for Vehicles V and 3, both of which had low accelerations early in the event and late peaks. In contrast, Vehicle U exhibited a higher acceleration early in the event, a much shorter pulse duration and much less dynamic crush.

In summary, vehicles offering "good" occupant protection had long pulse durations, large dynamic crushes, and acceleration pulse shapes characterized by low values early in the event and late peaks (which often were higher than those for vehicles offering "poor" protection).

It is interesting to observe that, in the intermediate weight class, the vehicle offering "poor" occupant protection (Vehicle O) was found to be significantly more aggressive to a small car in full and offset frontal collisions than was the vehicle offering "good" occupant protection (Vehicle Q) (3). Although structural override occurred in the Vehicle Q/small car crash test, raising the possibility that geometric differences contributed to the aggressiveness difference, it is likely that structural differences played the major role. Furthermore, another full frontal crash test with the same small car and Vehicle V (offering "good" occupant protection in the standard weight class), again resulted in less aggressiveness to the small car than was experienced in the Vehicle O/small car full frontal collision (4). This suggests that a correlation exists between good occupant protection and low aggressiveness.

ABAG Model Simulations

ABAG computer model simulations were run for 5th percentile female, 50th percentile male and 95th percentile male drivers and passengers. Maximum chest accelerations and steering column displacements are reported in Table 8. Figures 23-28 contain maximum chest accelerations plotted against vehicle curb weights, along with least squares lines. The following observations were made:

1. Although a large amount of variability among vehicles is apparent, it was somewhat less than that seen for dummy measurements and RID.
2. Peak chest acceleration was fairly insensitive to occupant size, with the exception of the 5th percentile female passenger.
3. A definite trend of improved occupant protection potential with increasing vehicle weight is seen.

Table 8. ABAG model simulation summary.

Vehicle			Driver Peak Acc. (g's) and Column Displacement (in.)						Passenger Peak Acceleration (g's)		
			5% F		50% M		95% M				
Class	Year	Symbol	Acc.	Disp.	Acc.	Disp.	Acc.	Disp.	5% F	50% M	95% M
Mini-Compact	1979	A	57.9	2.31	57.3	3.70	57.1	4.93	70.9	57.5	59.9
	1979	B	42.2	1.68	45.5	2.93	47.1	4.08	59.6	44.8	43.1
	1979	C	46.5	1.87	48.1	3.11	48.9	4.25	62.8	48.2	46.9
	1979	D	47.5	1.91	51.4	3.30	52.9	4.55	64.1	49.2	50.1
Sub-Compact	1979	E	46.8	1.85	49.4	3.20	51.5	4.43	64.0	49.9	48.9
	1979	F	52.2	2.12	50.3	3.24	48.7	4.18	69.8	53.7	53.2
	1979	G	44.7	1.78	46.9	3.04	48.6	4.19	64.9	47.0	46.1
	1979	H	26.6	1.06	32.1	2.07	35.7	3.04	39.3	39.7	33.9
	1979	I	32.7	1.31	39.8	2.55	43.6	3.74	48.8	42.0	36.7
Intermediate	1979	J	51.4	2.03	51.1	3.33	52.0	4.46	69.2	54.1	53.1
	1979	K	46.5	1.87	48.6	3.11	49.1	4.17	64.5	49.8	49.8
	1980	L	38.5	1.53	37.7	2.44	38.4	3.31	58.4	44.9	39.3
	1979	M	48.9	1.94	47.2	3.05	47.1	4.02	67.0	52.1	48.5
	1979	N	39.0	1.55	45.2	2.94	48.8	4.16	58.6	46.5	46.6
	1980	O	59.9	2.39	58.3	3.76	57.6	4.95	75.0	63.9	63.9
	1979	P	40.0	1.61	36.4	2.35	36.6	3.15	60.5	44.4	38.1
	1979	Q	29.7	1.21	40.4	2.62	44.2	3.82	41.0	40.1	35.4
Standard	1979	R	32.2	1.28	37.3	2.39	41.1	3.52	44.2	41.1	34.7
	1979	S	36.2	1.53	40.5	2.59	42.4	3.62	57.4	44.2	39.7
	1979	T	42.7	1.71	46.2	2.99	47.7	4.11	64.2	46.8	46.3
	1979	U	46.1	1.84	49.8	3.23	51.1	4.41	65.2	51.4	49.9
	1979	V	28.2	1.13	36.4	2.36	40.7	3.48	37.6	40.4	36.1
	1979	W	36.3	1.46	36.1	2.31	36.7	3.16	52.2	43.3	36.8
	1979	X	34.4	1.38	36.4	2.34	39.8	3.44	51.3	43.2	36.0
	1979	Y	35.8	1.42	31.9	2.06	34.4	2.95	50.7	43.6	35.1
	1979	Z	40.4	1.61	45.3	2.92	46.8	4.05	55.5	43.4	41.1
	1979	2	36.1	1.43	37.9	2.45	39.3	3.40	51.5	42.1	37.4
	1979	3	37.5	1.50	43.8	2.83	45.8	3.98	39.0	40.0	36.5
	1979	4	29.1	1.16	31.4	2.02	34.5	2.95	44.2	40.3	34.9

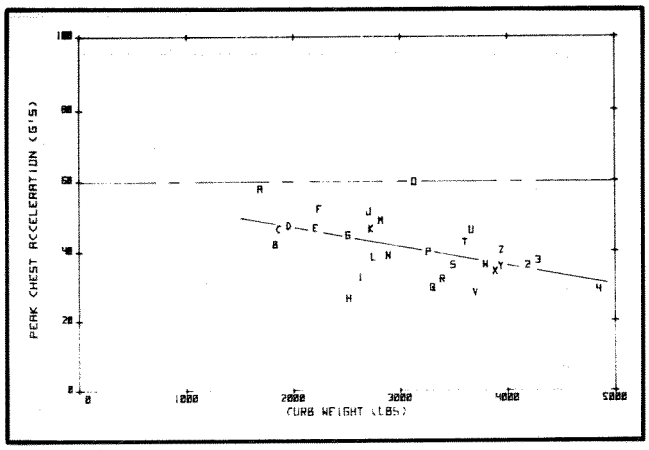


Figure 23. Maximum chest accelerations determined from ABAG model—5th percentile female driver.

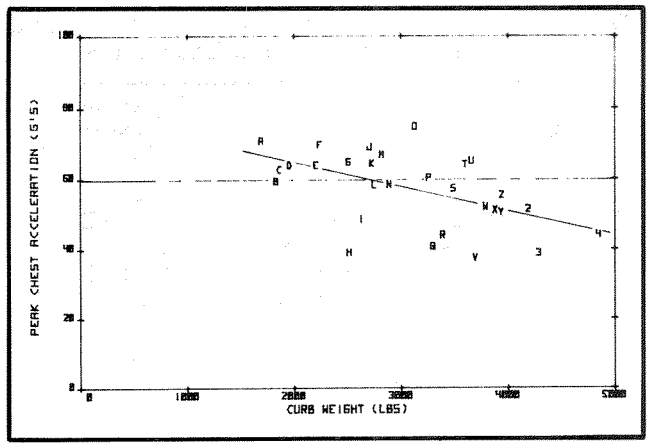


Figure 26. Maximum chest accelerations determined from ABAG model—5th percentile female passenger.

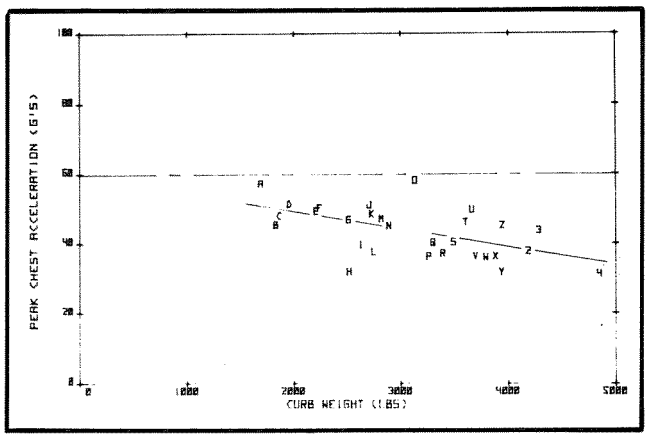


Figure 24. Maximum chest accelerations determined from ABAG model—50th percentile male driver.

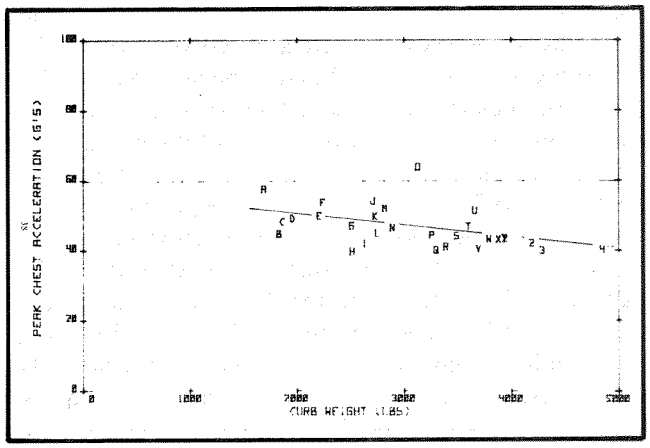


Figure 27. Maximum chest accelerations determined from ABAG model—50th percentile male passenger.

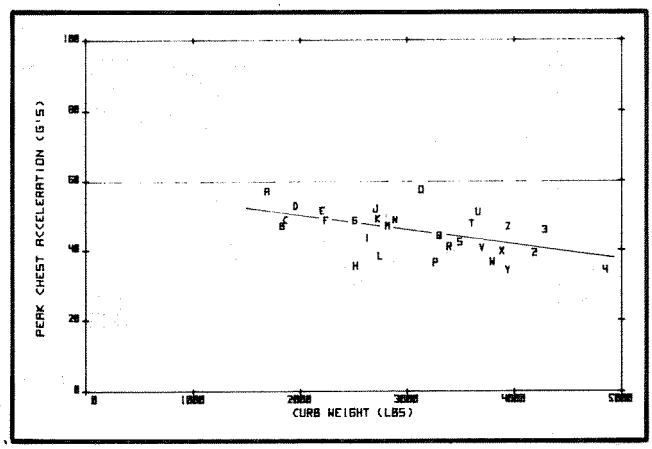


Figure 25. Maximum chest accelerations determined from ABAG model—95th percentile male driver.

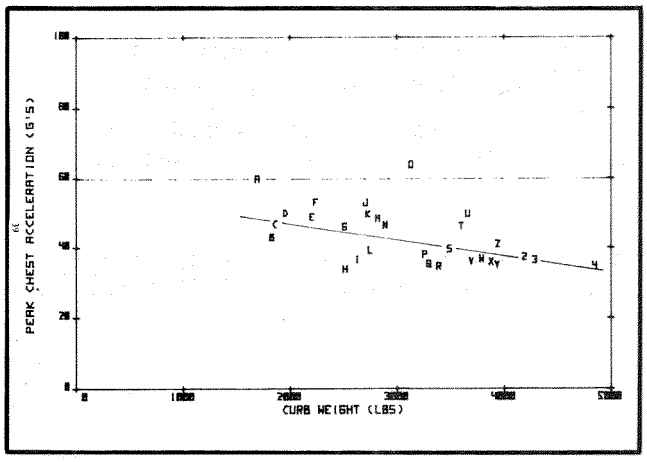


Figure 28. Maximum chest accelerations determined from ABAG model—95th percentile male passenger.

Table 9. Identification of "Best" and "Worst" vehicles as determined from ABAG simulation results.

Occupant	"Best Five" Vehicles	"Worst Five" Vehicles
5th % F Driver	H I Q R V	A F J O U
50th % M Driver	H I L P Y	A O U Z 3
95th % M Driver	H L P W Y	A O U Z 3
5th % F Passenger	H I Q R V	J M O T U
50th % M Passenger	B H I Q R	A J M O U
95th % M Passenger	B H I Q R	A J O T U
Vehicles appearing at least four times among the "Best Five": H I Q R		
Vehicles appearing at least four times among the "Worst Five": A J O U		

Using the same procedure as was done with the dummy data and RID calculations, the "best five" and "worst five" vehicles were identified from each of the six occupant plots (Figures 23-28). Those vehicles appearing among the "best five" or "worst five" at least four times were listed, as shown in Table 9. Of the four vehicles identified as "best", two (H and Q) were among the "best five" based on the RID calculation criterion, and one (H) was among the "best" according to all three criteria. All four of the "worst" vehicles were among the "worst five" based on the RID calculation criterion, and one (A) was identified in the "worst" category by all three criteria.

In Table 10, it is seen that the "best four" vehicles averaged significantly greater dynamic crush than the "worst four", as was the case for the RID criterion.

Occupant compartment responses (filtered at 40 Hz) for the eight vehicles appear in Figures 29-34. There was only one vehicle (A) in the Mini-Compact weight category, and both vehicles in the Sub-Compact category (H and I) were among the "best four"; therefore, these two categories were combined in Figures 29 and 30. Observations are as follows:

Mini-Compact and Sub-Compact:

Vehicle A—"poor" occupant protection.
Vehicle H—"good" occupant protection.
Vehicle I—"good" occupant protection.

Acceleration pulse shapes were very similar for Vehicles H and I. Vehicle A's, however, was very different, having

Table 10. Dynamic crush values of vehicles determined to be "Best" and "Worst" by ABAG simulations.

	Average Curb Weight (pounds)	Average Dynamic Crush (inches)
"Best Four" Vehicles	2958	35.60
"Worst Four" Vehicles	2797	25.98
All Vehicles	3094	32.02

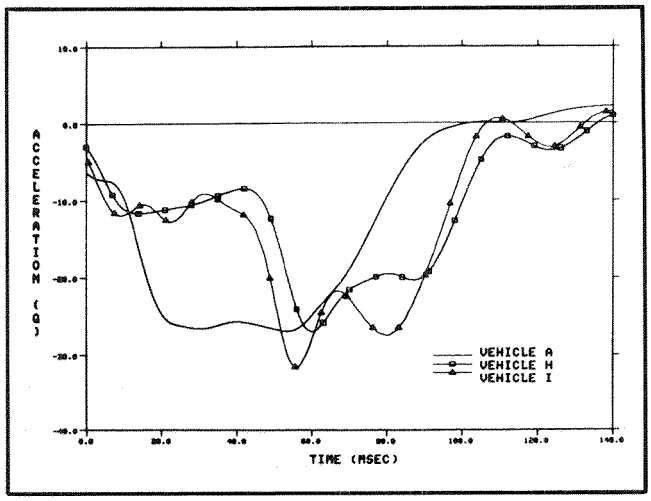


Figure 29. Mini-compact and sub-compact vehicle accelerations (ABAG modeling criterion).

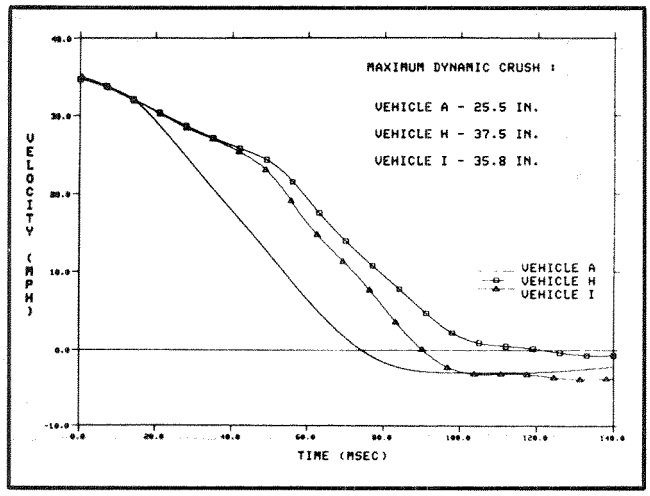


Figure 30. Mini-compact and sub-compact vehicle velocities (ABAG modeling criterion).

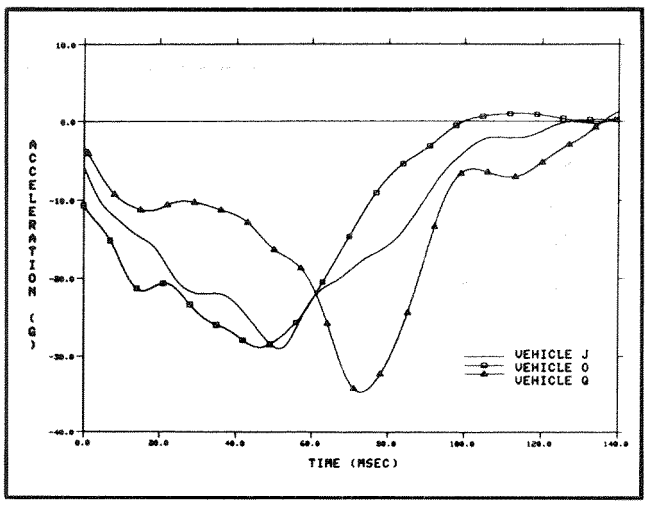


Figure 31. Intermediate vehicle accelerations (ABAG modeling criterion).

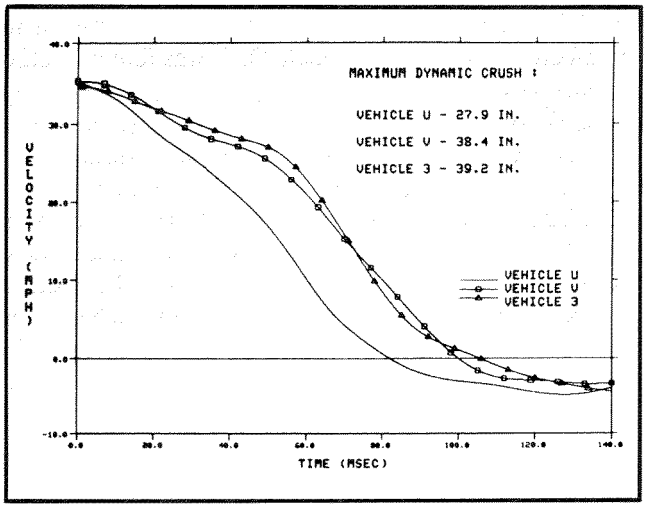


Figure 32. Intermediate vehicle velocities (ABAG modeling criterion).

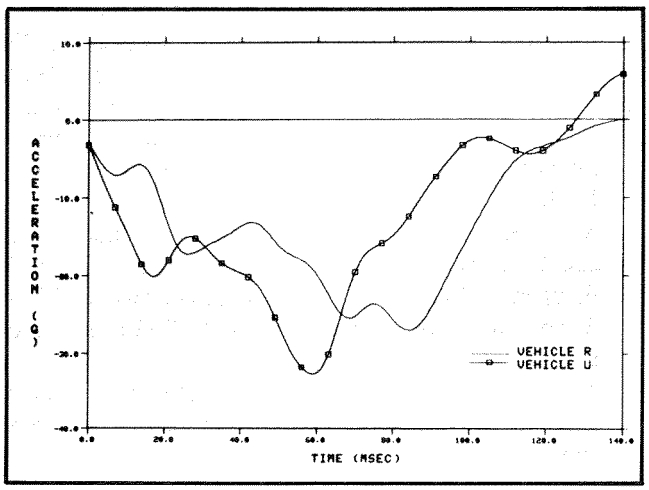


Figure 33. Standard vehicle accelerations (ABAG modeling criterion).

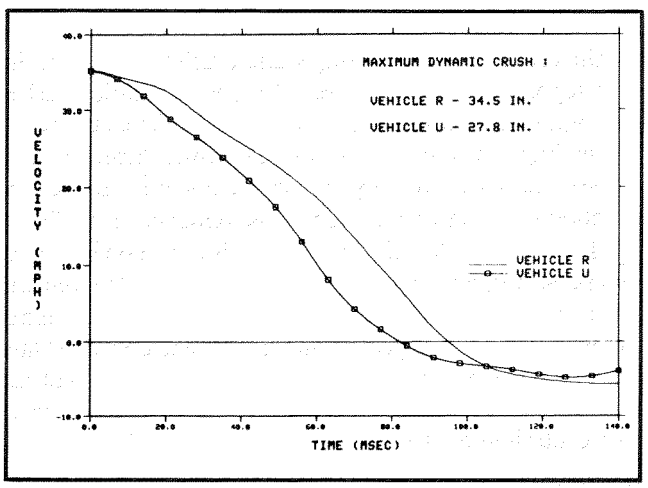


Figure 34. Standard vehicle velocities (ABAG modeling criterion).

higher acceleration levels early in the event and a much shorter pulse duration. The dynamic crush of Vehicle A was also much less.

Intermediate:

Vehicle J—"poor" occupant protection.
Vehicle O—"poor" occupant protection.
Vehicle Q—"good" occupant protection.

Acceleration responses were similar for Vehicles J and O, having early peaks and short durations. Although the peak acceleration for Vehicle Q was higher, it occurred very late, and the pulse shape was characterized by low values early in the event. Maximum crush was much greater for Vehicle Q.

Standard:

Vehicle R—"good" occupant protection.
Vehicle U—"poor" occupant protection.

The acceleration of Vehicle U rose to a higher peak earlier in the crash event than that of Vehicle R. Vehicle R had a substantially longer pulse duration and greater maximum crush.

In summary, vehicles offering "good" occupant protection had low accelerations early in the crash event, late peak accelerations, long pulse durations and large maximum dynamic crash values. As previously noted, Vehicles O and Q, two intermediate cars strongly suspected of having significantly different structural aggressiveness levels against a smaller car (32), were identified as offering "good" and "poor" occupant protection, respectively. All of these results are essentially identical to those observed when the RID criterion was used.

CONCLUSIONS

General Observations

A distinct and consistent trend of increased potential occupant survivability with increasing vehicle weight was seen. On average, including three indicators of occupant survivability (dummy measurements, RID calculations and ABAG modeling results), the analysis showed a 32% increase in occupant protection potential over the weight range from 1700 pounds to 4800 pounds (curb weight).

A strong correlation between maximum vehicle crush and occupant survivability (greater survival potential for higher crush values) was observed. Using dummy measurements as the occupant protection criteria, the difference between "best" and "worst" vehicles was found to be slight (less than two inches). Using the other criteria, however, very significant differences (nearly ten inches) were seen between "best" and "worst" vehicles. This suggests that when variabilities in restraint systems and

dummy measurements are eliminated (as they are in the RID and ABAG determinations), the relationship between crush and protection potential for restrained occupants is shown clearly to be significant.

General Reasons for Enhanced Crashsurvivability

A very large amount of variability among vehicles was observed in the dummy measurements. In the occupant modeling and stroking distance calculations, even though variability inherent with dummies and due to different restraints and compartment geometries was eliminated, significant variability was still evident. The required internal occupant stroking distances ranged from 2 to 9 inches, and chest accelerations from the ABAG modeling generally varied by a factor of two. This indicated that potential protection of restrained occupants is very dependent upon the structural response of the vehicle.

In general, vehicles showing potential for superior crashsurvivability experienced large dynamic crush values, and had occupant compartment responses which were characterized by long pulse durations, low accelerations early in the crash event, and late peak accelerations.

Selection of Vehicles for Future Modification

Only one vehicle was identified in the "best" crashsurvivability category according to all three criteria (dummy measurements, stroking distance calculation and ABAG modeling results). This was Vehicle H, a subcompact. One other vehicle, (Vehicle Q, an intermediate), appeared among the "best" according to two criteria, stroking distance and ABAG modeling. However, recommending either of these specific vehicles for future modification to achieve and demonstrate further enhancement of frontal crashsurvivability is not justified on the basis of this analysis alone. Also needed would be a more thorough examination of other aspects of the vehicle and its crash response (such as interior geometry, steering column behavior, firewall intrusion, etc.). It can be concluded from this study that any vehicle having an occupant compartment crash response similar to those of these two vehicles (i.e., low accelerations early in the event and late peak accelerations) has a frontal structure which potentially offers superior protection for its occupants.

Relationship Between Crashworthiness and Structural Aggressiveness

One of the vehicles identified in the "worst" occupant protection category according to two criteria (occupant modeling and stroking distance calculation) was an intermediate size vehicle, Vehicle O. It was found in other studies (3,4) that Vehicle O was significantly more aggressive to a small car in frontal collisions than were Vehicles Q and V (which this analysis indicates offer "good" occupant protection in the intermediate and standard size categories, respectively). This observation indicates that those frontal structural response characteristics which are responsible for providing the potential for good occupant protection are also responsible for assuring minimal aggressiveness to the occupants of a smaller car.

REFERENCES

1. T. F. MacLaughlin, "Derivation and Application of Restraint Survival Distance in Motor Vehicle Collisions," SAE Technical Paper 810092, February 1981.
2. S. W. Enouen, "Comparison of Models Simulating Occupant Response in Airbags," Master of Science Degree Thesis, The Ohio State University, January 1982.
3. R. A. Saul, T. F. MacLaughlin, C. A. Ragland, Jr., and D. Cohen, "Experimental Investigation of Crash Barriers for Measuring Vehicle Aggressiveness—Fixed Rigid Barrier Initial Results," SAE Technical Paper 810093, February 1981.
4. T. F. MacLaughlin, Bi-Monthly Progress Report, SRL-20, Vehicle Research and Test Center, NHTSA, June/July 1982 (unpublished).

APPENDIX

Uncertainties in extracting static crush values from the test reports were encountered. In general, static crushes are reported in at least three locations in the test reports, depending on the contractor. Dynamic Science, Inc. (DSI), and Calspan Corporation use a similar procedure to obtain pre- and post-crash measurements. In addition, DSI publishes a Vehicle Profile Data Sheet, showing crush values at several locations across the front of the vehicle. In Table A-1, crush values X1, X19, X20 and the maximum crush value appearing in DSI's Vehicle Profile Data Sheet are presented. The word "center" indicates that the maximum value in the Vehicle Profile Data Sheet is at the centerline of the vehicle.

It is clear from Table A-1 that discrepancies exist in the static crush values. For this reason, only dynamic crush values were used in the analysis.

Table A-1. Comparison of static crush values.

Vehicle			Test Contractor	Static Crush—Inches			
				Values from Fig., "Pre-Test & Post-Test Measurement Points"			Max. Values from "Vehicle Profile Data Sheet," DSI Reports
Class	Year	Symbol		Left ×20	Center ×1	Right ×19	
Mini-Compact	1979	A	Calspan	18.6	20.9	19.2	—
	1979	B	Dynamic Science	22.2	20.9	22.3	24.7 (center)
	1979	C	Calspan	21.7	22.7	22.1	—
	1979	D	Dynamic Science	25.3	25.0	24.9	25.8
Sub-Compact	1979	E	Dynamic Science	23.1	23.1	22.0	22.1 (center)
	1979	F	Calspan	21.9	23.4	21.5	—
	1979	G	Calspan	21.6	24.2	23.1	—
	1979	H	Dynamic Science	16.5	21.1	16.5	23.4
	1979	I	Dynamic Science	16.8	21.4	18.1	29.9 (center)
Intermediate	1979	J	Dynamic Science	20.1	20.2	20.0	25.1
	1979	K	Calspan	21.1	25.5	23.3	—
	1980	L	Calspan	21.4	22.8	21.3	—
	1979	M	Calspan	22.7	25.0	22.2	—
	1979	N	MSE	27.3	NA	28.3	—
	1980	O	Calspan	20.8	19.5	19.7	—
	1979	P	Calspan	21.0	23.9	22.6	—
	1979	Q	Dynamic Science	30.2	30.9	29.5	30.9 (center)
Standard	1979	R	Dynamic Science	26.8	23.0	27.3	28.1
	1979	S	Calspan	24.8	24.1	27.8	—
	1979	T	Calspan	22.3	24.6	22.7	—
	1979	U	Dynamic Science	22.2	25.0	24.1	25.0 (center)
	1979	V	Dynamic Science	26.2	30.3	28.5	30.1 (center)
	1979	W	Calspan	24.1	27.8	28.1	—
	1979	X	Calspan	23.1	27.4	25.1	—
	1979	Y	Dynamic Science	*	27.5	*	29.7
	1979	Z	Dynamic Science	28.8	29.2	28.0	26.3 (center)
	1979	2	Dynamic Science	26.8	27.0	30.6	30.6
	1979	3	Dynamic Science	32.8	34.0	32.8	34.2
	1979	4	Dynamic Science	30.8	26.9	28.6	30.8

*NA—Obscured

A Crashworthiness Rating System for Cars

S. PENOYRE
Transport and Road Research Laboratory

ABSTRACT

At the Conference on Crashworthiness Ratings held in Lancaster, USA, in December 1980, a paper was presented by TRRL which proposed a new Crashworthiness Rating scheme. This attempted to weight the contributions of front and side barrier impacts and internal headform impact tests in proportion to the pattern of injury frequencies which occur in Great Britain. It assumed that car occupants were wearing seat belts and that they were in cars of different model but broadly similar mass. On this basis the results of tests on twelve models of car were shown to give ratings which indicated marked differences in the probability of injury to occupants.

The present paper reports work carried out since then on this subject. The rating itself has been refined and now uses data from 40 measurements. Limited repeat testing on two models of car shows that the overall rating for a car is closely repeatable. It is suggested that the ratings should be expressed on a scale of from one to five stars, and that publication of these ratings would encourage manufacturers to compete in marketing safer designs.

INTRODUCTION

Legislation has produced major advances in vehicle safety over the past decade, but improved consumer information may lead to more progress in the coming years than can be achieved by new international legislation, which inevitably is agreed only slowly in present circumstances. In Europe the major problems with the new legislation approach seem to be (1) little evidence on whether car buyers and users actually want safer cars if this means increased cost or inconvenience, (2) the difficulty of devising acceptable tests for Europe when many nations must agree on them at the United Nations in Geneva and all the Community countries in Brussels, (3) technical problems with the proposed next generation of car safety tests, i.e., sub-system tests alone are not always representative of accidents, while whole-vehicle impact tests using dummies are highly variable and are too expensive if repeated with prototype vehicles. In view of these difficulties, and since road accidents are a major cause of suffering, disablement and premature death in most countries, it would clearly be very desirable to find a complementary approach which will encourage progress towards safer cars. The Crashworthiness Rating concept appears to be just such an approach.

THE POTENTIAL BENEFITS OF A CRASHWORTHINESS RATING SYSTEM

The principle of this proposed Crashworthiness Rating concept is to provide a guide to a car's ability to protect its occupants in crashes. Ratings would be based on objective measurements made in official tests and would be published, just as fuel consumption figures are already published in both USA and Europe.

Several major benefits should follow from such a rating system, e.g.,

1. It would allow consumers to make informed choices in relation to occupant protection when buying cars.
2. Manufacturers should be encouraged to compete in producing safer vehicles.
3. The rating system would give credit for cars which offer more occupant protection than a basic legal minimum requirement. Manufacturers could therefore benefit from introducing worthwhile safety innovations, such as seat belt webbing locks.

THE BASIS FOR DERIVING A CRASHWORTHINESS RATING SYSTEM

To achieve these benefits from a rating system, it is essential that the ratings are objective assessments of a car's ability to protect its occupants in crashes. There appear to be two possible sources of data on which to base the Crashworthiness Rating, (1) real accident and injury statistics for the car model in question, (2) laboratory testing which simulates real crashes. Mathematical structural analysis has not yet reached the stage where crashworthiness can be assessed without actually deforming metal, although of course analysis may be very helpful to the car designer in helping him to achieve a good rating by producing a safer car. Use of real accident and injury statistics would have several advantages, in avoiding both the costs of laboratory testing and the inevitable arguments about whether such tests are valid representations of accidents. However there appear to be two major problems with using real accident data; (1) this cannot be available early enough in a model's life for the rating system to be useful to new car buyers, (2) it is almost certainly not possible to eliminate driver factors or to determine crash severity and individual occupants' injury thresholds when analysing accidents to assess the car's crashworthiness. The only satisfactory basis for deriving a Crashworthiness Rating therefore appears to be laboratory testing which simulates accidents. Both whole-vehicle impact tests using dummies and sub-system tests (e.g., interior impact tests with a headform) have disadvantages if used alone, since whole-vehicle impact tests are highly variable and are too expensive to be repeated if prototype vehicles are required, while sub-system tests are not always representative of accidents and cannot show, for example, mismatches between intrusion resistance and restraint system performance. A combination of the two types of test therefore seems necessary, as is of course already accepted for current occupant protection legislation in both USA and Europe. The tests must be designed to represent the most frequent kinds of accidents which cause occupant death or serious injury, i.e., frontal and side impacts, but tests representing less common causes of injury, e.g., roll-overs and rear impacts, could of course be included in the rating system later on if this was thought worthwhile.

THE PROPOSED CRASHWORTHINESS RATING SYSTEM

This proposal is based on using occupant protection data from three sources, (1) a whole-vehicle frontal impact test with restrained front seat occupant dummies, (2) a whole-vehicle side impact test using a mobile barrier and a restrained dummy in the driver's seat, (3) a set of interior impact tests using a headform. These three procedures

are those currently used at TRRL. In a few years time it may be possible to use agreed international test procedures instead.

For reasons already published elsewhere (ref 1), it is proposed that the frontal impact test should consist of a high speed (58-60 km/h, 36-37 mile/h) impact into a wood faced rigid barrier at 30° off perpendicular, with the driver's side hitting first. In this test measurements would be made of the driver and passenger peak head decelerations (> 3 ms cumulative), chest peak decelerations, and femur compression loads. Post-test "survival space" measurements of intrusion resistance would be made, provisionally those of ECE Reg 33, i.e., instrument panel to R point, front of passenger compartment to R point, and width of footwell through the brake pedal. While HIC (Head Injury Criterion) is probably a better indicator of likely head injury than is peak head deceleration, using it in this application would have the drawback of complexity. Since the rest of this proposed rating system is so simple and it is essential that the car buying public should be able to understand the crashworthiness rating system, it would seem better to avoid the complications of HIC in this case.

For assessing side impact protection, the whole-vehicle impact test would be the present TRRL standard procedure which uses a small rigid faced mobile barrier weighing 1100 kg and impacts the stationary car at 90° at 35 km/h (22 mile/h) centered on the driver's R point (ref 2). A restrained TRRL force measuring dummy would be used in the driving seat (refs 3,4), and measurements would be made of pelvis and thorax loads (e.g., the two largest of the four dummy rib loads). With such a rigid barrier the maximum barrier deceleration reached in this test is a measure of the car side's ability to resist intrusion and so to make the front of a car hitting it crush and absorb energy. It is therefore proposed to measure barrier peak deceleration, with the aim of achieving a satisfactorily high level (provisionally 15 g for an 1100 kg barrier, i.e., 162 kN or 36,400 lb). Since present dummies do not often given head contacts in side impact tests, even though head injuries are a major source of serious and fatal casualties in real side impact accidents, an interior headform test rather than dummy head acceleration should be used to measure the head protection provided.

There are two major reasons for requiring interior headform tests (ref 1) as well as the front and side whole-vehicle impacts: (1) in a whole-vehicle test the dummy could strike only one point of the car's interior, whereas in real accidents with their combinations of different occupant sizes and impact conditions there are many possible impact points, (2) headform tests are simpler, cheaper and more repeatable than dummy tests and can be carried out on components early in the vehicle design process before complete vehicles are available. It is suggested that the 24 km/h (15 mph) 6.8 kg (15 lb) headform impact already required in FMVSS 201 and ECE Reg 21 is used to record peak resultant acceleration (> 3 ms). The test could be done with a pendulum rig, but it may be preferable to use a free flight headform (ref 1) launched from an air gun or catapult, since this allows likely head impact points to be reached without cutting up the car and also gives more realistic results than a pendulum when impacting obliquely or on curved surfaces. For front crash protection assessment it is proposed to carry out 20 interior headform impacts to measure the stiffness of 7 likely occupant contact areas: (1) the header rail (mean of 5 points), (2) facia top (mean of 5 points), (3) A post (mean of 2 points), (4-6) steering wheel (3 separate points, i.e., on the rim at a spoke, on the rim away from a spoke, and on the hub, (7) lower facia knee impact area, (mean of 5 points). For side crash protection 5 headform impacts would be used on 2 likely occupant contact areas: (1) the B post (mean of 2 points, one on and one off the seat belt anchorage if present), (2) the cant rail, i.e., above the window glass (mean of 3 points).

These proposed measurements are listed in Table 1. For each of the 24 items per vehicle the Crashworthiness Rating calculation will require two figures to be allotted, (1) a Critical Value, (2) a Weighting Factor. The Critical Value of each measured parameter is intended to be the level at which approximately half of the vehicle occupant population would be seriously injured. The Weighting Factor determines the relative contribution made by that parameter to the overall Crashworthiness Rating, and for convenience is chosen such that it can be considered as a percentage, i.e., the total of the Weighting Factors used must equal 100. Typical Critical Values and Weighting Factors are given in Table 1, and their choice is discussed below. The term "Critical Value" is preferred to the more commonly used "tolerance" because the latter suggests that a figure only slightly better than the stated one will not injure anyone, while in fact because of the very wide range in people's strengths such an implication is misleading.

At this stage in the procedure the aim is to have measured those parameters which best describe the occupant protection offered by a car, and to have agreed Critical Values and Weighting Factors for these parameters. These data could of course be processed in a large number of ways to produce the required Crashworthiness Rating, and the method proposed below should be considered as the preferred possibility; there may well be other methods which could be shown to yield Ratings more representative of occupant protection. However this proposal has the merit of simplicity. Three steps are involved:

(1) The first step is to express each measurement as a proportion of the Critical Value for that parameter. For most parameters the Critical Value is such that a bigger number means more risk of injury, and for these the required proportion or quotient is formed by dividing the measured value by the Critical Value. For example, if the

Table 1. Measurements required, with proposed critical values and weighting factors.

		Critical value	Weighting factor %	
Frontal barrier impact:				
Instrument panel to R point,	mm	450 min	5	
Front of pass comp to R point,	mm	650 min	5	
Width of footwell,	mm	250 min	5	
Driver's head, peak resultant acc	>3 ms, g	80 max	7)	10
Passenger's head, peak resultant acc		80 max	3)	
Driver's chest, peak resultant acc	>3 ms, g	60 max	14)	20
Passenger's chest, peak resultant acc		60 max	6)	
Driver's left femur compressive load	kN	4 max	1.4)	2
Passenger's left femur compressive load		4 max	0.6)	
Driver's right femur compressive load	kN	4 max	1.4)	2
Passenger's right femur compressive load		4 max	0.6)	
Frontal headform interior impact:				
Header rail (mean of 5 points)	g	80 max	3	
Facia top (mean of 5 points)	g	80 max	3	
A Post (mean of 2 points)	g	80 max	3	
Steering wheel rim, on spoke	g	80 max	3	
Steering wheel rim, off spoke	g	80 max	3	
Steering wheel hub	g	80 max	3	
Lower facia, knee impact area (mean of 5 points)	g	80 max	3	
Side mobile barrier impact:				
Barrier peak acc	g	15 min	5	
Largest rib load	kN	1 max	5	
Next largest rib load	kN	1 max	5	
Pelvis load	kN	6 max	5	
Side headform interior impact:				
B Post, (mean of 2 points)	g	80 max	5	
Cant rail (mean of 3 points)	g	80 max	5	

measured value of peak head acceleration is 135 g and the Critical Value for this parameter is 80 g, then the required quotient is 135/80 = 1.69. However when the Critical Value is such that a smaller number means more risk of injury, as with survival space measurements and side impact barrier deceleration, then the quotient is formed by dividing the Critical Value by the measured value. For example, if the measured value of footwell width is 685 mm and the Critical Value for this parameter is 250 mm, then the required quotient is 250/685 = 0.365. In all cases the aim is to form a quotient whose value is unity if the measured value equals the Critical Value, and increases with injury risk. It is proposed to limit each quotient to a maximum value of 2, on the grounds that when a level of twice the critical load (or half the critical survival space) has been exceeded, even further infringement is unlikely to produce still worse injuries.

(2) Having formed the 24 quotients for each car, and limiting these to 2 where necessary, the next step is to square each quotient. This squaring is intended to increase the contribution to the overall rating made by those parameters in which the particular car's occupant protection is inadequate. Although the decision to square the quotients (rather than to raise them to some other power) is arbitrary, it has the advantages of being simple to do and to explain, and of giving results in agreement with subjective assessments of how injury rate varies with load in the important region between about 0.5 and 1.5 times the Critical Value of load.

(3) The final steps in this proposed procedure for calculating crashworthiness ratings are first to multiply each squared quotient by its appropriate weighting factor. One approach would be to present for each car the 24 values obtained as outlined above so that the keen motorist could

judge for himself the particular areas of weakness and strength when comparing one model with another. However it is the author's view that this method of presentation would not be attractive to many people and that a single rating figure should be calculated by summing the 24 results into a single figure. This final figure will equal 100 for a vehicle exactly on the critical value for each parameter and could rise to 400 for one with every measurement two or more times as bad as the critical value. It will be important to emphasise that "smaller means safer" with this rating, and it is possible that a different name rather than Crashworthiness Rating would be better to avoid confusing car buyers, e.g., Crash Injury Rating. However motorists cope perfectly well with other car performance figures where smaller is better, e.g., acceleration times (and indeed car prices!), so the problem does not seem serious. An even simpler presentation would be to convert the single overall rating figure to a star rating on a scale of 1-5 stars. It may be found desirable to quote one or more of these three possible presentations but this is a matter of detail and not principle.

The proposed procedure for calculating a single overall rating can be summed up in mathematical notation as

Crashworthiness Rating

$$= \sum W1.(Q1)^2 + W2.(Q2)^2 + \ldots W24.(Q24)^2$$

where W1 to W24 are the Weighting Factors for each parameter totalling 100 so they can be considered as percentages and Q1 to Q24 are the quotients formed for each parameter, as either

1. measured value/Critical Maximum Value, or
2. Critical Minimum Value/measured value, where (2) applies to those parameters (i.e., survival space dimensions and barrier deceleration) where a smaller measured value means a greater injury risk. All quotients are limited not to exceed 2.

EXAMPLES OF CALCULATED CRASHWORTHINESS RATINGS

The proposed rating system has been applied to the previously published (refs 1,2) results of tests carried out at the Motor Industry Research Association, Nuneaton, UK, under TRRL contract, on 12 popular small and medium sized European and Japanese cars purchased in 1976. Table 2 gives the relevant figures for high speed (58-60 km/h, 36-37 mile/h) 30° angled impact tests into a wood faced barrier using restrained OPAT dummies, while Table 3 gives the results of mobile barrier side impact tests using restrained TRRL Side Impact dummies. Table 4 shows the results of interior headform im-

Table 2. Front barrier impact test results (from Ref 1 and first 12 cars tested) 30° angled wood faced barrier, 58–60 km/h (36–37 mile/h) restrained OPAT dummies.

CARS (1976 models unless marked*)	Inst panel to R point mm	Front of pass comp to R point mm	Width of driver's footwell mm	Head peak resultant acc (>3ms) g		Chest peak resultant acc (>3ms) g		Left femur load kN		Right femur load kN	
Proposed Critical Value	450 min	650 min	250 min	80 max		60 max		4 max		4 max	
				Driver	Passenger	Driver	Passenger	Driver	Passenger	Driver	Passenger
BL Marina	760	1090	685	135	51	38	38	1.3	2.0	1.9	1.4
Datsun Sunny	360	760	285	77	60	48	41	2.2	0.9	1.1	0.2
Ford Escort	510	865	533	171	66	44	46	2.9	1.7	3.1	1.2
Colt Lancer	560	865	273	166	82	61	53	3.3	0.6	2.3	0.2
Reliant Kitten	452	833	457	194	62	37	32	2.3	1.7	1.7	1.3
Vauxhall Chevette	413	686	254	119	114	42	41	14.2	1.1	1.5	1.4
BL Princess	425	656	660	89	97	46	38	4.5	1.2	2.4	0.6
Chrysler Alpine	390	630	0	59	123	55	40	2.7	0.6	16.6	2.9
VW Golf	445	762	432	44	50	42	40	5.9	0.8	4.8	1.7
Fiat 133	257	349	0	143	27	38	36	14.1	0.9	8.8	3.4
Ford Fiesta	450[1]	735	648	80[1]	54	39	41	9.8	0.9	1.3	3.8
Ford Fiesta A*	330	685	380	70	60	38	41	5.8	2.1	4.4	3.3
Ford Fiesta B*	380	685	380	44	64	64	44	7.3	1.9	1.8	3.4
Renault 5	406	727	279	108	184	57	61	9.2	1.1	5.6	6.2
Renault 5A*	395	825	330	98	134	52	67	5.0	2.7	7.2	3.3
Renault 5B*	425	790	280	91	119	53	65	4.2	3.4	4.2	3.1

[1]: Data not available: proposed Critical Values substituted.

Table 3. Side mobile barrier impact test results (from Ref 2 for first 12 cars tested) barrier mass 1100 kg: rigid face 1 m wide × 0.6 m high, edge radius 75 mm, ground clearance 200 mm, barrier speed 35–38 km/h (22–24 mile/h).

TRRL Side Impact Dummy

	Barrier peak acc (>3 ms) g	Largest rib load kN	Next largest rib load kN	Pelvis load kN
Proposed Critical Value	15 min	1 max	1 max	6 max
BL Marina	10.0	2.2	1.2	2.4
Datsun Sunny	10.4	2.2	1.6	9.1
Ford Escort	11.0	3.1	2.4	3.5
Colt Lancer	12.0	1.5	0.9	6.9
Reliant Kitten	9.7	2.1	1.9	14.0
Vauxhall Chevette	12.0	3.2	2.8	5.5
BL Princess	9.5	1.6	1.1	3.0
Chrysler Alpine	11.0	2.0	1.9	12.6
VW Golf	10.0	2.3	1.9	5.5
Fiat 133	13.0	2.5	1.9	9.0
Ford Fiesta	9.0	2.2	2.0	4.9
Ford Fiesta A	10.7	3.1	3.0	13.5
Ford Fiesta B	9.6	2.7	2.6	9.9
Renault 5	11.0	2.0	1.9	4.2
Renault 5A	12.6	2.4	1.7	12.0
Renault 5B	11.0	2.4	2.2	12.3

pact tests. The latter were carried out on cars which had previously been front impact tested, which had the advantage that the headform hit the structure in a deformed state, i.e., partially reproducing the real accident situation. Offsetting this advantage, however, were the facts that (a) some of the chosen impact points could not be reached in the headform test because of the crash damage, and (b) some of the structural deformation had been caused by the dummies themselves, and it is clearly unfair to retest an energy-absorbing structure with the headform when this structure had already performed correctly in yielding to protect the dummy. In future, therefore, it is proposed that the interior impact testing should be done on undamaged cars.

After the ratings had been calculated for these 12 cars, questions were raised about the repeatability of this type of Crashworthiness Rating. To resolve these it was decided to choose two models from the 12 of similar sizes but significantly different rating, and to re-test two new samples of each. The cars selected were the Ford Fiesta and the Renault 5, and each sample was subjected to both the frontal impact test and the side impact test, followed by the interior headform tests. The results for these additional cars (Fiesta A and B, Renault 5A and B) are included in Tables 2-4.

Table 5 shows the detailed steps in calculating the Crashworthiness Rating for one car, and the first column of Table 6 gives the rankings and ratings for all 16 cars using the critical values and weighting factors of Table 1.

CHOICE OF CRITICAL VALUES AND WEIGHTING FACTORS

As explained above, the critical values are intended to be the loads and accelerations at which about 50% of the car occupant population would experience more than mi-

Table 4. Interior free flight headform test results (from Ref 1 for first 12 cars tested) 24 km/h (15 mile/h) impacts with 6.8 kg (15 lb) headform, diameter 165 mm (6.5 ins).

	Peak resultant acceleration of headform, g (>3 ms)								
	Header rail (mean of 5 points)	Facia top (mean of 5 points)	A post (mean of 2 points)	Steering wheel rim (on spoke)	Steering wheel rim (off spoke)	Steering wheel hub	Lower facia (knee area) (mean of 5 points)	B post (mean of 2 points)	Cant rail (mean of 3 points)
BL Marina	84	82	85	127	26	60	68	164	*
Datsun Sunny	108	70	103	70	35[2]	97	64	114[4]	*
Ford Escort	81	72	80	68	42	143	88	134	*
Colt Lancer	96	55	114	44	34	126	107	138	*
Reliant Kitten	32	32	42	62[1]	35[2]	84[3]	62	82	*
Vauxhall Chevette	73	50	86	64	35[2]	84[3]	52	134	*
BL Princess	111	62	91	76	68	50	44	119	*
Chrysler Alpine	69	63	77	62[1]	35[2]	84[3]	57	112	*
VW Golf	91	42	68	62[1]	35[2]	84[3]	41	114	*
Fiat 133	92	101	67	62[1]	35[2]	84[3]	144	108	*
Ford Fiesta	74	56	84	62[1]	35[2]	125	58	114	*
Ford Fiesta A	59	53	64	28	20	58	59	84	[81]
Ford Fiesta B	57	54	86	24	20	66	50	77	[88]
Renault 5	99	72	79	62[1]	48	84[3]	77	130	*
Renault 5A	48	58	71	59	24	64	97	111	[101]
Renault 5B	47	48	76	61	34	53	75	91	[119]

1: Data not available: average of other vehicles substituted (62 g)
2: " : " (35 g)
3: " : " (84 g)
4: " : " (114 g)
*: Cant rails not measured: proposed Critical Value, 80 g, used for all vehicles in rating calculations. [ ] = values measured but not used

nor injuries. Of course people vary widely in their ability to withstand forces and accelerations, and only very limited data are available as a basis for determining these values. Figures from present legislation have therefore been used where possible, and the crashworthiness calculations have been repeated as described below with different figures to see how sensitive the results are to the critical values assumed. The choice is of course much less important for a Crashworthiness Rating system than it is for pass/fail legislation.

Choosing the weighting factors to be used is a more controversial matter. The problem can be considered in four parts, the relative weight allocations between (1) front and side protection, (2) driver and passenger, (3) different parts of the body, (4) whole-vehicle impact tests and interior headform tests. It is assumed that occupants wear their seat belts. For the present it is proposed that the front/side split should be based on the ratio of serious accidents in these two directions, which in Europe is generally agreed to be about 2.3:1, i.e., 70% front and 30% side (refs 5,6). The same 70/30 split between driver and front seat passenger appears reasonable from the observed occupancy of cars in the UK.

As regards the relative importance of the different areas of the body, for simplicity this has been grouped into four areas: head, chest, pelvis and legs. The quotients derived from the measurements made in the barrier and interior headform tests should be related to the costs of injury of these parts by applying appropriate weightings. This injury cost information could come, for instance, from the average number of hospital bed-days resulting from injuries to that part of the body together with the costs of associated deaths and disabilities. At present in UK total car occupant deaths are costed at almost twice the total for all non-fatal injuries but full information seems not to be currently available. Instead, the empirical relationship (ref 7) that societal costs are approximately proportional to the cube of the injury severity on the Abbreviated Injury Scale (AIS) could perhaps be used. It would then be necessary to know what injury levels the adopted criteria protect against, and this is not always clear from the published literature. However it may be reasonable to assume that the head and chest should be protected against AIS 4 and the pelvis and legs against AIS 3. This would make the relative weightings 64 for head and chest to 27 for pelvis and legs and this and the 70/30 frontside split would give the following weighting factors:

Front impact:	Head weighting	24.6%	
	Chest "	24.6%	
	Pelvis "	10.4%	20.8%
	Legs "	10.4%	

Table 5. Details of crashworthiness rating calculation for BL marina.

Measured Value[2]	Critical Value	Quotient =		Quotient Limited & Squared	x Weighting Factor	= Contribution to Rating	Cumulative Total
760	450 min	450/760	0.592	0.350	5	1.75	1.75
1090	650 min	650/1090	0.596	0.356	5	1.78	3.53
685	250 min	250/685	0.365	0.133	5	0.67	4.20
135	80 max	135/80	1.688	2.848	7	19.93	24.13
51	"	51/80	0.638	0.406	3	1.22	25.35
38	60 max	38/60	0.633	0.401	14	5.62	30.97
38	"	38/60	0.633	0.401	6	2.41	33.38
1.3	4 max	1.3/4	0.325	0.106	1.4	0.15	33.53
2.0	"	2.0/4	0.500	0.250	0.6	0.15	33.68
1.9	"	1.9/4	0.475	0.226	1.4	0.32	34.00
1.4	"	1.4/4	0.350	0.123	0.6	0.07	34.07
84	80 max	84/80	1.050	1.103	3	3.31	37.38
82	"	82/80	1.025	1.051	3	3.15	40.53
85	"	85/80	1.063	1.129	3	3.39	43.92
127	"	127/80	1.588	2.520	3	7.56	51.48
26	"	26/80	0.325	0.106	3	0.32	51.80
60	"	60/80	0.750	0.563	3	1.69	53.49
68	"	68/80	0.850	0.723	3	2.17	55.66
10.0	15 min	15/10.0	1.500	2.250	5	11.25	66.91
2.2	1 max	2.2/1	2.200	4.000[1]	5	20.00	86.91
1.2	"	1.2/1	1.200	1.440	5	7.20	94.11
2.4	6 max	2.4/6	0.400	0.160	5	0.80	94.91
164	80 max	164/80	2.050	4.000[1]	5	20.00	114.91
80	"	80/80	1.000	1.000	5	5.00	119.91

1: Limit of 2 applied to quotient
2: For definitions of values see Table 1.

∴ Crashworthiness Rating = 120

Side impact:

Head weighting	10.6%	
Chest "	10.6%	
Pelvis "	4.4%	8.8%
Legs "	4.4%	

This method of allocating weightings if of course somewhat arbitrary and these numbers can be rounded off. For the front impact case it is felt that the method has estimated the relative costs for the head too low when compared with those for chest injuries. Chest injuries tend to be either rapidly recoverable or quickly fatal, whereas head injuries involving brain damage cause many of the fatalities and also may result in permanent disability which is both very distressing and very expensive (ref 8). It is not proposed to make this adjustment for the side impact case because it appears that head injuries in side impacts are often caused by striking the impacting car's front or the intruding roadside object rather than the interior of an occupant's own car.

Finally, the split of weighting between the whole-vehicle impact tests and the interior headform tests must be decided. For some types of occupant protection which are only measured in one of these tests (e.g., pelvic protection in side impacts) there is no room for choice. For side impacts, if all the head protection measurement is allocated to the headform test and all the chest and pelvis/legs protection measurement to the whole-vehicle test, then weighting factors are arrived at of:

10% total for side headform results (e.g., 5% for cant rail and 5% for B post)

10% total for side whole-vehicle impact chest results (e.g., 5% for each of the two largest rib loads)

Table 6. Rankings of crashworthiness ratings for 16 production cars. First number = ranking: number in brackets = crashworthiness rating.

CARS (1976 models unless marked*)	Column 1 Weighting factors & critical values nominal, as Table 1. Car results as Tables 2-4	Column 2 Front/side weighting changed from 70/30 to 50/50	Column 3 Front/side weighting 70/30 driver/passenger weighting changed from 70/30 to 50/50	Column 4 Front/side weighting 70/30 driver/passenger weighting 70/30. Total front chest acc weights reduced from 20 to 10%. Total femur load weights increased from 4 to 14%	Column 5 As Column 4 but femur critical values increased from 4 kN to 10 kN	Column 6 As Column 1 but Crashworthiness Rating =EW.Q
BL Marina	3 (120)	4 (147)	3 (115)	2 (118)	3=(116)	2= (96)
Datsun Sunny	6=(128)	5=(158)	7 (126)	4 (123)	7 (121)	8 (106)
Ford Escort	12 (145)	10 (171)	11 (139)	11 (144)	13 (139)	10 (109)
Colt Lancer	9=(138)	3 (146)	9 (130)	5=(132)	8 (127)	11 (110)
Reliant Kitten	8 (137)	11 (174)	8 (129)	8=(135)	10 (133)	6 (102)
Vauxhall Chevette	9=(138)	8=(166)	10 (136)	12 (148)	12 (137)	9 (108)
BL Princess	1 (104)	1 (121)	1 (103)	1 (105)	1 (98)	2= (96)
Chrysler Alpine	15 (160)	15 (193)	15 (161)	14 (169)	15 (160)	14 (117)
VW Golf	2 (110)	2 (144)	2 (109)	3 (119)	2 (103)	1 (95)
Fiat 133	16 (191)	16 (203)	16 (182)	16 (216)	16 (189)	16 (127)
Ford Fiesta	4 (124)	5=(158)	4 (122)	8=(135)	5 (118)	4=(101)
Ford Fiesta A*	5 (126)	8=(166)	5=(125)	7 (134)	6 (119)	4=(101)
Ford Fiesta B*	6=(128)	7 (163)	5=(125)	5=(132)	3=(116)	7 (103)
Renault 5	14 (154)	12 (175)	14 (158)	15 (170)	14 (142)	15 (118)
Renault 5A*	13 (146)	13 (177)	13 (149)	13 (156)	11 (134)	13 (113)
Renault 5B*	11 (142)	14 (179)	12 (145)	10 (143)	9 (132)	12 (111)

10% total for side whole-vehicle impact pelvis/legs results (e.g., 5% for pelvis load and 5% for car side strength as measured by barrier peak deceleration).

For front impact protection more choice is possible, but a similar split of approximately one-third for the interior headform results and two-thirds for the whole-vehicle impact results appears reasonable, giving weighting factors of:

Whole-vehicle test:	3 intrusion measurements	5% each (mainly leg protection)
	Head accelerations	10% total (head)
	Chest accelerations	20% total (chest)
	Femur loads	4% total (pelvis/leg)
Headform test:	6 head/chest impact areas	3% each (mainly head, some chest)
	1 knee impact area	3% (legs)

The total head weighting is then about 28%, chest about 20%, pelvis/legs 22%, in reasonable agreement with the split suggested above. The frontal whole-vehicle/headform test split is 49/21, i.e., 7/3 rather than 2/1 as suggested. This decision on the best whole-vehicle/headform test split could be reconsidered, taking into account the likely effects on car design (e.g., increasing the weighting of the whole-vehicle impact could encourage use of seat belt locks or tighteners and load limiters). It is also related to whether any importance should be placed on those who are unrestrained.

Since these proposed allocations of weighting factors (as in Table 1) are clearly somewhat arbitrary and provisional, it is important to know how sensitive the calculated Crashworthiness Ratings using them are to different assumed weightings. With so many variables the possible permutations of weighting factors and critical values are endless and confusing. The Crashworthiness Ratings given in the first column of Table 6 have therefore been recalculated for five different combinations:

Column 2.
Changing the front/side split from 70/30 to 50/50, by altering all weighting factors of Table 1 appropriately (i.e., by multiplying the frontal ones by 5/7 and the side ones by 5/3).

Column 3.
With the front/side split at 70/30, changing the driver/passenger split from 70/30 to 50/50.

Column 4.
Keeping the original front/side and driver/passenger splits of 70/30 but changing the relative importance of chest and leg loadings in the frontal whole-vehicle impact test, by reducing the total chest accelerations weighting factor from 20% to 10% and increasing the total femur loads weighting from 4% to 14%.

Column 5.
With the front/side and driver/passenger splits at 70/30,

the chest accelerations at 10% and femurs at 14% total, increasing the femur critical load value from 4 kN (the generally agreed level for serious injuries in Europe) to 10 kN (a proposed tolerance level in USA).
Column 6.
As first column (i.e., as Table 1) but without squaring the quotients.

In spite of these fairly large changes in weighting factors and critical values the effects on the rankings and relative Crashworthiness Ratings are quite small, and the proposed system does not therefore appear to be excessively sensitive to the values assumed. Even the differences in rankings between the first column and the last, produced by using the quotients linearly rather than squaring them, seem small. This direct use of quotients would compress the range of ratings significantly (from 104-191 with squared quotients to 95-127) but it is the ranking that is of interest.

Repeatability among the three samples of the Ford Fiesta is good, with ratings of 124, 126, 128 when using the nominal Critical Values and Weighting Factors. The repeatability of the Renault 5 samples also appears satisfactory with ratings of 142, 146, 154, especially as the two lower figures relate to the more recent test cars which incorporated interior changes introduced by Renault since the original test cars bought in 1976.

An example of the effects of vehicle improvements on Crashworthiness Rating may be obtained by imagining that its designers have decided that the Marina's rating must be reduced from the present 120 to below that of the VW Golf (110). Inspection of Table 5 shows that large contributions to the Marina's rating are being made by: (1) the largest rib load of 2.2 kN in the side mobile barrier test, contributing 20 points, (2) the B post headform deceleration of 164 g in the interior impact test, contributing 20 points, (3) the driver's peak head acceleration of 135 g in the frontal barrier test, contributing 19.9 points, (4) the barrier peak deceleration of only 10 g in the side mobile barrier test, contributing 11.3 points, (5) the steering wheel rim stiffness (on-spoke) headform deceleration of 127 g in the interior impact tests, contributing 7.6 points, (6) the second largest rib load of 1.2 kN in the side mobile barrier test, contributing 7.2 points.

Options considered by the Marina designers would therefore probably include (1) energy-absorbing door trim to reduce side impact rib loads, (2) energy-absorbing material on the B post, especially a redesign of the upper seat belt anchorage, (3) improving the seat belts to prevent head contact and thus reduce the driver's peak head acceleration, (4) strengthening the vehicle side, e.g., by modifying the seats and mountings to prevent door intrusion, using door sill buttons, foam filling the sills, (5) changing the steering wheel design slightly to reduce on-spoke stiffness. The likely improvements to the car's Crashworthiness Rating which these changes would make could be estimated quite easily, e.g., (1) reducing the largest rib load from 2.2 kN to the 1.6 kN obtained for the Princess would make this parameter contribute only $(1.6/1)^2 \times 5 = 12.8$ points instead of 20 points, a reduction of 7.2 points. Similarly, (2) padding the B posts should allow a reduction of peak headform deceleration from 164 g to perhaps 110 g, with a contribution of $(110/80)^2 \times 5 = 9.5$ points, a reduction of 10.5 points. Improving the seat belts, (3), for example the use of webbing locks should reduce driver head acceleration from 135 g to perhaps the 89 g measured for the Princess, giving a contribution of $(89/80)^2 \times 7 = 8.7$ points instead of $(135/80)^2 \times 7 = 19.9$, a reduction of 11.2 points. Strengthening the car side, (4), to give 12 g barrier deceleration instead of 10 g would contribute $(15/12)^2 \times 5 = 7.8$ points, a reduction of 3.4 points, and (5) changing the steering wheel design to give an on-spoke headform deceleration of 75 g instead of 127 g would contribute $(75/80)^2 \times 3 = 2.6$ points, saving 4.9 points.

If all these five measures were taken the total reduction in Crashworthiness Rating should be 37 points, giving a new value of 83 points instead of the original 120. The designers might consider that door padding would reduce the interior space too greatly, and that the vehicle side strengthening would be too expensive in relation to the improvement in rating it would produce. However the remaining three alterations (B post padding, seat belt improvement, minor steering wheel design change) should reduce the rating by nearly 27 points to 93, well below the VW Golf's 110. It is of course to be hoped that the sales advantage resulting from this difference will last only as long as it takes the Golf's designers to study the equivalent of Table 5 for their vehicle and implement their own safety improvements!

DISCUSSION

Before considering the viability of a Crashworthiness Rating system, several points of detail should be clarified.

(1) Restraints: This proposed rating method is based on the results of testing with restrained dummies, and therefore does not attempt to predict the protection offered to unrestrained occupants. This is considered acceptable, since people who do not wear seat belts are clearly unlikely to be interested in their vehicles' crashworthiness. However, many of the design changes made to obtain a low rating (especially in reducing the interior headform test (decelerations) will also benefit unrestrained occupants.

(2) Mass ratio: This rating will use a fixed frontal barrier impact test carried out at the same speed for all cars. It does not therefore take into account the facts that (a) in a collision between a light car and a heavy one, conservation of momentum ensures that the light vehicle experiences a bigger velocity change and a more severe

impact than the heavy one, (b) the probability that any collision will be with a car lighter than one's own increases as the weight of one's own car increases. By ignoring these facts the Crashworthiness Rating will understate the relative safety of heavy cars in comparison with light ones. Although the point is controversial, it seems possible to justify this on several different grounds, e.g., (a) a high proportion of car collisions involve solid roadside objects or heavy trucks and coaches, where car mass is unimportant, (b) introducing a rating system that would permit simply increasing vehicle weight to produce a better result would act against the world need for lighter cars to save fuel, (c) legislation has always required the same severity of test impact e.g., a 30 mile/h barrier test, regardless of car mass, and there is no need to add to the difficulties of introducing a Crashworthiness Rating system by advocating a change to this principle now, (d) even if there is good theoretical justification for testing heavy cars at lower frontal barrier impact speeds than light ones, such a procedure seems unlikely to receive political support. The proposed Crashworthiness Rating scheme does not give a fair comparison of safety between cars of greatly different mass, but is intended for comparison between cars of similar mass.

(3) Missing data: The action to take when items of data are lost during a test, e.g., from instrumentation failure, must be agreed. Tentative proposals are (a) for head and chest accelerations in the frontal barrier test, set the missing item equal to the critical value for that parameter, (b) if a femur load is lost, replace it with the highest of the three remaining measured femur loads, (c) if one of the loads from the upper three ribs is lost in the side mobile barrier test (at a time in the impact before the peak rib loads have been reached), use the largest measured rib load figure twice, i.e., for both the "largest rib load" and the "next largest rib load" data items, (d) if the pelvis load measurement is lost in the side impact, use a figure obtained by multiplying the peak pelvis lateral acceleration by the effective mass of the dummy's pelvis (approx 10 kg for the TRRL Side Impact Dummy), (e) if a steering wheel headform impact measurement is lost (and the wheel is damaged), install a new wheel and/or column and repeat the test.

(4) Manufacturers' representation: Clearly car manufacturers' representatives should be encouraged to be present when their vehicles are being tested so that any objections to the test conditions can be raised before rather than after the testing.

(5) Test variability: Variability between nominally identical impact tests is a well-known problem, and it would clearly be very desirable to test more than one example of each car model in each type of test. This multiple testing is normally considered to be financially impossible under the present system where passing the test is a legal necessity before a car can be sold, since the manufacturer must test with early and very expensive prototypes if he is to avoid risking the catastrophic loss resulting from tooling up for an unsaleable model. For a Crashworthiness Rating system the financial penalties from getting a poor result are comparatively small, since the cars can continue to be sold. The impact testing can therefore be done with early cars from the normal production line, which will be more representative of production vehicles and also cheap enough to allow multiple testing (with test results being averaged) if this is considered worthwhile.

(6) Publication of results: Detailed results of all cars tested should be made publicly available, so that everyone can see how each model's Crashworthiness Rating has been arrived it, although of course the normal car buyer may only be interested in the overall rating figure. It appears that these ratings will vary from approximately 80 for the best cars to 200 for the worst, and it is not clear whether the general public will be able to use these numbers effectively to compare cars. As suggested above, it would probably be useful in addition to divide the range into five bands to which stars would be allocated (from one star for the worst to five for the best), as is done for petrol, hotel and freezers. Table 7 shows a provisional star banding system.

Although these and other questions require debate, it is felt that they do not cast doubts on either the value of a Crashworthiness Rating system or the feasibility of deriving one on the lines suggested. The major problem preventing introduction seems likely to be simply the cost of carrying out the necessary crash testing. At least two samples of each car model would be needed (one for frontal interior headform testing followed by the whole-vehicle side impact, and the other for side interior headform testing followed by the whole-vehicle frontal barrier test), and as suggested above use of more samples would be very desirable. Some possible methods of reducing the system's costs to the government are: (a) restrict the rating

Table 7. Proposed "Star" allocation method.

Crashworthiness Rating	"Stars"	Cars and Ratings (from Table 6, column 1)	
≤100	5 star	None	
101 to 120	4 star	BL Princess	104
		VW Golf	110
		BL Marina	120
121 to 140	3 star	Ford Fiesta	124, 126, 128
		Datsun Sunny	128
		Reliant Kitten	137
		Colt Lancer	138
		Vauxhall Chevette	138
141 to 160	2 star	Renault 5	142, 146, 154
		Ford Escort($_{1980}^{pre}$)	145
		Chrysler Alpine	160
≥161	1 star	Fiat 133	191

scheme initially to only say the 5 or 10 models predicted to be the best sellers in the next year, (b) encourage manufacturers of quality low-volume cars to pay for officially witnessed tests of their products so they can use the Crashworthiness Rating in their advertising, (c) encourage consumer organisations to contribute to test costs, (d) obtain international agreement on the tests to be carried out and divide the testing of "world cars" between countries where they are sold; if necessary different weighting factors could be used when calculating the ratings to reflect each country's accident situation (e.g., front/side split), (e) purchase and test only the minimum two samples of each model, but encourage any manufacturer who feels his product has been unfairly rated to pay for another vehicle and a repeat set of tests, whose results would be averaged with the first set.

Even without these cost-sharing proposals, however, the price of testing 10 models per year in UK should not be more than £200,000, i.e., less than a tenth of the cost of one day's road casualties (ref 9). It seems highly probable that the benefits resulting from a Crashworthiness Rating system would justify this small investment.

PROPOSED FUTURE DEVELOPMENT PROGRAMME

No decisions will be taken about any Crashworthiness Rating system in the UK until after 9th ESV Conference, to allow consideration of criticisms and suggestions for improvements or alternatives. However at present it appears that the best plan would be to proceed in two phases. In the first, TRRL would continue to test samples of popular car models each year, using the sort of test procedures described in this paper. During this phase, discussions would be held with all interested parties in Europe and elsewhere, to agree to a new set of procedures. Questions to be settled before then would include the choice of the front and side impact dummies to be used and the possibility of changing to a deformable side impact barrier instead of the present rigid one. In other words the revised system would make the best use of official test procedures including test levels above the legislative ones.

Public reaction to the Crashworthiness Rating system would be sought and assessed during the first phase, so that any necessary changes in procedures or proposed presentation of results could be incorporated in the second phase.

The impact tests chosen for phase two would be intended to remain unchanged for perhaps five years before being updated again, but of course the arithmetical part of the rating system (e.g., choice of Critical Values and Weighting Factors) could be changed sooner if this was considered advisable, since this would continue to use the valuable accumulated store of test data. It is hoped that at least ten popular car models would be tested each year during this second phase.

CONCLUSIONS

1. A Crashworthiness Rating System could well be a method of achieving safer cars without requiring new legislation. Vehicle buyers and users could benefit from its introduction and manufacturers would be encouraged to improve the safety of their products.
2. A rating system based on a frontal impact test alone would not be satisfactory. A Crashworthiness Rating system should be based on the results of both whole-vehicle barrier front and side impact tests and interior impacts using a pendulum or free-flight headform. A simple arithmetical process is described which combines the results of 40 measurements from these tests into a single Crashworthiness Rating figure.
3. A procedure for deriving weighting factors is described which matches the contribution of each measured parameter to the likelihood and importance of the corresponding car occupant injuries. In other words, the system attempts to take account of the relative proportions of front and side crashes, front passenger seat occupancy, and the cost of injuries to different parts of the body.
4. Ratings are calculated for 12 models of small and medium sized European and Japanese production cars. The system is shown not to be unduly sensitive to the assumptions made about the critical values and weighting factors for each measured parameter. However hypothetical modifications to improve occupant protection are shown to produce significant improvements in rating.
5. Tests of two additional samples of each of two of the 12 car models indicate that the proposed rating system gives repeatable results.
6. The proposed system rates cars' safety on the assumption that occupants will be wearing seat belts. It is designed to enable comparisons to be made between cars of approximately similar mass and does not indicate the relative safety of cars of very different mass.
7. Methods of sharing the crash test costs among interested parties and countries are proposed. Even without these, however, the annual cost of a Crashworthiness Rating scheme to cover 5 additional models each year is estimated at about £100,000, which is less than a hundredth of one per cent of the annual cost of road casualties in the UK.
8. No decisions will be taken about any Crashworthiness Rating system in the UK until after 9th ESV Conference, so that criticisms and alternative pro-

posals can be considered. However a possible two-phased development programme is described.

ACKNOWLEDGEMENT

The work described in this paper forms part of the programme of the Transport and Road Research Laboratory and the paper is published by permission of the Director.

REFERENCES

1. Neilson, I. D., S. Penoyre and S. P. F. Petty. Improved Test Procedures for Front Impact. Proceedings of 7th International Technical Conference on Experimental Safety Vehicles, Paris, 1979. NHTSA, U.S. Dept. of Transportation.
2. Neilson, I. D., S. Penoyre, S. P. F. Petty and A. K. Dyche. Improved Test Procedures for Side Impact. Proceedings of 7th International Technical Conference on Experimental Safety Vehicles, Paris, 1979. NHTSA, U.S. Dept. of Transportation.
3. Lowne, R. W., S. P. F. Petty, J. Harris and C. A. Hobbs. The Need for a Force Measuring Dummy in Side Impact Testing. SAE p790750, June 1979.
4. Harris, J. The Design and Use of the TRRL Side Impact Dummy. Proceedings of the 20th Stapp Car Crash Conference, 1976, SAE p760802.
5. Riley, B. S. and C. P. Radley. Traffic Accidents to Cars with Directions of Impact from the Front and Side. Proceedings of 6th International Technical Conference on Experimental Safety Vehicles, Washington, 1976. NHTSA. U.S. Dept. of Transportation.
6. Kampen, L. T. B. V. Institute for Road Safety Research SWOV, Netherlands, Private communication, July 1980.
7. Peterson, R. Interim Report on Accident Analysis (Minicars). NHTSA Contracts DOT HS 113 3 746, 1974.
8. Grattan, E. and J. A. Hobbs. Permanent Disability in Road Traffic Accident Casualties. TRRL Laboratory Report 924, Transport and Road Research Laboratory, Crowthorne, Berks, UK, 1979.
9. Road Accidents Great Britain 1980. HMSO, London, 1981.

Crown Copyright. Any views expressed in this Paper are not necessarily those of the Department of the Environment or of the Department of Transport. Extracts from the text may be reproduced, except for commercial purposes, provided the source is acknowledged. Reproduced by permission of Her Britannic Majesty's Stationery Office.

The New Car Assessment Program—Status And Effect

JAMES HACKNEY and
VINCENT QUARLES
National Highway Traffic Safety Administration

INTRODUCTION

In 1978, the National Highway Traffic Safety Administration began the crashworthiness assessment of new cars by running high speed frontal barrier crash tests. This New Car Assessment Program (NCAP) has as a primary goal the development of a methodology for providing consumers with a measure of the relative safety potential of automobiles. Therefore, a successful NCAP should provide the technical basis for the development of vehicle crashworthiness rankings or ratings.

Since the beginning of NCAP, ninety-two model year 1979, 80, 81 and 82 production automobiles have been crash tested at a nominal velocity of 35 mph into a rigid barrier. Eighty-seven of these tests were full frontal impacts and five were oblique frontal impacts. The oblique tests were run to evaluate the relative crash severity of different frontal modes. The results of all these tests are summarized in Table 1. For consistency in analysis, references in this report are made to the available full frontal test data only.

The performance of the tested vehicles strongly indicated that different levels of occupant safety may have existed. The measurements on the restrained dummies in these crash tests ranged from a low of 381 to a high of 4513 for the Head Injury Criterion, (HIC) and from 33 g's to 108 g's for the chest acceleration. These results were sufficient to identify potential safety design problems in the individual vehicles (1). Primarily, these problems were associated with the safety belt systems and the steering assemblies.

All information from these tests has been made available to manufacturers and consumers through various NHTSA press releases, the Car Book (2), media, and direct contact. This report presents the reaction to this information by the consumer, the manufacturers, and by NHTSA. The effects of this information on occupant safety are examined and major NCAP issues are discussed.

CONSUMER REACTION CONTINUES POSITIVE

Consumer reaction to the NCAP has continued positive since the initial release of occupant safety information. The first NHTSA press release of safety data and the media coverage of the "Small Car Press Day" in August 1980 created considerable consumer interest. The publication of "The Car Book" in December 1980 by NHTSA was highly successful. Five hundred thousand of the first edition and more than 1.4 million of a revised second edition were requested by the public.

The Consumer Union has published their interpretation of the NCAP results each year. Their surveys have indicated that the articles on automobile safety are consistently high in reader interest (3).

This interest is supported by the most recent NHTSA sponsored consumer survey by Robert Kernish of Booz-Allen and Hamilton (4). In this survey, "Consumers indicated their approval of the principle of government ratings and their willingness to pay for those ratings in the price of the car they buy." The survey also gives "evidence that the ratings will play a subsidiary, but not trivial part in determining consumer automotive choice."

Under present economic conditions, the consumer seems to be evaluating all aspects before deciding which automobile to buy. The new car purchase is now viewed as a longer term investment.

Two forces will continue to maintain or increase the consumer's interest in automobile safety information, the consumer's view that he will keep his car longer and the renewed emphasis on safety from the National Safety Belt Campaign.

AUTOMOBILE MANUFACTURERS' REACTION TAKES TWO FORMS

The manufacturers' reaction occurred in two forms, verbal or written comments relative to problems associ-

Table 1. Summary of new car assessment test results.

MAKE	MODEL	DOOR	MODEL YEAR	Test Mode (F=Front) (O=Oblique) (R=Rear)	Test Speed (mph)	Test Weight (lbs.)	HIC No. d/p	Chest Resultant d/p	Driver Femur L/R	Passenger Femur L/R	Meets Criteria Standards at 35 mph 301 212	219	Frontal	Rear
AMERICAN MOTORS	CONCORD	2	1979	F	34.7	3681	1078/1457	61/69	1300/910	375/337	Y	Y	Y	-
AMERICAN MOTORS	CONCORD	2	1979	R	35.0	3720								Y
AMERICAN MOTORS	SPIRIT	2 HB	1981	F	35.0	3190	702/652	43/35	NA/1300	280/560	Y	Y	Y	-
AMERICAN MOTORS	SPIRIT	2 HB	1981	R	35.4	3213								N
AUDI	4000	4	1980	F	35.3	2836	1322/1428	70/45	408/353	1030/527	Y	Y	Y	NT
AUDI	5000	4	1981	F	34.7	3361	Invalid	43/52	480/712	628/394	Y	Y	Y	NT
BUICK	CENTURY	4	1980	F	(See Olds Cutlass)									
BUICK	CENTURY	4	1980	R	(See Olds Cutlass)									
BUICK	ELECTRA	4	1979	F	(See Olds 98)									
BUICK	ELECTRA	4	1979	R	35.3	4617								N
BUICK	LE SABRE	4	1979	F	(See Chevy Impala)									
BUICK	LE SABRE	4	1979	R	(See Pontiac Catalina)									
BUICK	REGAL	2	1979	F	(See Cutlass Supreme))									
BUICK	REGAL	2	1979	R	(See Pontiac Grand Prix)									
BUICK	RIVIERA	2	1979	F	35.3	4440	541/782	42/39	943/892	1371/1272	Y	Y	N	-
BUICK	RIVIERA	2	1979	R	34.8	4413								N
BUICK	SKYLARK	4 HB	1980	F	(See Chevy Citation)									
BUICK	SKYLARK	4 HB	1980	R	(See Chevy Citation)									
CADILLAC	DE VILLE	4	1979	F	(See Olds 98)									
CADILLAC	ELDORADO	4	1979	F	(See Buick Riviera)									
CADILLAC	ELDORADO	4	1979	R	(See Buick Riviera)									
CADILLAC	SEVILLE	4	1980	F	34.7	4615	623/523	43/35	1057/681	791/608	Y	Y	Y	NT
CHEVROLET	CAMARO	2	1979	F	(See Pontiac Firebird)									
CHEVROLET	CAMARO	2	1979	R	35.0	3980								N
CHEVROLET	CAMARO	2	1982	F	(To Be Tested)									
CHEVROLET	CAPRICE	4	1979	F	(See Chevy Impala)									
CHEVROLET	CAPRICE	4	1979	R	(See Pontiac Catalina)									
CHEVROLET	CAVALIER	2	1982	R	35.4	2865								N
CHEVROLET	CAVALIER	2 HB	1982	F	(To Be Tested)									
CHEVROLET	CELEBRITY	4	1982	F	(To Be Tested)									
CHEVROLET	CHEVETTE	2 HB	1979	F	34.8	2720	871/859	47/45	1280/1600	990/1400	N	Y	Y	-
CHEVROLET	CHEVETTE	2 HB	1979	R	34.9	2666								Y
CHEVROLET	CHEVETTE	2 HB	1980	F	35.2	2641	668/699	45/40	1649/1777	766/802	N	Y	Y	NT
CHEVROLET	CHEVETTE	4 HB	1982	F	(To Be Tested)									
CHEVROLET	CITATION	4 HB	1980	F	35.0	3260	845/623	48/35	560/760	1040/350	Y	Y	Y	-
CHEVROLET	CITATION	4 HB	1980	R	35.1	3220								Y
CHEVROLET	IMPALA	4	1979	F	35.2	4179	1277/1254	62/51	368/808	NA/391	Y	Y	Y	-
CHEVROLET	IMPALA	4	1979	R	(See Pontiac Catalina)									
CHEVROLET	IMPALA	4	1982	F	(To Be Tested)									
CHEVROLET	MALIBU	2	1978	O	35.4	3740	1032/722	48/37	220/330	420/380	NA	NA	Y	NT
CHEVROLET	MALIBU	4	1980	F	(See Olds Cutlass)									
CHEVROLET	MALIBU	4	1980	R	(See Olds Cutlass)									
CHEVROLET	MONZA	2	1979	F	35.1	3240	1108/1033	42/41	580/400	600/325	Y	Y	Y	-
CHEVROLET	MONZA	2	1979	R	(See Pontiac Sunbird)									
CHEVROLET	MONTE CARLO	2	1979	F	(See Cutlass Supreme)									
CHEVROLET	MONTE CARLO	2	1979	R	(See Cutlass Supreme)									
CHRYSLER	CORDOBA	2	1980	F	(See Dodge Mirada)									
CHRYSLER	CORDOBA	2	1980	R	(See Dodge Mirada)									
CHRYSLER	IMPERIAL	2	1981	F	35.3	4562	976/590	47/32	742/371	750/564	Y	Y	Y	-
CHRYSLER	IMPERIAL	2	1981	R	35.1	4567								Y
CHRYSLER	LE BARON	2	1979	F	35.0	4160	2402/1071	45/39	740/300	420/440	Y	Y	Y	NT
CHRYSLER	LE BARON	2	1980	F	35.1	3880	1742/1252	54/45	913/860	678/688	Y	Y	Y	NT
CHRYSLER	LE BARON	2	1982	F	(To Be Tested)									
CHRYSLER	NEWPORT	4	1979	F	(See Dodge St. Regis)									
CHRYSLER	NEWPORT	4	1979	R	35.4	4330								Y
DATSUN	SENTRA	4	1982	F	(To Be Tested)									
DATSUN	STANZA	4 HB	1982	F	(To Be Tested)									
DATSUN	200 SX	2 HB	1980	F	34.1	3038	1091/1032	62/44	1150/893	663/242	Y	Y	Y	-
DATSUN	200 SX	2 HB	1980	R	35.1	2952								Y
DATSUN	210	2	1979	F	35.2	2425	1358/1745	69/59	NA/536	781/218	Y	Y	Y	-
DATSUN	210	2	1979	R	35.0	2392								Y
DATSUN	310 GX	2 HB	1980	F	34.7	2404	1059/2019	68/108	1218/1090	1369/1190	Y	Y	Y	-
DATSUN	310 GX	2 HB	1980	R	35.2	2389								Y
DATSUN	810	4	1981	R	34.9	3420								N
DODGE	ARIES	4	1981	F	(See Plymouth Reliant)									
DODGE	ARIES	2	1981	R	35.2	2800								Y
DODGE	ASPEN	2	1979	F	(See Chrysler Le Baron)									
DODGE	COLT	2	1979	F	(See Plymouth Champ)									
DODGE	COLT	2	1979	R	35.3	2302								Y
DODGE	COLT	4 HB	1982	F	(To Be Tested)									

Table 1 (cont.)

MAKE	MODEL	DOORS	MODEL YEAR	Test Mode (F=Front) (O=Oblique) (R=Rear)	Test Speed (mph)	Test Weight (lbs.)	HIC No. d/p	Chest Resultant d/p	Driver Femur L/R	Passenger Femur L/R	Meets Criteria Standards at 35 mph 212	219	Frontal	301 Rear
DODGE	DIPLOMAT	4	1979	R										N
DODGE	MAGNUM	2	1979	F	35.3	4440	646/731	39/44	250/725	360/170	Y	Y	Y	-
DODGE	MIRADA	2	1980	F	35.5	4136	948/959	43/37	784/950	1032/431	Y	Y	Y	-
DODGE	MIRADA	2	1980	R	35.2	3922								Y
DODGE	OMNI	2 HB	1979	F	(See Plymouth Horizon)									
DODGE	OMNI	2 HB	1979	R	(See Plymouth Horizon)									
DODGE	OMNI	4 HB	1982	F	(To Be Tested)									
DODGE	ST. REGIS	4	1979	F	34.3	4457	1909/NA	67/50	832/531	647/589	Y	Y	Y	-
DODGE	ST. REGIS	4	1980	R	(See Chrysler Newport)									
DODGE	400	2	1982	F	(To Be Tested)									
FIAT	STRADA	4 HB	1980	F	34.8	2707	790/962	41/43	1159/2143	1101/464	Y	Y	N	-
FIAT	STRADA	4 HB	1980	R	35.5	2583								N
FORD	ESCORT	2 HB	1981	F	35.2	2590	618/1011	50/40	640/740	480/280	Y	Y	Y	-
FORD	ESCORT	2 HB	1981	R	(See Mercury Lynx)									
FORD	ESCORT	2 HB	1981	O	35.2	2368	243/603	32/38	672/934	469/763	NA	NA	Y	-
FORD	ESCORT	4 HB	1982	F	(To Be Tested)									
FORD	EXP	2 HB	1981	F	35.0	2542	745/NA	49/53	857/19	320/189	Y	Y	Y	NT
FORD	FAIRMONT	4	1979	F	35.4	3296	939/1583	54/85	825/1155	1245/600	Y	Y	Y	-
FORD	FAIRMONT	4	1979	R	(See Mercury Zephyr)									
FORD	FIESTA	2	1979	F	35.0	2185	1656/1932	70/48	340/1050	NA/240	Y	Y	Y	-
FORD	FIESTA	2	1979	R	35.1	2228								Y
FORD	GRANADA	4	1979	F	34.6	3950	1442/1279	61/56	1750/350	390/570	Y	Y	Y	-
FORD	GRANADA	4	1979	R	(See Mercury Monarch)									
FORD	GRANADA	4	1982	F	(To Be Tested)									
FORD	LTD	2	1979	F	35.4	4366	1452/616	38/34	750/180	510/360	Y	Y	Y	NT
FORD	LTD	4	1982	F	(To Be Tested)									
FORD	LTD II	2	1979	F	34.9	4815	1088/781	61/40	1063/2775	584/429	Y	Y	Y	-
FORD	LTD II	2	1979	R	(See Ford T-Bird)									
FORD	MUSTANG	2	1979	F	34.7	2951	819/567	41/33	221/946	781/376	Y	Y	Y	-
FORD	MUSTANG	2	1979	R	35.3	3183								Y
FORD	PINTO	2 HB	1979	F	(See Mercury Bobcat)									
FORD	PINTO	2 HB	1979	R	35.2	2950								Y
FORD	T-BIRD II	2	1980	F	35.3	3783	988/994	50/52	1720/2203	1733/784	Y	Y	Y	-
FORD	T-BIRD II	2	1980	R	32.5	4854								Y
HONDA	ACCORD	4	1982	F	(To Be Tested)									
HONDA	CIVIC	2	1979	F	34.8	2166	2030/2093	93/46	1080/838	1520/1460	Y	N	Y	-
HONDA	CIVIC	2	1979	R	35.0	2093								Y
HONDA	CIVIC	2 HB	1980	F	34.7	2298	2626/1506	54/47	1006/3118	418/218	Y	Y	Y	-
HONDA	CIVIC	2 HB	1980	R	34.5	2234								Y
HONDA	CIVIC	2 HB	1981	F	35.1	2160	607/492	41/35	200/500	1100/540	N	Y	Y	
HONDA	CIVIC	4 HB	1981	F	35.0	2456	985/1391	53/43	462/1386	1194/797	Y	Y	Y	NT
HONDA	CIVIC	4	1981	R	35.0	2386								-
HONDA	PRELUDE	2 HB	1980	F	34.9	2545	2904/1759	52/45	445/1057	465/277	Y	Y	Y	Y
HONDA	PRELUDE	2	1980	R	35.0	2651								-
ISUZU	I-MARK DELUXE	2	1981	R	35.5	2626								Y
LINCOLN	CONTINENTAL	4	1979	F	35.1	5362	521/919	45/53	395/393	577/986	Y	N	Y	N
LINCOLN	CONTINENTAL	4	1982	F	(To Be Tested)									NT
MAZDA	626	2	1980	F	35.2	3066	1435/2206	101/54	923/939	380/209	Y	Y	Y	
MAZDA	626	4	1980	R	35.1	2911								-
MAZDA	626	4	1982	F	(To Be Tested)									Y
MAZDA	GLC	4 HB	1981	O	35.3	2427	555/516	48/35	313/507	284/146	NA	NA	Y	-
MAZDA	GLC	4 HB	1981	R	35.2	2412								Y
MERCEDES-BENZ	240D	4	1980	F	35.0	3714	1262/1369	54/44	674/1687	666/1449	Y	Y	N	NT
MERCURY	BOBCAT	2 HB	1979	F	35.1	2998	723/1878	64/51	463/1343	741/571	Y	Y	Y	-
MERCURY	BOBCAT	2 HB	1979	R	(See Ford Pinto)									
MERCURY	CAPRI	2 HB	1979	F	35.0	3067	NA/770	NA/44	1322/NA	676/397	Y	Y	Y	-
MERCURY	CAPRI	2 HB	1979	R	(See Ford Mustang)									
MERCURY	LYNX	2 HB	1981	F	(See Ford Escort)									
MERCURY	LYNX	2 HB	1981	R	34.7	2450								
MERCURY	MONARCH	4	1979	F	(See Ford Granada)									Y
MERCURY	MONARCH	4	1979	R	35.1	3750								Y
MERCURY	MARQUIS	2	1979	F	35.4	4224	1204/868	61/42	580/804	378/NA	Y	Y	Y	-
MERCURY	XR7	2	1980	F	(See Ford T-Bird)									
MERCURY	XR7	2	1980	R	(See Ford T-Bird)									
MERCURY	ZEPHYR	4	1979	F	(See Ford Fairmont)									
MERCURY	ZEPHYR	4	1979	R	35.3	3328								
OLDSMOBILE	CUTLASS	4	1980	F	35.4	3815	1334/1125	62/47	801/1958	476/459	Y	Y	Y	Y
OLDSMOBILE	CUTLASS	4	1980	R	35.1	3983								-
OLDSMOBILE	CUTLASS SUP.	2	1979	F	34.8	3799	695/501	42/40	1130/2082	567/523	Y	Y	Y	Y
OLDSMOBILE	CUTLASS SUP.	2	1979	R	(See Pontiac Grand Prix)									-
OLDSMOBILE	CUTLASS SUP.	2	1979	F	35.1	3816	997/799	58/37	1675/1800	350/650	N	Y	Y	-
OLDSMOBILE	CUTLASS SUP.	2	1979	R	(See Pontiac Grand Prix)									

ated with the data and tests and positive action to improve the safety performance of their products.

The issues raised by the manufacturers included items such as:

1. relationship of injury criteria/test condition to real world accident environment
2. the use of pass/fail rather than a continuous function
3. test repeatability/variability-NCAP results are based on only one test.

Most of these items were discussed extensively at the International Automotive Ratings Symposium sponsored by NHTSA in December 1980 (5).

For the first issue, industry members generally felt that any rating system which is based on crash tests should be validated through the use of accident data. Since testing to date has been done with restrained dummies it was suggested to investigate the use of accident data in a country in which safety belt usage is compulsory.

For the second issue, the use of pass or fail to characterize the test results, it was the general consensus of the symposium workshop participants that some type of numerical index is a better approach both for developing the information and from a consumer standpoint.

For the test repeatability/variability issue, it was agreed that the test results may vary because of vehicles, dummies, test instruments, facilities, test procedures, and other factors. Industry concern was that this will cause a significant variation in test results on nearly identical cars. This would be a critical consideration in a comparative test methodology which employs pass/fail criteria.

These three major issues and the action NHTSA has taken to resolve them are discussed in later sections.

One of the most encouraging aspects of the NCAP has been the positive actions by the manufacturers. These actions were in the form of changes in their safety systems and followed soon after the release of the 1979 and 1980 model year data. Table 2 lists many of these changes. This list is not to be considered as a complete list of either manufacturers or changes that may improve safety in the

Table 1 (cont.)

MAKE	MODEL	DOOR	MODEL YEAR	Test Mode (F=Front) (O=Oblique) (R=Rear)	Test Speed (mph)	Test Weight (lbs.)	HIC No. d/p	Chest Resultant d/p	Driver Femur L/R	Passenger Femur L/R	Meets Criteria Standards at 35 mph 212	219	301 Frontal	301 Rear
OLDSMOBILE	DELTA 88	4	1979	F	(See Chevy Impala)									
OLDSMOBILE	DELTA 88	4	1979	R	(See Pontiac Catalina)									
OLDSMOBILE	OMEGA	4 HB	1980	F	(See Chevy Citation)									
OLDSMOBILE	OMEGA	4 HB	1980	R	(See Chevy Citation)									
OLDSMOBILE	98	4	1979	F	35.0	4709	910/1734	59/54	774/535	370/439	Y	Y	Y	NT
PEUGEOT	504	4	1979	F	35.3	3526	4513/2498	63/43	504/1786	1082/679	Y	Y	Y	NT
PLYMOUTH	CHAMP	2 HB	1979	F	35.3	2313	1270/1918	72/66	893/435	686/561	Y	Y	Y	-
PLYMOUTH	CHAMP	2 HB	1979	R	(See Dodge Colt)									
PLYMOUTH	HORIZON	2 HB	1979	F	34.9	2661	653/780	52/38	974/708	581/657	Y	Y	Y	-
PLYMOUTH	HORIZON	2 HB	1979	R	35.5	2809								Y
PLYMOUTH	RELIANT	4	1981	F	34.8	2910	605/1731	52/59	1000/540	720/800	Y	Y	Y	-
PLYMOUTH	RELIANT	2	1981	R	(See Dodge Aries)									
PLYMOUTH	RELIANT	4	1981	O	34.9	2798	355/566	31/50	1655/883	886/1429	NA	NA	Y	Y
PLYMOUTH	SAPPORO	2	1981	R	35.0	3247								R
PLYMOUTH	VOLARE	2	1979	F	35.0	3820	724/1677	40/40	1000/1000	1200/570	Y	Y	Y	
PLYMOUTH	VOLARE	2	1979	R	(See Dodge Aries)									
PONTIAC	BONNEVILLE	4	1979	F	(See Chevy Impala)									
PONTIAC	BONNEVILLE	4	1979	R	(See Pontiac Catalina)									
PONTIAC	CATALINA	4	1979	F	(See Chevy Impala)									
PONTIAC	CATALINA	4	1979	R	34.9	4350								Y
PONTIAC	FIREBIRD	2	1979	F	35.2	3909	965/1297	42/47	582/472	503/717	Y	Y	Y	
PONTIAC	FIREBIRD	2	1979	R	(See Chevy Camaro)									
PONTIAC	GRAND PRIX	2	1979	F	(See Cutlass Supreme)									
PONTIAC	GRAND PRIX	2	1979	R	35.1	3920								N
PONTIAC	LE MANS	4	1980	F	(See Olds Cutlass)									
PONTIAC	LE MANS	4	1980	R	(See Olds Cutlass)									
PONTIAC	PHOENIX	4	1980	F	(See Chevy Citation)									
PONTIAC	PHOENIX	4	1980	R	(See Chevy Citation)									
PONTIAC	SUNBIRD	2	1979	F	(See Chevy Monza)									
PONTIAC	SUNBIRD	2	1979	R	34.9	3223								Y
RENAULT	FUEGO	2	1982	F	(To Be Tested)									
RENAULT	LE CAR	2 HB	1980	F	34.5	2196	1938/1844	85/53	1095/1663	2236/1840	Y	Y	Y	
RENAULT	LE CAR	2 HB	1980	R	35.2	2271								N
RENAULT	18i	4	1981	F	35.2	2750	1150/1659	47/36	360/280	800/700	N	Y	Y	-
RENAULT	18i	4	1981	R	35.5	2688								Y
RENAULT	18i	4	1981	O	34.5	2808	731/1001	38/39	269/458	430/543	NA	NA	Y	Y
SAAB	900	4	1982	F	(To Be Tested)									
SUBARU	GLF	4	1980	F	35.0	2618	1087/2837	72/94	799/1291	966/1583	N	Y	Y	-
SUBARU	GLF	4	1980	R	35.1	2560								Y
TOYOTA	CELICA	2 HB	1979	F	34.8	3025	849/1862	61/59	2920/435	400/520	Y	Y	Y	-
TOYOTA	CELICA	2 HB	1979	R	34.7	2960								Y
TOYOTA	CELICA	2	1982	F	(To Be Tested)									
TOYOTA	COROLLA	2	1979	F	35.0	2651	NA/NA	NA/NA	2000/640	1400/440	Y	Y	Y	-
TOYOTA	COROLLA	2	1979	R	35.0	2538								Y
TOYOTA	COROLLA	4	1980	F	35.0	2680	838/1162	69/92	740/775	200/270	Y	Y	Y	-
TOYOTA	COROLLA	4	1980	R	35.3	2605								N
TOYOTA	CORONA	4	1982	F	(To Be Tested)									
TOYOTA	CRESSIDA	4	1981	F	35.1	3417	1980/771	55/50	1710/1982	1644/1807	Y	Y	Y	-
TOYOTA	CRESSIDA	4	1981	R	34.9	3371								Y
TOYOTA	STARLET	2 HB	1981	F	35.1	2214	1836/1351	65/48	830/989	652/124	Y	Y	Y	-
TOYOTA	STARLET	2	1981	R	35.4	2221								Y
TOYOTA	TERCEL	2	1980	F	35.3	2314	1218/1179	48/53	1055/1078	1386/449	Y	N	N	-
TOYOTA	TERCELL	2	1980	R	35.2	2271								Y
VOLKSWAGEN	JETTA	4	1981	F	34.9	2650	1210/1272	68/52	1276/1191	1559/1286	N	Y	Y	-
VOLKSWAGEN	JETTA	4	1981	R	35.0	2650								Y
VOLKSWAGEN	JETTA	4	1981	O	34.8	2521	161/517	35/31	758/1295	1547/1163	NA	NA	Y	Y
VOLKSWAGEN	RABBIT	2	1979	F	34.8	2600	1024/429	67/33	1170/630	937/1460	Y	Y	Y	-
VOLKSWAGEN	RABBIT	2	1979	R	35.0	2470								N
VOLKSWAGEN	RABBIT CONV.	2	1980	F	34.9	2767	1328/829	48/54	458/424	1364/722	Y	Y	Y	-
VOLKSWAGEN	RABBIT CONV.	2	1980	R	35.0	2841								N
VOLKSWAGEN	SCIROCCO	2	1982	F	(To Be Tested)									
VOLKSWAGEN	QUANTUM	4	1982	F	(To Be Tested)									N
VOLVO	244 DL	4	1979	F	35.0	3374	1782/1889	52/61	320/900	700/320	Y	Y	Y	
VOLVO	244 DL	4	1979	R	34.6	3390								Y
VOLVO	DL	2	1982	F	34.9	3354	550/381	45/35	154/1147	892/227	NA	NA	NA	NA

81 and 82 models. It is presented only to illustrate the capability that the auto industry displayed as it became evident that different performance levels existed in the vehicle population.

As illustrated in Table 2, the changes to the vehicles were primarily modifications to belts systems and steering assemblies. These items were the predominant cause of poor performance in the higher speed tests.

The ideal situation would be to test all vehicles that were modified to determine the effect of the changes on their safety performance. Due to budget constraints, it has not been feasible for NHTSA to retest all the vehicles but two prime examples that will be examined in detail in the next sections are the 1981 Honda Civic and the 1982 Volvo.

THE 1981 HONDA CIVIC—AN EXAMPLE OF POTENTIAL SAFETY IMPROVEMENTS IN SMALL CARS

Honda Civics were tested in three consecutive model years, 1979, 1980, and 1981. The 1980 MY was tested due to a significant dimensional change from the previous year design. The 1981 MY was tested when NHTSA became aware of the design changes that Honda had incorporated specifically to improve safety performance. Occupant responses from the three tests are given in Table 3.

By comparing the 1980 and 1981 results, we see that the HIC was reduced by a factor of *four* for the driver and by a factor of *three* for the passenger. Excellent results are also obtained for the chest g's and femur loads. In a study by MGA Research Corporation (6), sponsored by NHTSA, it was concluded that the design changes related to the steering column and the restraint system were most significant in reducing the occupant responses.

The steering column performance of the 1980 Civic was typical of many of the 79 and 80 model year transverse engine front wheel drive vehicles. The upward movement of the column placed the steering wheel hub in the direct path of driver's head. With the redesign, the column not only remained out of the way of head impact but also provided effective energy absorption for the chest. It is clear that column performance of this type is beneficial for both restrained and unrestrained drivers.

Table 2. Design changes to 1981 and 1982 model year automobiles that may affect safety performance.

	Component Changed	Safety Belt and Assembly	Seat Structure	Steering Wheel, Column, or Assembly
1981 Models	Toyota Tercel	X	X	
	Toyota Corolla	X		
	Toyota Corona		X	
	Toyota Celica	X		
	Subaru	X		
	Fiat Brava	X		
	Datsun 310	X		
	Datsun 510			X
	Datsun 200SX			X
	Honda Accord	X	X	X
	Honda Prelude	X	X	X
	Honda Civic	X	X	X
1982 Models	Volvo	X		
	Fiat Spider	X		
	Honda Civic	X		X
	Honda Prelude	X	X	X
	Mercedes	X		
	Datsun 310	X		
	Subaru	X		
	Toyota Starlet	X		
	Toyota Cressida	X	X	
	Toyota Corolla	X		X

From examination of the vehicles and comparison of the test films, it was observed at least two changes to the Civic's belt system were made. The D-ring was relocated on the B-pillar and the retractor was modified to reduce belt spool-out. These changes caused an earlier belt loading and reduced or prevented head impact.

The engineers at Honda did an excellent job of running design changes to a production vehicle to obtain these outstanding safety results. Certainly, the few items discussed above do not constitute all changes to the vehicle. Only the manufacturer could provide the complete details and processes that were involved.

Table 3. Comparison of results from Honda Civic tests.

Vehicle Model Year	HIC		Chest g's		Femur lds.	
	Driver	Passenger	Driver	Passenger	Driver	Passenger
1979	2031	2094	93	46	1080	1520
1980	2691	1510	58	56	1006	3181
1981	605	492	41	35	500	1100

Based on the dummy measurements, the Honda results illustrate that it is feasible, both technically and economically, to significantly improve small car performance in severe frontal impacts.

THE 1982 VOLVO—NHTSA RESEARCH RESULTS PROVIDE INFORMATION

A 1979 model year Volvo 244DL was one of the first vehicles tested in the NCAP. The HIC's were in excess of 1700 for both the driver and passenger. These results were surprising in that the Volvo had been used in several of NHTSA's advanced restraint programs because of its favorable safety characteristics. These results led to action by both Volvo and NHTSA. Volvo conducted several 35 mph tests on similar vehicles and, although their results were not as high as the NHTSA test results, they found marginal performance. The NHTSA embarked on a project to evaluate and possibly upgrade the belt system in vehicles such as a Volvo (7). This project was concluded with testing of a Volvo 244DL and a Volvo 242DL with reduced belt length. This testing indicated a significant improvement in occupant response by reducing belt spool-out and decreasing the forward motion of the occupant. Results of this project were made available to Volvo and other manufacturers.

In their 1982 MY vehicle, Volvo incorporated a redesigned belt system as indicated in Table 2. NHTSA has completed tests on production 1982 Volvo 242DL. Results of these tests along with the results of the 1979 test are shown in Table 4. Significant improvement for the belted occupant is evident.

THE RELIANT K—SIGNIFICANT IMPROVEMENT IN SAFETY PERFORMANCE IS DEMONSTRATED

Soon after its introduction, Chrysler's Reliant K was tested in the NCAP. Test results showed that the passenger experienced serious head impact with a HIC of 1731. The NHTSA initiated research to identify those belt restraint system design characteristics which permit excessive front seat barrier collision exposure and improve the production belt restraint system to ensure that the occupant injury criteria are reduced to acceptable levels in such a crash (8). From this research, it was concluded:

1. Right-front passenger high HIC value stemmed directly from head impact with the unpadded metal dashboard top cover.
2. Excessive fore-aft occupant stroke (relative to the passenger compartment), combined with substantial upward/rearward dashboard intrusion, permitted the above contact to occur.
3. The Plymouth Reliant has a relatively limited amount of available passenger compartment stroking distance (e.g., as provided by a dummy chest-to-dash measurement) compared to other cars in its size/weight class.
4. The aforementioned dashboard intrusion seriously compromised the (somewhat limited) space available for the occupant to ride down the crash.
5. Belt spool-off from the retractor is the principal mechanism responsible for excessive occupant stroking. Significant belt playout and head motion, at relatively low torso belt loadings, occur early in the event.

An experimental design program was conducted. Resulting modification of the Reliant consisted of the following:

1. installation of a modified Takata Kojyo webbing clamps and webbing clamp mounting brackets to the B-pillars and side roof rails,
2. removal of the production shoulder belt D-rings located at the B-pillars,
3. replacement of the production belt webbing with 8% elongation Takata Kojyo webbing maintaining the production belt length, and
4. stiffening of the front seat cushion.

A 35 mph barrier crash test was run with the modified vehicle. Results of that test are compared with the baseline vehicle in Table 5. Significant improvements in safety performance are demonstrated by the large reduction in both the HIC values and the chest g's. These results again illustrate the possibility for better occupant safety with only minor vehicle changes.

COMPARISON OF NCAP INJURY CRITERIA TO ACCIDENT DATA

As mentioned earlier, the correlation of crash test data to real world accidents continues to be an issue. Direct correlation of the NCAP data to the real world is a very difficult if not impossible task. By testing with the restrained dummies, the opportunity to develop this correlation with available United States accident data is sacrificed. With belt usage continuing at approximately 10 percent inadequate accident data are available to evaluate the relative safety of vehicle makes and models in protecting belted occupants. However, this does not preclude some comparisons between certain parameters of the NCAP test results and existing U.S. accident data studies. In the following discussion and analysis, these comparisons will be made and the recommendation from the International Symposium to utilize accident data from a country where restrained occupant data are available will be applied.

Initially, the relationship of the dummy injury criteria

Table 4. Comparison of results from Volvo tests.

Vehicle	HIC		Chest g's	
	Driver	Passenger	Driver	Passenger
1979 244DL	1782	1889	52	61
1982 242DL	550	381	43	34

Table 5. Comparison of results from Reliant K tests.

Vehicle	HIC		Chest g's	
	Driver	Passenger	Driver	Passenger
Baseline	605	1731	52	59
Modified	391	296	34	37

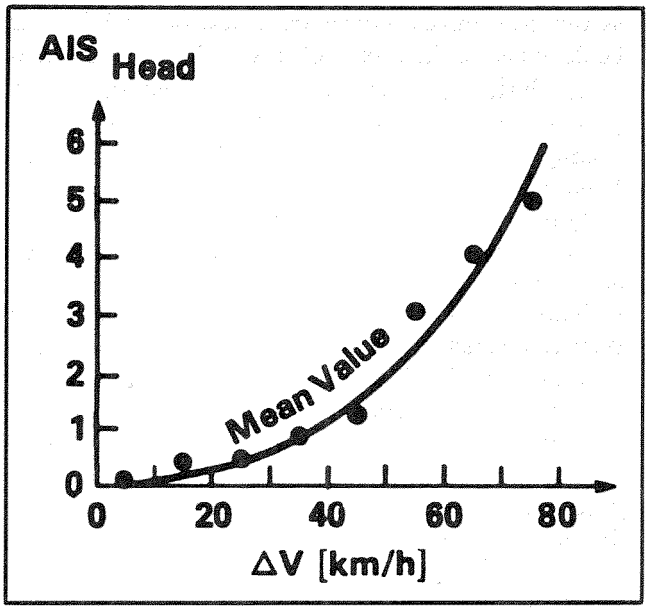


Figure 1. Relationship of ΔV and head AIS from accident data.

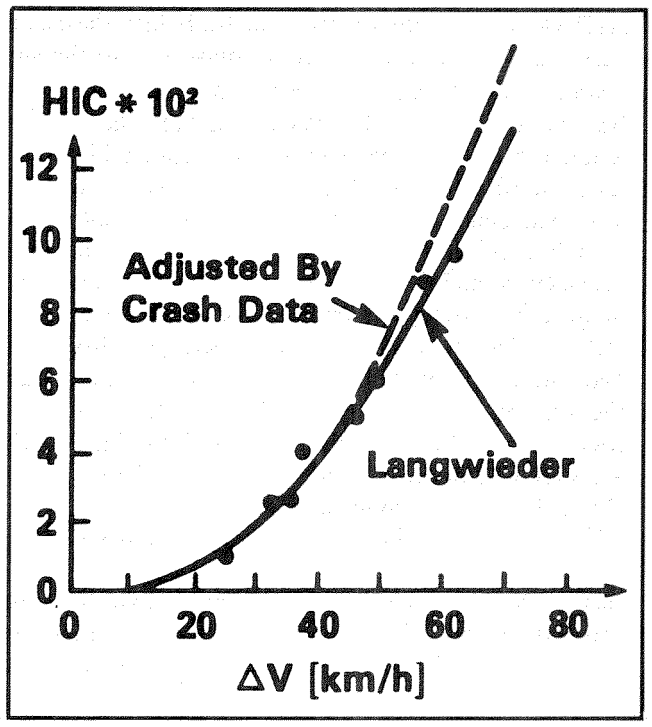


Figure 3. Relationship of ΔV and HIC from P572 simulations and tests.

to the human in the crash event must be established. How do HIC and Chest g's measured on a dummy translate to AIS levels of people in accidents? Dr. K. Langwieder addressed this question in a paper presented at the Twenty-Third Stapp Conference (9). First, he established relationships between head and chest AIS levels and crash severity (delta V) for restrained accident victims. These relationships are shown in Figures 1 and 2. Dr. Langwieder utilized the accident data on restrained occupants from West Germany.

He then developed relationships between the HIC, CSI, and the delta V for the P572 dummy. These are shown in Figures 3 and 4. These relationships were developed from analytical simulations of restrained dummies.

A question arising at this stage of Dr. Langwieder's approach is the accuracy of the analytical simulations. With the number of full scale crash tests available in the

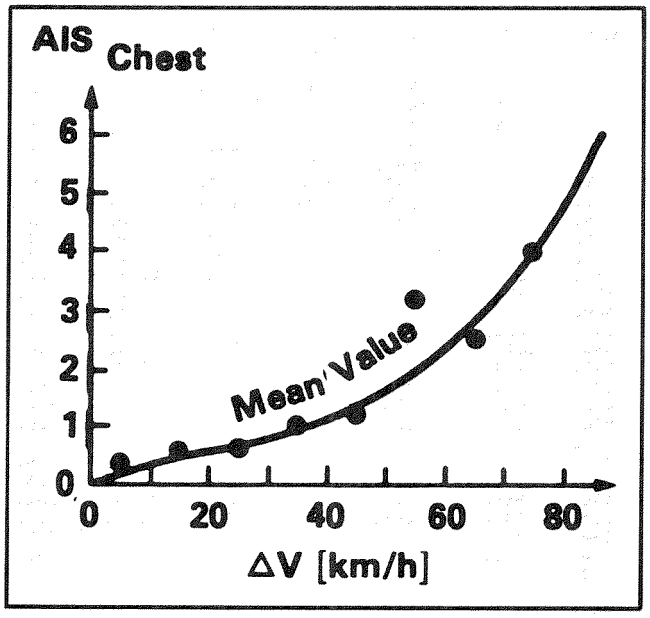


Figure 2. Relationship of ΔV and chest AIS from accident data.

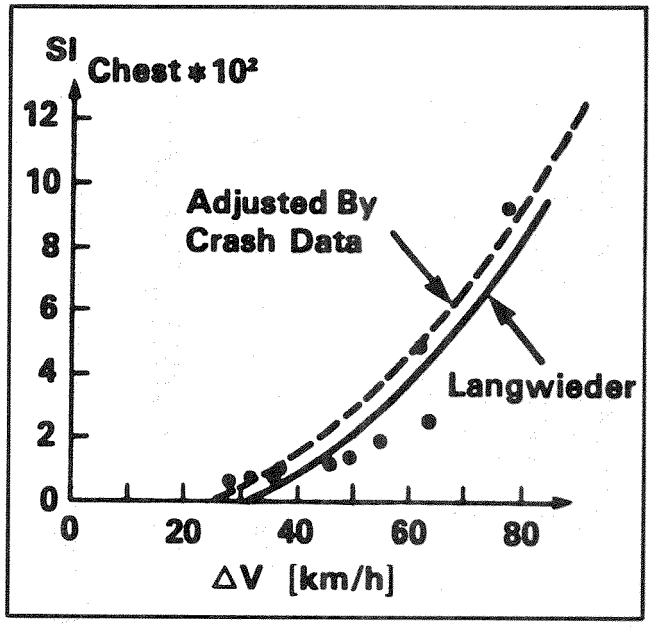


Figure 4. Relationship of ΔV and CSI from P572 simulations and tests.

NHTSA data base this question can be. In fact, the dashed curves in Figures 3 and 4 show adjustment to the simulations that are based on average dummy responses in NHTSA crash tests. The frontal crash test data utilized to make these adjustments included 31 automobiles crash tested at 30 mph and 45 automobiles crash tested at 35 mph. The delta V's for these speeds were 33 mph and 40 mph. Tables 6 and 7 list these vehicles along with vehicle registrations and the injury data from the restrained P572 driver and passenger dummies. The mean values of the HIC and CSI for the dummies were calculated from these data and are given in Table 8. By using these mean data, the adjustments were made to Langwieder's simulation results. Limited crash test data at lower and higher delta V's were also examined and found to fall within reasonable bounds of the adjusted curves.

By taking the accident victim injury data from Figures 1 and 2 and dummy injury data from Figures 3 and 4, relationships between human injury and surrogate criteria can be developed. Figures 5 and 6 show these relationships as generated by Langwie ler and as adjusted by the crash test data. By using these adjusted curves, it then becomes possible to derive estimates of the relationship between NCAP results and accident data.

In the following paragraphs, what is attempted is the application of Langwieder's accident data to a large body of U.S. test data. In aggregate, his data appear consistent with our own. In the course of this analysis, these relationships will be applied to individual vehicles. Clearly, more analysis of the U.S. data files for belted occupants as well as complete evaluation of test repeatability must be done before the results of this analysis can be viewed as conclusive. The approach, however, appears to have promise and the NCAP results to date indicate the continuing commitment of automobile manufacturers to build enhanced levels of protection into cars.

By referring again to the group of 30 and 35 mph tests and utilizing these injury relationships, AIS levels were determined for all occupants in the crash tests. Then, with the AIS levels available, fatality rates for each vehicle were calculated by using the fatality rate equation developed from NCSS data by Eppinger and Partyka (10).

By using this information and the vehicle registration data the overall fatality rates for delta Vs of 33 and 40 mph are calculated and the probabilities for serious injuries (AIS 3 and greater) are also determined and given in Table 9. These rates and probabilities can be directly compared with statistical accident data from the National Crash Severity Study.

Extensive statistical analyses of the NCSS file have been performed by the Highway Safety Research Institute of the University of Michigan (11). These analyses produced logistic curves of the probability of injury versus impact severity. The curves for the frontal accident subset are shown in Figure 7. In this figure, the probability of serious injuries, AIS 3 or greater, versus delta V for central impacts are shown with occupant age fixed at 30. The probabilities of serious injury from the crash test results, Table 9, are also shown in this figure. Both values from the crash tests show reduced probabilities for severe injury.

Table 6. Vehicle registrations and dummy injury data for 30 mph crash tests.

		DRIVER				PASSENGER				
VEHICLE	REGISTR.	HIC	CHEST G	CSI	LFEM	RFEM	HIC	CHEST G	CSI	LFEM	RFEM
78 CHRYSLER LEBARON	318743.	878.	64.	423.	0.	0.	985.	41.	345.	0.	0.
78 CHEVROLET NOVA	1048371.	1150.	48.	378.	0.	0.	1641.	56.	479.	0.	0.
78 AMC GREMLIN	50534.	800.	49.	307.	0.	0.	855.	40.	288.	0.	0.
78 DATSUN 810	49595.	603.	40.	221.	0.	0.	763.	35.	202.	0.	0.
78 MAZDA RX	38905.	1451.	52.	395.	0.	0.	2042.	54.	383.	0.	0.
78 PEUGEOT 604 SL	3168.	1347.	48.	325.	0.	0.	694.	40.	274.	0.	0.
78 TOYOTA CRESSIDA	15010.	582.	61.	345.	0.	0.	910.	39.	259.	0.	0.
78 DODGE CHALLENGER	19657.	509.	59.	360.	0.	0.	885.	47.	289.	0.	0.
78 CHEVROLET CHEVETTE	298981.	1024.	43.	314.	0.	0.	936.	43.	337.	0.	0.
78 VW RABBIT	291049.	1552.	59.	448.	0.	0.	661.	42.	233.	0.	0.
78 FORD FAIRMONT	517844.	744.	41.	269.	154.	212.	396.	31.	186.	2286.	214.
78 CHEVROLET MALIBU	1444240.	931.	41.	393.	539.	452.	589.	31.	237.	240.	538.
78 PLYMOUTH HORIZON	188383.	1202.	51.	356.	489.	362.	595.	38.	267.	564.	685.
78 BUICK LESABRE	1421078.	812.	46.	240.	298.	222.	699.	36.	180.	222.	285.
78 PLYMOUTH SAPPORO	13143.	665.	60.	389.	660.	1440.	766.	34.	234.	480.	526.
78 CHEV MONTE CARLO	1207236.	783.	31.	249.	538.	413.	779.	30.	227.	340.	516.
78 OLDSMOBILE CUTLASS	1061597.	760.	39.	296.	234.	308.	828.	39.	266.	186.	585.
78 HONDA CIVIC	154035.	652.	70.	431.	442.	1902.	915.	40.	261.	1253.	722.
78 HONDA ACCORD	196826.	665.	53.	276.	876.	802.	1025.	34.	228.	677.	408.
77 VOLVO 242	22783.	404.	28.	197.	275.	345.	268.	25.	154.	634.	271.
77 FORD GRANADA	859761.	511.	37.	231.	793.	313.	470.	34.	196.	397.	369.
77 CHEVROLET IMPALA	1521372.	608.	35.	263.	2161.	218.	552.	39.	311.	331.	415.
77 DATSUN 200SX	66189.	749.	41.	304.	154.	556.	616.	33.	259.	1013.	102.
77 MAZDA GLC	83940.	894.	45.	351.	1053.	534.	690.	35.	283.	200.	97.
77 FORD LTD II	402868.	664.	51.	307.	650.	712.	700.	42.	248.	814.	478.
77 DODGE ASPEN	1152912.	813.	42.	280.	820.	1032.	731.	35.	262.	572.	533.
77 CHEVROLET CHEVETTE	133468.	838.	42.	292.	228.	2077.	887.	40.	300.	493.	199.
77 AMC PACER	79495.	819.	37.	316.	2175.	947.	890.	45.	338.	618.	490.
77 HONDA CIVIC	147648.	675.	50.	440.	462.	1931.	900.	40.	247.	2438.	599.
77 TOYOTA COROLLA	472101.	555.	45.	336.	652.	966.	981.	50.	424.	543.	286.
77 FORD CUSTOM	783387.	687.	45.	327.	656.	1513.	1144.	35.	188.	605.	543.

Table 7. Vehicle registrations and dummy injury data for 35 mph crash tests.

VEHICLE	REGISTR.	DRIVER HIC	DRIVER CHEST G	DRIVER CSI	DRIVER LFEM	DRIVER RFEM	PASSENGER HIC	PASSENGER CHEST G	PASSENGER CSI	PASSENGER LFEM	PASSENGER RFEM
79 HONDA CIVIC	155541.	2030.	93.	994.	1080.	838.	2093.	46.	424.	1520.	1460.
80 HONDA CIVIC	165269.	2626.	54.	613.	1006.	3118.	1506.	47.	415.	418.	218.
79 FORD FIESTA	146704.	1656.	64.	678.	340.	1050.	1932.	48.	483.	0.	240.
79 PLYMOUTH CHAMP	217728.	1345.	72.	593.	893.	435.	1886.	66.	684.	686.	561.
79 DATSUN 210	454117.	1467.	69.	706.	0.	536.	1848.	59.	619.	781.	218.
79 VW RABBIT	180787.	1024.	67.	532.	1170.	630.	429.	33.	226.	937.	1460.
80 VW RABBIT	186022.	1328.	48.	489.	458.	424.	829.	54.	539.	1364.	722.
79 CHEVROLET CHEVETTE	340877.	871.	47.	417.	1280.	1600.	859.	45.	339.	690.	1400.
80 CHEVROLET CHEVETTE	362677.	668.	45.	411.	1649.	1777.	699.	40.	358.	766.	802.
79 PLYMOUTH HORIZON	559384.	661.	52.	466.	974.	708.	786.	38.	360.	581.	657.
79 FORD MUSTANG	785540.	802.	41.	332.	221.	946.	777.	33.	273.	781.	376.
79 MERCURY BOBCAT	342312.	720.	58.	446.	463.	1343.	1872.	51.	526.	741.	571.
79 TOYOTA CELICA	314789.	849.	61.	473.	2920.	435.	1862.	59.	446.	400.	520.
80 CHEVROLET CITATION	1243391.	845.	48.	334.	560.	760.	623.	35.	295.	1040.	350.
79 CHEVROLET MONZA	612387.	1108.	42.	501.	580.	400.	1033.	41.	432.	600.	325.
79 FORD FAIRMONT	577764.	939.	54.	417.	825.	1155.	1583.	85.	715.	1245.	600.
80 PEUGEOT 504D	22326.	4513.	63.	539.	504.	1786.	2498.	43.	424.	1082.	679.
80 AMC CONCORD	181097.	1078.	61.	564.	1300.	910.	1457.	39.	375.	375.	337.
80 MERCEDES BENZ 240D	80989.	1301.	54.	579.	674.	1687.	1363.	44.	412.	666.	1449.
80 FORD THUNDERBIRD	637504.	993.	50.	459.	1720.	2203.	991.	52.	416.	1733.	784.
79 PLYMOUTH VOLARE	453454.	724.	40.	297.	1000.	1000.	1677.	40.	286.	1200.	570.
80 CHRYSLER LEBARON	105418.	1742.	54.	494.	913.	860.	1252.	45.	406.	678.	688.
79 PONTIAC FIREBIRD	707936.	969.	42.	360.	582.	472.	1307.	47.	391.	503.	717.
79 FORD GRANADA	458808.	1442.	61.	492.	1750.	350.	1279.	56.	435.	390.	570.
79 CHRYSLER LEBARON	163472.	2402.	45.	416.	740.	300.	1071.	39.	354.	420.	440.
79 CHEVROLET IMPALA	2107504.	1277.	62.	617.	368.	808.	1254.	51.	599.	0.	391.
79 MERCURY MARQUIS	628121.	1111.	61.	529.	580.	804.	880.	42.	398.	378.	0.
79 DODGE MAGNUM	25367.	646.	39.	325.	250.	725.	731.	44.	314.	360.	170.
79 BUICK RIVIERA	214651.	547.	42.	416.	943.	892.	782.	39.	355.	1371.	1272.
80 CADILLAC SEVILLE	99018.	623.	43.	318.	1057.	681.	523.	35.	307.	791.	608.
79 OLDS '98	647841.	925.	59.	468.	774.	535.	1712.	54.	552.	370.	439.
79 FORD LTD II	48564.	1082.	61.	598.	1063.	2775.	809.	40.	318.	584.	429.
79 LINCOLN	121989.	521.	45.	331.	395.	393.	919.	53.	364.	577.	986.
80 RENAULT LECAR	41577.	1938.	85.	1100.	1095.	1663.	1844.	53.	517.	2236.	1840.
80 TOYOTA TERCEL	38289.	1218.	48.	454.	1055.	1078.	1179.	53.	426.	1386.	449.
80 DATSUN 310	170096.	1059.	68.	588.	1218.	1090.	2019.	108.	1428.	1369.	1190.
80 HONDA PRELUDE	82153.	2904.	52.	545.	445.	1057.	1759.	45.	434.	465.	277.
80 SUBARU GLF	270839.	1087.	72.	630.	799.	1291.	2837.	94.	900.	966.	1583.
80 FIAT STRADA	20036.	790.	41.	335.	1159.	2143.	962.	43.	341.	1101.	464.
80 AUDI 4000	16476.	1322.	70.	679.	408.	353.	1428.	45.	407.	1030.	527.
80 DATSUN 200SX	63284.	1091.	62.	520.	1150.	893.	1032.	44.	364.	663.	242.
80 MAZDA 626	54235.	1435.	101.	1132.	923.	939.	2206.	54.	602.	380.	209.
79 OLDS CUTLASS SUP V8	835079.	997.	58.	500.	1675.	1800.	799.	37.	364.	350.	650.
80 OLDS CUTLASS	1453477.	1334.	62.	707.	801.	1958.	1125.	47.	402.	476.	459.
80 DODGE MIRADA	27595.	950.	43.	350.	784.	950.	960.	37.	313.	1032.	431.

The crash data from the 33 mph delta V tests indicate a significant difference from the accident statistics. The crash data at 40 mph delta V are only slightly below the accident statistics.

Intuitively, the results from the 33 mph delta V crash tests are expected since the test data are based on a 100% restrained population and the NCSS on only about a ten percent restrained population. It might also be expected that a similarly large difference would be found at the 40 mph delta V. The lack of separation between the accident data and the test data at 40 mph delta V may reflect an inconsistency in the correlation and/or the difference in the severity of the crash tests relative to the real world events.

Table 8. Mean of occupant response.

Crash Test	HIC	CSI	Chest g's
30 MPH	825	297	43
35 MPH	1292	490	53

However, a review of the fatality rates between the NCSS and the crash tests provides another explanation. As seen in Table 9, the fatality rate for the 40 mph delta V data is .109. The probability of fatality at this crash severity in NCSS is .199. The decrease in fatality rate by almost a factor of two in the crash tests in comparison to the NCSS file indicates that a significant reduction in

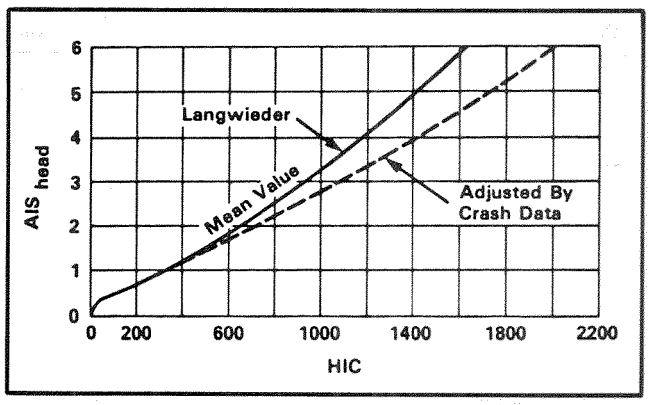


Figure 5. Relationship of HIC and head AIS.

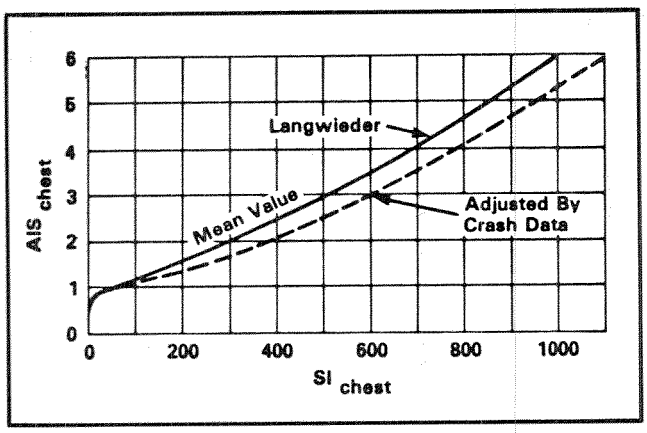


Figure 6. Relationship of CSI and chest AIS.

life threatening injuries for the belted occupants has occurred. Even though the probability of AIS 3 at 40 mph delta V is not vastly different for the two data sets, the fatality rates definitely reflect the expected improvements in the protection for belted occupants.

Conclusions that may be drawn from this analysis are:

1. Absolute correlation of accident data to crash test results is not yet feasible but relative comparison can be established.
2. Dummy responses in controlled crash tests when compared with accident statistics appear to provide some measure in injury.

PASS/FAIL ALTERNATIVES

Another of the primary issues of the New Car Assessment Program that invoked substantial criticism by the manufacturers was the use of the pass/fail concept to characterize a vehicle's crash test performance at 35 mph with respect to the injury criteria of Federal Motor Vehicle Safety Standard (FMVSS) No. 208. The limits established by this standard are 1000 for the HIC, 60 g's for the chest acceleration and 2250 pounds for the femur load. The pass/fail concept has been used by NHTSA in

Table 9. AIS distribution probability and overall fatality rates.

AIS	AIS Distribution Probability*	
	ΔV 33 Mph	ΔV 40 Mph
3	.198	.355
4	.017	.248
5	.020	.048
6	.001	.058
Total AIS ≥ 3	.236	.710
Fatality Rate*	.013	.109

* Based on a total vehicle fleet of 14,064,319 for ΔV of 33 Mph and 16,422,484 for ΔV of 40 Mph.

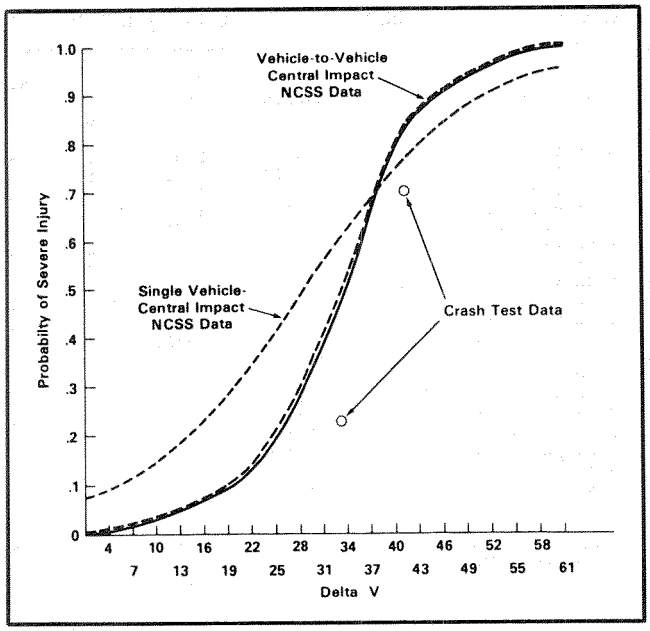


Figure 7. Logistic curves for front impact subsets (age = 30 years).

all compliance testing to evaluate performance of vehicles to the Federal Motor Vehicle Safety Standards requirements. Initially, NHTSA decided to adopt this concept for the New Car Assessment Program.

The 35 mph test speed and the pass/fail concept were viewed as approaches that would permit the test results to distinguish the overachievers from the vast number of vehicles that simply meet the requirements of FMVSS No. 208 at 30 mph. However, this viewpoint was strongly contested by the manufacturers after the program's first press release. Furthermore, *The Car Book*'s depiction of pass/fail using stick man images that inferred life or death was even more controversial to the manufacturers. Some consumers also indicated a misunderstanding, concerning the use of pass/fail. The most common was the belief that if test results for a particular vehicle indicate that a front seat occupant failed the requirements, that occupant would be considered a fatality. This misunderstanding was also reversed, implying that the front seat occupant of a vehicle that passed the requirements would be able to simply walk away from this type of accident.

These misunderstandings lead to another controversial topic under the pass/fail concept—marginal vehicle performance. Indeed, the pass/fail concept permitted a vehicle that demonstrated marginal performance to either reap the benefits afforded to the overachievers or the wrath shared by the others. This also heightened the concern being generated over the degree of variability that exists in all crash testing methodology.

The NHTSA responded to this controversy by eliminating the pass/fail concept and by using the actual test data to report HIC, chest g's and femur loads in the 1981 New Car Assessment Program test results. The data were

shown in two formats, first, a numerical table of the injury criteria which included a yes/no indication for compliance to the requirements of FMVSS Nos. 212, 219 and 301 at 35 mph. The table was accompanied by a narrative and legend that explained the content. Secondly, the data were shown in a graphic form which permitted easy comparison of the results. The National Highway Traffic Safety Administration believes that this change will be more useful to consumers because it allows them to compare vehicles on a continuous scale of performance rather than grouping in just two categories.

Use of this continuous data with the correlations as presented in the previous section, provides a conversion to the more real world injury levels as defined by the AIS injury scale. Figure 8 displays this scale as taken from HIC/AIS relationship curve in Figure 5. Similar chest injury relationships for either CSI or g's could be developed from this approach. Broadly defined AIS levels are: AIS 1—Minor, AIS 2—Moderate, AIS 3—Serious, but not life threatening, AIS 4—Severe, life threatening, AIS 5—Critical, life threatening, and AIS 6—Maximum injury. The American Association for Automotive Medicine provides detailed descriptors for these AIS levels in "The Abbreviated Injury Scale" manual which was revised in 1980 (11).

It should be noted that the scale in Figure 8 and the analysis of the last section are based on the limited accident data from Langwieder's study and are subject to change as other data systems such as the National Accident Sampling System provide more complete information. It should also be noted that NHTSA is considering alternatives to HIC and dummy injury parameters, such as the mean strain criteria. These alternatives or others that may be developed in the biomechanical community may provide better correlation with accident data and human injury.

As shown in Figure 8, each AIS level spans a large range of HIC values. An AIS 1 occurs from HIC's of 135 to 520, an AIS 5 from 1575 to 1860. In the "real world" considerable overlap probably occurs within these ranges, but these data provide indications of the average levels.

By defining these broad bands of HIC/AIS relationships, a more reasonable evaluation of vehicle and test procedure variability or repeatability may be possible. In the following section the NHTSA test repeatability program will be discussed.

TEST REPEATABILITY/VARIABILITY

The third major issue raised by the manufacturers after the first NCAP press release is that the data from a single crash test of a vehicle has questionable significance because of test repeatability and variability. Their complaints were based on several conditions of the NCAP tests. The tests were conducted at four different test laboratories and variations between test sites could make data comparison very difficult. They criticized the Part 572 dummy because they felt that its characteristics are variable and it is difficult to achieve repeatable dummy placement even in the same vehicle. They knew that a vehicle contained inherent variables due to the manufacturing process alone, without considering other design tolerance stack-ups. The instrumentation utilized to collect and process the crash test data may have variable characteristics. These complaints, along with others, were presented formally to NHTSA and documented as part of the NCAP Docket Number 79-17.

Since the initiation of NCAP the NHTSA has continuously researched ways to develop improvements in the testing methodology. A first major step has been taken

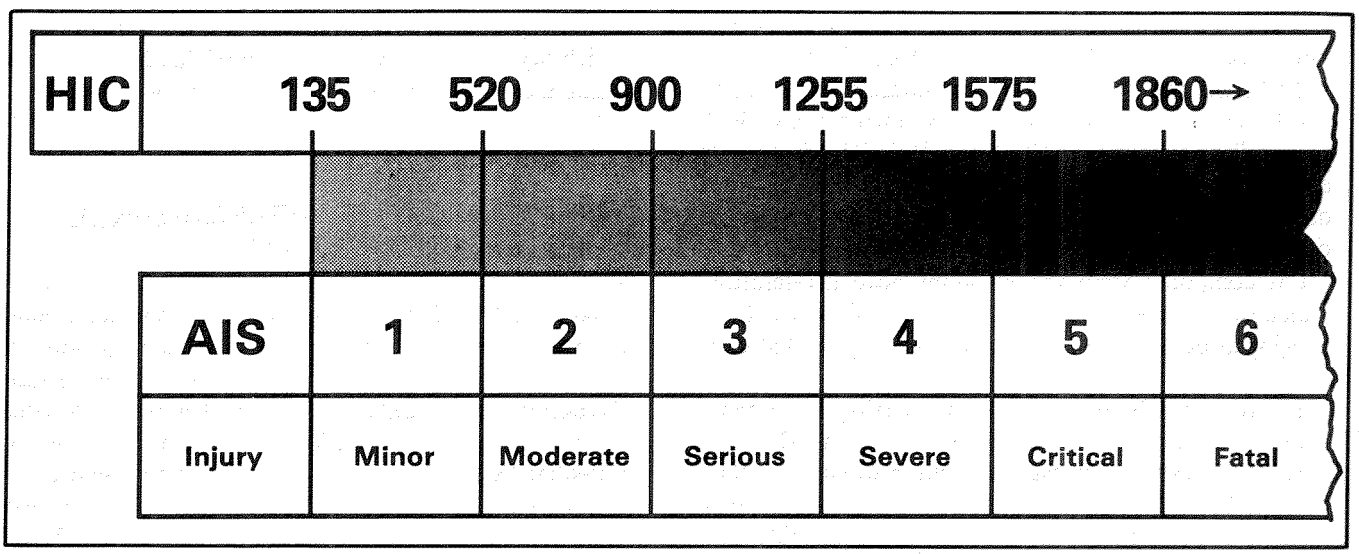


Figure 8. Scale of AIS versus HIC.

to evaluate variability that may exist in the different contracted laboratory's crash testing instrumentation systems by using a signal wave form generator. The results of this study are given in Reference 12. The next step was the incorporation of more seat belt data collection methodology and camera coverage into the NCAP test procedure. The third step was the standardization of the HIC algorithm for use by every NCAP testing contractor. From these steps, the Agency embarked upon its study of the 35 mph crash testing variability issue. The primary product of this study would be an improved NCAP test procedure. The improvements are directed toward collecting data on the movement of critical components in the vehicle, such as the steering column, restraint system, seats, etc. In addition, the photographic coverage of dummy kinematics has increased and the data collection and processing specification was upgraded to J211B-Class 1000.

Most importantly the Agency decided to initiate a 35 mph Crash Test Repeatability Program designed to provide a statistically sound basis for studying the variability issue. The test vehicles would be controlled by limiting the variables of the manufacturing process. They will be identical vehicles assembled on the same day at one plant by the same shift of workers. The Chevrolet Citation 4-door Hatchback was chosen as the test vehicle because the Agency has more high speed crash data on it than any other vehicle. The program's design also provides a measure of site-to-site variability and within-site variability. The program consists of a sixteen test series, four tests at each of four test sites. General Motors Corporation has volunteered to be one of the participants and conduct testing at their own test site, in accordance with NHTSA test procedures. The three other participants are Calspan Corporation in Buffalo, New York; Dynamic Science, Inc. in Phoenix, Arizona; and the Transportation Research Center in East Liberty, Ohio. General Motors Corporation and Ford Motor Company provided technical assistance in the design of this program. At each test site, four test vehicles are to be crashed at 35 mph into a fixed barrier in a zero degree frontal impact.

The crash test data of particular interest are the HIC, chest acceleration, and femur loads. Two types of HIC data will be generated, HIC-I and HIC-III. HIC-I data are computed from resultant head accelerations that occur during the complete crash event. This is the method as defined in FMVSS 208 currently used by NHTSA. HIC-III is computed from the resultant head accelerations which occur only during head contact. This method was developed by General Motors and is being evaluated by NHTSA.

In order to effectively monitor the testing, the Agency contracted with MGA Research Corporation (MGA) to observe all testing and data acquisition to ensure adherence with the program guidelines. MGA is also responsible for monitoring the test vehicle assembly and dimensional analysis.

The data that are generated from this testing will be subjected to engineering and statistical analyses. The engineering analyses will include a structural performance review to determine significant differences, restraint system performance assessment, steering column movement, and dummy kinematic photographic analysis. Test film coverage and analysis have a vital role in this testing series. HIC-I and HIC-III data will be compared. HIC-III will be statistically analyzed only if there are a significant number of head strikes. The statistical analysis will be based on measurements of HIC, chest acceleration, right femur load, and left femur load taken from the two dummies in each vehicle. Analysis of variance techniques will be applied to these data and will be used to estimate within-site and between-site variances. These techniques will also be used to test whether results from different sites are statistically different. Various data plots will also be made to possibly uncover data characteristics not evident from the analysis of variance. If there is evidence that the data are not normally distributed, a suitable transformation will be sought. The analysis of variance will then be performed on the transformed data.

Ford Motor Company has suggested the use analysis of covariance. This technique uses the data collected on the vehicle variables to estimate the effects of the inherent variables due to the manufacturing process on the dummy crash test response. NHTSA will also evaluate this technique.

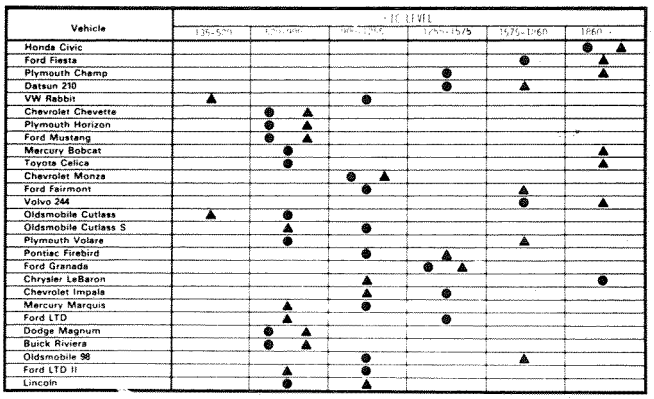
It is recognized that this program has limitations. First, vehicle variability has been reduced but not eliminated. Since this variability cannot be eliminated and it cannot be completely monitored by instrumentation, it will be included in the overall variability that is determined. Part 572 dummy variability, like vehicle variability, cannot be eliminated and it will also be reflected in the results. Indeed, the data collected during this program could indicate another source of variation that is presently unknown. Therefore, it is concluded that this single phase of the repeatability program will not answer all of the variability questions. If the results of this first phase indicate a clear direction for further study, a second phase will be designed.

TRENDS IN SAFETY PERFORMANCE SINCE THE NCAP BEGAN

As noted in Table 2, the manufacturers have made changes to their automobiles that are likely to improve their safety performance in 35 mph barrier crash tests. Certainly absolute data have already been presented that show these improvements for Honda and Volvo and the potential for similar improvements in the Reliant K.

To study the trend in the vehicle fleet safety performance, it becomes necessary to examine all the NCAP crash test data on a model year (MY) basis. In Tables 12

Table 10. Levels for NCAP occupants for 1979 model year vehicles.



• Driver
Δ Passenger

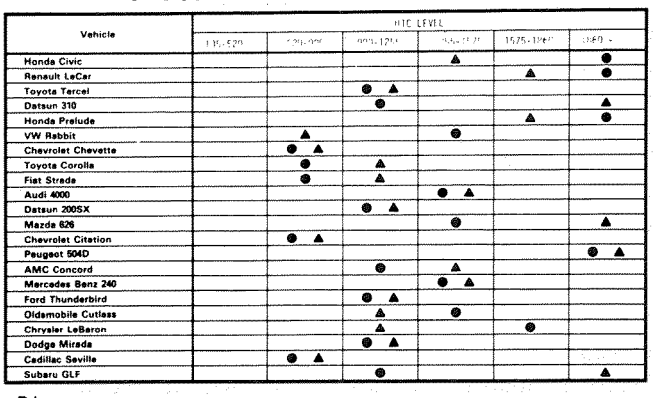
through 15, the vehicles are separated into the four MYs that have been tested.

Since the head has been the predominant body part injured in the tests, the HIC range for the head of the driver and passenger of each vehicle is given. These values are taken from the scale as shown in Figure 8. The first two years of the NCAP data for model years 1979 and 1980 are considered as the baseline information. This information was presented to the manufacturers essentially as one package by NHTSA. Therefore no trend attributable to the NCAP is expected in these two model years. By examining the HIC levels for MY 79 and 80, it is found that 41 percent of the values exceeded 1255. Based on the assumptions which were used to develop the scale in Figure 8, these values could indicate life threatening injuries.

In the MY 1981 vehicles, it was shown that Honda reacted rapidly to improve the safety performance of the Civic. It is not likely, however, that other major changes to improve safety were incorporated in the limited number of MY 81 vehicles that were tested. A slight trend in improvement, only 35% of the HIC levels indicated the potential for life threatening injuries, can be noted.

The time between the NHTSA release of the 1979 and

Table 11. Levels for NCAP occupants for 1980 model year vehicles.



• Driver
Δ Passenger

Table 12. Levels for NCAP occupants for 1981 model year vehicles.

Vehicle	HIC LEVEL					
	135-520	520-900	900-1255	1255-1575	1575-1860	1860 -
Ford Escort		•	Δ			
Plymouth Reliant K		•			Δ	
Honda Civic 2 dr.	Δ	•				
Toyota Starlet				Δ	•	
Honda Civic 4 dr.			•	Δ		
VW Jetta			•	Δ		
Renault 18i			•		Δ	
AMC Spirit		• Δ				
Toyota Cressida		Δ				•
Chrysler Imperial		Δ	•			

• Driver
Δ Passenger

1980 MY data and the 1982 MY allowed the manufacturers to incorporate improved safety systems in many of their vehicles. The data from Table 13 indicate that only 17% of the HIC levels were in the assumed life threatening injury range. This is one-third the percentage for the 1979 and 80 MY vehicles. Additionally, for the low end of the injury scale, six of the occupant responses for the 1982 MY vehicles are in the HIC range below 520. This compares to only three in this range for all previous occupants. On the high end of the injury scale, two HIC values about 1860 are observed for the MY 82 vehicles. Seventeen values in this range were recorded in previous MY vehicle tests. As shown in Figure 9, these data indicate that in a frontal accident with severity such as a 35 mph crash into a barrier that for the 1982 MY vehicles, 17% of the occupants would have suffered only minor injuries, 41% moderate injuries, 25% serious but not life threatening injuries and that only 17% would have suffered life threatening injuries. Comparable numbers for the 79 and 80 data are 2% for minor, 29% for moderate, 28% serious and 41% life threatening or fatal. Again, these injury levels are based on the assumptions used to develop the scale in Figure 8. The improvements in vehicle safety systems that these numbers reflect potentially trans-

Table 13. Levels for NCAP occupants for 1982 model year vehicles.

Vehicle	HIC LEVEL					
	135-520	520-900	900-1255	1255-1575	1575-1860	1860 -
Dodge Omni 4 dr.		•			Δ	
Dodge 400	•	Δ				
Ford Escort 4 dr.			• Δ			
Chevrolet Camaro		• Δ				
Chevrolet Celebrity	• Δ					
Honda Accord	• Δ					
Nissan Sentra		• Δ				
Nissan Stanza		Δ	•			
Renault Fuego						• Δ
Saab 900		•	Δ			
Toyota Celica		• Δ				
Volvo 242	Δ	•				
VW Quantum			Δ	•		
VW Scirocco		Δ		•		
Chevrolet Impala 4 dr.		Δ	•			
Ford LTD 4 dr.		Δ	•			
Mazda 626 4 dr.			•		Δ	
Ford Granada 4 dr.		•	Δ			

• Driver
Δ Passenger

Table 14. Preliminary list of 1983 passenger cars to be crash tested at 35 mph.

1.	Buick Riviera 2-dr. convertible
2.	Chevrolet Cavalier 2-dr. convertible
3.	Ford Mustang 2-dr. convertible
4.	Ford Tempo 4-dr. sedan
5.	Ford Thunderbird 2-dr. coupe
6.	Dodge 600 4-dr. sedan
7.	AMC/Renault Alliance 4-dr. sedan
8.	Honda Prelude 2-dr. coupe
9.	Isuzu Impulse 2-dr. coupe
10.	Mazda 626 4-dr. sedan
11.	Mitsubishi Cordia 2-dr. hatchback
12.	Mitsubishi Starion 2-dr. coupe
13.	Mitsubishi Tredia 4-dr. sedan
14.	Nissan Pulsar 4-dr. hatchback
15.	Toyota Camry 4-dr. sedan
16.	Toyota Tercel 4-dr. hatchback
17.	Volvo 760 GLE 4-dr. sedan
18.	BMW 320 4-dr. sedan
19.	Ford LTD 4-dr. sedan
20.	Chevrolet Caprice 4-dr. sedan
21.	Buick Century 4-dr. sedan
22.	Mercury Capri 2-dr. fastback
23.	Peugeot 505 4-dr. sedan

late into higher levels of protection for automobile consumers who utilize their belts.

THE NATIONAL SAFETY BELT CAMPAIGN AND THE NCAP

On April 14, 1982, President Reagan announced a National Safety Belt Campaign designed to prevent injuries and save lives in car crashes by increasing safety belt use. In the NHTSA press release on this campaign, it was again pointed out that of the estimated 28,000 fatalities per year in passenger cars as many as 14,000 could have been saved if safety belts had been used. Secretary of Transportation, Drew Lewis, also remarked at the opening of the campaign that "This horrendous and destructive problem has a simple solution. We must do more to develop safe drivers as well as safer cars. . . . It doesn't cost a dollar to buckle your safety belt when you get into your car tonight. Safety belts are there and paid for and ready to use."

The timing and results of the NCAP have provided ideal technical support for the safety belt campaign. By testing with restrained dummies, difference in safety belt systems could be determined. The 1979 and 1980 NCAP results strongly indicated the shortcomings of belt systems in severe vehicle crashes in some vehicles. As shown in previous sections, many manufacturers have responded by improvements to belt systems. Therefore, as Secretary Lewis requested, *manufacturers are doing more to develop safer cars.*

Philip Caldwell, Chairman of the Board of Ford Motor Company, (FMC) in his response to the National Seat Belt Campaign stated that today FMC is developing a range of advanced safety concepts for new vehicle models.

It is imperative that if the consumer is asked, urged, and educated to use safety belts that not only should these belts provide comfort and convenience, but they should provide maximum protection. The NCAP or a vehicle ratings program helps to assure that this goal is reached.

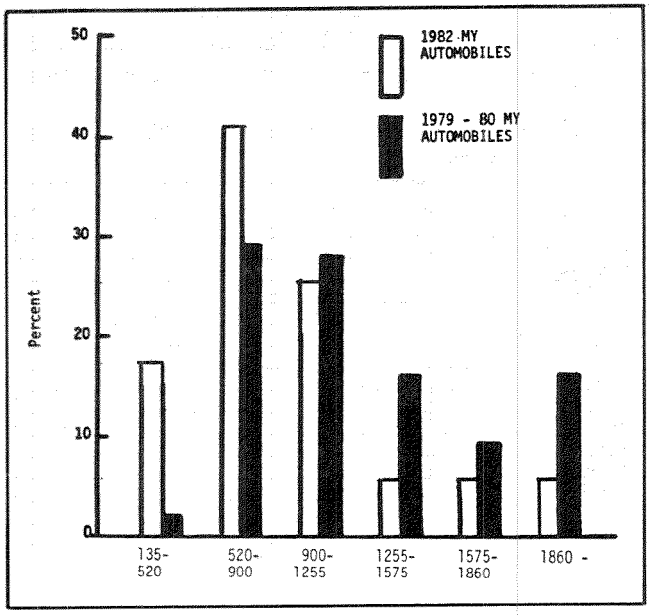


Figure 9. Comparison of injury severity—1979 and 80 model year automobiles to 1982 model year automobiles.

FUTURE ACTIVITIES

The NCAP is only a first phase in the development of methods to evaluate relevant vehicle crashworthiness and to supply this information to consumers. However, this first phase has proven very beneficial in assessing the performance of automobiles in frontal crashes and has provided information to the manufacturers about the safety systems of their vehicles relative to others in the fleet. The information from NCAP also provides NHTSA with an extensive data base of vehicle safety characteristics from which direction in research can be formulated. This is gained at a minimal cost to the government and taxpayers since it is primarily an add-on to a scheduled compliance test program.

Given the proven value of NCAP, the higher speed frontal crash testing of automobiles will be continued by NHTSA. All 1983 MY automobiles scheduled for crash testing to evaluate compliance to Federal Motor Vehicle Safety Standards 212, 219, and 301 will be tested at 35 mph. The list of these automobiles is given in Table 16.

Some supplemental testing may also be performed as required.

It remains that advances need to be made in several technical areas in order to more completely evaluate vehicle crashworthiness in the accident/traffic mix. Research projects that are continuing in NHTSA to assist in making these advances include:

1. The development and application of test devices and procedures for assessing side impact crashworthiness. The NHTSA program and schedule were presented in Technical Session number 3 of this conference. In addition, the international reports in session 3 give the extensive efforts and resources that are being directed to the side impact safety problems. Cooperative and coordinated projects need to be emphasized to assist in reaching an accepted solution for this accident mode.
2. The assessment and/or development of advanced dummies. Although the P572 dummy has become an accepted device in much of the safety community for frontal testing, research should not be curtailed in improving the capacity for acquiring more and better injury data. NHTSA is pursuing this improvement in two ways; evaluation and testing of existing advanced dummies and exploring the development of new generation dummies. Cooperative projects are underway to evaluate advanced dummies such as the General Motors Hybrid III and Association Peugeot Renault APROD. The Hybrid III will be used in several full vehicle and component test projects during the next year.

   Phase I of a project to explore the development of new generation dummies will begin in the near future. This phase will determine the specification and requirements for several dummy sizes.

   Based on the results of this phase, NHTSA will assess the direction for prototype designs of advanced dummies.
3. The evaluation of a deformable moving barrier for use in frontal crash testing. Seven frontal crash tests have been completed of automobiles into a deformable moving barrier. The data from these tests are being analyzed to establish the experimental capability of the moving barrier for evaluating the mass differential and stiffness effects in frontal collisions between two vehicles. Studies will be performed to relate the results of these tests to fixed barrier tests and to real world events. Additional research will likely be required to evaluate this approach relative to improved test techniques and data analysis.

In addition to these specific items, most projects in NHTSA Research and Development in biomechanics, structures, and occupant packaging areas are used to contribute to improvements and advancements that support the activities of the New Car Assessment Program.

CONCLUSIONS

After four years of higher speed crash tests in the NCAP, positive reactions from consumers and manufacturers are evident. The consumer remains very interested in measures of potential crashworthiness of the automobile he may purchase. The manufacturer, in many instances, has demonstrated the capacity to react to the crash test results either by incorporating improved safety systems into existing production vehicles (Honda and Volvo) or by upgrading levels of safety performance in new vehicle designs.

The major issues surrounding the program have received continuing attention from NHTSA. A comparison of dummy injury criteria to accident data has been made, with a possible scale of HIC values to AIS levels being suggested for further study. The use of pass/fail for presenting crashworthiness data to consumers has been discontinued and replaced with the presentation of the actual test data. The potential for conversion to AIS levels from these data has been pursued. Several activities have focused on the repeatability/variability issue. Improved test procedures and techniques are being used. Methods for evaluating and upgrading data gathering and processing have been developed and are now being applied. A crash test program is underway that will provide data for an intensive assessment of variability.

Based on the safety performance trends from the NCAP crash tests, significant improvements are noted from MY 79 vehicles to MY 82 vehicles. These results indicate 41% of the HIC values for the MY 79 and 80 vehicles exceeded 1255 and only 17% of the dummies exceeded this value for the MY 82 vehicles. These trends indicate the capability and feasibility of the manufacturers to significantly reduce the response levels of the restrained dummies in the high speed crash tests and potentially improve the protection for consumers (who use their belt systems) in the real world accident environment.

REFERENCES

1. Brownlee, Michael; Hackney, James; and Abney, Tim, "Implications of the New Car Assessment Program for Small Car Safety," Eighth International Technical Conference on Experimental Safety Vehicles (1980), pp 403-411.
2. *The Car Book*, U.S. Department of Transportation, National Highway Traffic Safety Administration, December 1980.
3. Telephone conversations with Bob Knoll of Consumers Union, August 1982.
4. Final report for NHTSA Contract Number DTNH22-80-C-02000, "Title II Consumer Survey," Prepared by Robert Kernish, National Analysts, A Division of Booz-Allen and Hamilton, Inc., July 1981.

5. Proceedings of the International Automotive Ratings Symposium, Sponsored by NHTSA, December 1980.
6. Miller, Patrick "Review of Honda Civic Hatchback Crash Test Data", Sponsored by NHTSA under Purchase Order Number NHTSA-9-6434, November 1981.
7. Final Report for NHTSA Contract Number DOT-HS-9-02178, "Upgrade Volvo Production Restraint Systems," Prepared by Michael Foster, Minicars, Inc., May 1981.
8. Final Report for NHTSA Contract Number DTNH22-81-C-07111, "Improved Performance of Production Belt System Assembly for the Plymouth Horizon and Plymouth Reliant," Prepared by Robert Galganski, Calspan Corporation, July 1982.
9. Langwieder, Klaus; Donner, Maximilian; and Schmelzing, Walter, "Comparison of Passenger Injuries in Frontal Car Collisions with Dummy Loadings in Equivalent Simulations," Proceedings of the 23rd Stapp Car Crash Conference, Society of Automotive Engineers; SAE 791009, pp 199-231, 1979.
10. Eppinger, Rolf and Partyka, Susan, "Estimating Fatality Reductions Associated with Safety Improvements," Eighth International Technical Conference on Experimental Safety Vehicles (1980), pp 432-438.
11. The Abbreviated Injury Scale (AIS); American Association for Medicine, 1980.
12. Report Number DOT-HS-805-979, Prepared by Rudy Arendt and Pat Miller, MGA Research Association, Inc., June 1981.

Relevance and Feasibility of a Vehicle Passive Safety Rating

B. GAUVIN, Chief Engineer
Director of the Vehicle Regulation Section
Safety and Road Traffic Department
Ministry of Transportation

This session invites us to reflect upon the rating of vehicles from the passive safety point of view, and before going into any detailed technical considerations, it would seem necessary to ask two basic questions: Is this rating theoretically justified? Is it practicably feasible today?

At present, we do not know how to answer the first question, and we must answer the second in the negative.

The first question is that of consistency between rating and regulation, since the means of action unanimously adopted by governments in the field of safety is regulation.

The principle of rating itself, where it is the buyer who decides, somewhat conflicts with that of regulation, where it is the government that decides.

Regulation clearly lays down a performance threshold, and vehicles put on sale must necessarily rank above this threshold; but, until that time, attempts had not been made to transform regulation performance into a sales argument; and this was so for two reasons:

—The first is that it is not necessarily possible to establish a clear relationship between regulation performance and a level of safety for the buyer. This is the whole problem of rating feasibility, which we shall come back to.

—The second is related to the principle that fixes the level of regulation. This level is laid down by the government as a reasonable compromise between safety requirements and technico-economic constraints. Clearly, if commercial competition comes to be based on regulation performance, well-meaning people are going to wonder about the validity of the threshold laid down by the regulations.

One should thus be very cautious when considering the commercial use that may be made of regulation performance. If vehicles are characterized by means of a variable parameter, there is unlikely to be any significant commercial impact resulting from this since there is no fundamental difference in the protection technology of most present day cars; and far too few users attach any importance to the technical aspects of their protection, as can be seen by noting the seat belt usage rate when it is not mandatory. If, however, vehicles are characterized as has been done recently by the United States, i.e., by laying down a rating threshold with an all-or-nothing criterion, then the debate is given a dramatic turn by distinguishing between good and bad vehicles without any gradation between the two; and there is total contradiction between such a rating and regulation.

In these conditions, and for the reasons just mentioned, the relevance of a vehicle rating system existing in parallel with regulation seems to us to remain a problem.

The problem of the feasibility of such a rating also arises.

Although accidentology has, over the last decade, made remarkable progress, the problem of determining satisfactory laboratory criteria for assessing the quality of protection afforded by an automobile cannot at present be considered as being perfectly solved.

The utilization of injury criteria measured on a humanoid dummy is considered, from the regulation point of view, as being a notable improvement on purely geometrical and mechanical criteria. But neither the dummies nor the criteria can be considered as being wholly perfect, and, in both cases, there can only be average values, irrelevant to the young, the old and, more generally speaking, to any person biomechanically far removed from the average chosen. Furthermore, current tests are excessively sensitive to initial setting-up conditions and offer a dispersion of measurement results such that fine comparison

between two models of cars cannot be meaningfully made.

This is why currently known methods would not seem to be usable in order to draw up a general classification of cars considered from the point of view of the quality of protection they afford in the event of a crash.

The only case in which current methods give a useful rating is where a vehicle is fitted with an original protection system designed to noticeably increase the efficacy of traditional systems used on other cars. For instance, taking the European situation, where the three-point inertia reel seat belt is mandatory for front seats, real benefit is to be gained by objectively quantifying the supplementary protection afforded by pyrotechnic preloader devices, auxiliary air bags, anti-laceration windscreens, etc.

As a conclusion to this first part, we consider a vehicle safety rating system to be an interesting idea that is worth an in-depth study, but in our present state of knowledge, it is premature to rate anything but technologically new protection systems.

We shall now illustrate the abovementioned difficulties of basic principles by analyzing the aspects of the rating system in force in the United States, which seems to us to be the most unreliable.

PRELIMINARY REMARKS ON A PASSIVE SAFETY RATING SYSTEM

The comments hereafter apply essentially to the relevance of the rating method proposed in the draft of Part 583 "CRASHWORTHINESS RATING" (Docket No. 79-17, Notice 1, F.R. of 22 January 1981, page 7025) and to the consequences that would result from its implementation.

In its draft of Part 583, the NHTSA proposes a test method for the assessment of vehicle passive safety performance. Unfortunately, it answers either badly or not at all those questions that are prerequisite to the running of such a program.

In our view, these questions are the following:

Are the technical data taken into consideration the best that can be presently chosen? Do the criteria adopted form a coherent whole that correlates as far as possible with reality?

It might be worth listing other points which involve, in particular, the potential interest of consumers for such a program, and also the legal aspects of the proposal as it is known at the present time.

ANALYSIS OF THE BASES OF THE PROPOSED PROGRAM

The action envisaged in the draft of Part 583 applies essentially to the measurement of humanoid dummy injury criteria during front-end crash tests at 35 mph. Other estimates have been produced concerning windscreen retention, non-intrusion into the windscreen and also fuel leaks during front-end and rear-end crashes. These, however, only constitute an auxiliary program. The importance given by the NHSTA to the results of injury criteria measurements carried out during the NCAP clearly shows that this Administration considers this to be a primordial point.

The remarks hereafter will therefore be essentially directed towards this type of test.

The Dummy

Considering that all dummies are identical and have the same dynamic response and that all data processing and collecting devices comply with the same specifications, which was not verified in the range of frequencies met with in 35 km/h crashes, the validity of the general behavior of the complete dummy after each test must be verified; and any situation outside tolerance levels must imperatively cause the validity of the test to be rejected. This is all the more important in that whereas interpretations may be acceptable during isolated certification tests, this is not the case when a comparison is made between two vehicles. It is not mentioned whether such a procedure was adopted during the 35 mph program.

Injury Criteria

a) Head injury criteria (HIC)

The PASS/FAIL distinction indicated by the NHTSA after the NCAP is based mainly on the results obtained for this criterion.

The 1000 value adopted in the United States has been debated in other venues, in particular at the ECE Geneva WP 29—Structure Behaviour Commission. France had proposed a maximum of 1500, determined only during the head's phase of contact with a part of the passenger compartment, with the data collection and information processing methods being perfectly codified. This value was opposed to the 1000 value adopted in other countries, with measurement and information processing devices often being different.

Supposing that HIC correlate with a head lesion severity, the maximum value of 1000 is, as admitted by the NHTSA, a "conservative estimate." It will incidentally be noted that on several occasions, in what is to follow, the NHTSA makes use of the "he who can do more, can do less" principle. Unfortunately, this is a luxury that automobile designers can afford less and less in the present period of expensive energy. The severe efforts made by the manufacturers should be accompanied by a similar effort on the part of the regulators. With Part 583, the NHTSA claims to be preparing for the automobile of the 1985-1995 decade. Having neglected the fine tuning of passive safety assessment criteria and also the taking into

account of criteria other than those initially adopted, it is undertaking an ambitious program with a technology left unupdated since its acquisition in the sixties.

b) The thorax criterion: γ max $\geq$ 60 g during less than 3 ms accumulated

Thorax lesions still constitute an important point that must be taken into account in vehicle passive safety performance assessment. In addition, numerous accidentology surveys have shown that seat belt usage can cause substantial lesions in high-intensity crashes. It is therefore essential that an effective criterion be made available. For want of anything better, the proposed criterion may be adopted without neglecting to associate it with the restraint system used and the other criteria retained.

c) The femur criterion (F $\leq$ 1000 daN (2250 lb))

There is very little to be said in relation to this criterion. It is not outmoded in any of the NCAP program crash cases. Besides, lesion severity to this part of the body is clearly potentially less important than to the thorax and head discussed above.

d) Other criteria

Although the NHTSA analysis covers only the elements (a), (b) and (c) mentioned above, the following question must be asked: Are the head injury, thorax acceleration and femur load criteria adequate to describe the protection of a 50th percentile male occupant in a straight front-end crash at 35 mph?

A quick look into what was published after the first phase of the NCAP unfortunately implies a negative answer: the results initially stated mention the following comments which were not taken up in later presentations.

Vehicle	NHTSA Comment	Consumer Report Comment
Plymouth Horizon	Driver and passenger: PASS	Data imply that passenger submarined
Dodge Magnum	Driver and passenger: PASS	Passenger submarined
Plymouth Volare	Driver: PASS	Driver and passenger submarined

Submarining involving the loading of the soft parts of the abdomen on the one hand and of the spine on the other by the ventral strap of the belt may be the cause of severe lesions.

One of the ways of diminishing the contact loads of the head against the passenger compartment walls or thorax loads is to have anchorage points that cause submarining, the consequences of which are as harmful as those resulting from high HIC. This is what led the WP 29 to introduce the verification of abdominal protection criteria into the overall regulation draft in the case of seat belt restraint and when anchorage points are arranged in the zones provided for in ECE regulation No. 14.

It can only be regretted that the NHTSA, while having noted the existence of such phenomena during the NCAP, has not found it fit.

—either, to make an in-depth analysis of these cases;
—or, and what is worse, to mention them in the published results.

This becomes all the more serious in the present case in that one might be tempted to increase this risk, for occupants, so as to reduce the stroke of the dummy's head during a crash.

e) Remarks

As regards the head criterion, the ISO has adopted, in the DTR 7861 document, the 1500 value for HIC. This value comes out of studies conducted by research teams in the 11 countries taking part in working out the standard and corresponds to an AIS/03, with information having been collected on equipment adhering to the ISO 6487 standard.

The importance of device characteristics has in fact been demonstrated by a NHTSA study carried out in 1980 in the United States, relating to 20 different installations. Some of them did not adhere either to ISO 6487 or to SAE J211, and significant variations were noted in the determination of HIC when the same test was repeated on the 20 installations.

These observations simply draw one's attention to the overall interpretation of the test, before being able to make comparisons using the values taken and published for the consumers' use.

The Vehicle

Can it be stated that a vehicle passing the 35 mph test is, in real accidentology, statistically safer than a vehicle only passing the regulatory 30 mph test?

Without wanting to cast a judgment on this paragraph on the front-end crash procedure, it must however be remarked that the energy to be dissipated increases by 36 percent in the case of the 35 mph test, compared to that dissipated in the 30 mph crash.

If a vehicle has been designed for a 30 mph 90° barrier test, there are good reasons for thinking that the manufacturer has planned for the structure to work at a maximum at this speed in order to reduce decelerations in the passenger compartment—a prerequisite for good protection.

When the front of the vehicle is crushed, it is well known that loads go through successive maxima showing

a cascade breakage of parts. In the case of the 35 mph test, there may be, owing to the high energy level, planned breakage of the protection barrier at 30 mph and straining on the more rigid parts, themselves deformed. The higher impulse given to the dummy may cause it to strike the interior of the passenger compartment at a higher speed, thus producing higher HIC.

For a vehicle of a given mass and designed for a regulatory 30 mph 90° crash test, the increase of the test speed to 35 mph may give results that are entirely unforeseeable.

EFFICACY OF PART 583

Discussion of the Type of Test Adopted by the NHTSA during the NCAP

First of all, the NHTSA has quite logically chosen the front-end crash, which accounts for nearly 50 percent of all occupants killed in the United States. Unfortunately, the second selection (within the numerous configurations of front-to-front collisions), i.e., the choice of the 90° front-end test against a flat rigid barrier, seems to have been dictated by a much less rigorous and logical approach than the first one.

The NHTSA has seemingly directed itself towards a test where the results would highlight the noticeable differences between vehicles, rather than towards a test having greater correspondence with the reality of road accidents.

This seeking a difference at all costs has resulted in the choice of the 90° crash against a fixed rigid barrier, even if it is recognized that this type of test is unrealistic.

Besides, the NHTSA has carried out tests against a 30° angled wall, much more representative of reality and adopted in the ECE Geneva draft, and has noted that the difference between current vehicles was much less since for the whole group of vehicles the criteria were satisfied at a speed of 35 mph.

Seat Belt Usage

Results during the NCAP were obtained on belted dummies. The potential efficacy of a modification of vehicles in accordance with the requirements of Part 583 could therefore only affect belted occupants. At present, according to the NHTSA, this percentage is 14 percent in the United States.

Unfortunately, no quantitive estimate has been supplied concerning the real increase in the use of restraint systems as a result of their automation. The study of some documents allows us to obtain merely the following trends.

Although the belt usage rate is in the order of 14 percent for all vehicles, it has been observed that 34 percent is the figure for the VW Rabbit equipped with manual belts. By contrast, VW Rabbits equipped with automatic belts had a 77 percent usage rate, i.e., a multiplication factor of 2.3 percent exists between the usage rates of the two types of belt.

Without giving excessive importance to the absolute values for usage rates mentioned above, we should note a coefficient of 3 between usage rates with and without automatic belts. It can thus be estimated, in conclusion, that the usage rate would rise from 14 percent at present to 40 percent after automatic belts are introduced (in the whole fleet).

We shall not take into account for the moment those vehicles equipped with air bags, for which little statistical information is available.

Occupants Actually Affected by the Draft of Part 583

In addition, it must be recalled that measurements taken in accordance with requirements of FMVSS 208 were done so in extremely precise conditions. For example:

—50th percentile male dummy
—seat adjustment in the middle of rails, in an accurately defined position (knees, back support, quality of seat belt usage, etc.).

But, at the same time, the MGA report states:

> because large differences in occupant injury criteria values may result from rather small differences in occupant kinematics, it is difficult to attribute differences observed in the test results to fundamental differences in vehicle characteristics.

Real Efficacy of FMVSS 208 Requirements

Finally, in the case of an occupant involved in a pure 90° front-end crash against a fixed obstacle, and wearing a seat belt, with the 50th percentile male in exactly the conditions described by the Standard, an estimate must be made of the real increase in safety afforded by a vehicle classified as PASS according to Part 583. If the probability of real efficacy can be put at 0.10, it should be pointed out that this value can only be retained provided that classification in Part 583 does not induce manufacturers to make the front part of vehicles more rigid, and therefore more aggressive for other cars.

INFLUENCE OF PART 583 ON VEHICLE COST

In this paragraph, it is advisable to separate two types of cost which will affect the cost price of the vehicle. They are:

a) the cost of fitting out vehicles for classification as PASS in Part 583,

b) the cost of final adjustment of vehicles (preliminary prototype tests, tests for supplying information to the NHTSA).

Inadequacy of Structure

The NHTSA utilizes three parameters to account for structural defects of vehicles not fulfilling the FMVSS 208 requirements at 35 mph, i.e.,

—impact duration
—maximum deceleration
—available crush distance (but not in fact achieved during the crash) in the front compartment of the vehicle.

From an analysis of the roles of these three factors, it appears that occupant stopping distance (and consequently vehicle crushing, impact duration, etc.) can in no way be the only cause of differences observed between vehicles from the protection criteria viewpoint.

No action is therefore to be taken in this field in order to make vehicles comply with Part 583. There is thus no need to discuss the costs as the NHTSA did. May we incidentally remark that reference to structural defects has totally disappeared from the NPRM, which now only mentions the role of steering columns and restraint systems.

Steering Columns

Work undertaken on this point shows that the steering column is an important component in the retention of the driver upon impact. By its energy dissipation characteristics (for the thorax and the head) and its movement relative to the passenger compartment during vehicle front part deformation, the steering column produces varying degrees of performance for the contact of the driver's head and thorax. These contacts occur quite systematically, as is indeed mentioned by the NHTSA, which puts steering column modification cost at about $15. Unfortunately, no justification was supplied concerning the methods used to estimate this sum. It would have been desirable for the NHTSA to carry out, on some of the vehicles considered poor from this point of view, attempts at modification which could have been examined to supply a solid basis for estimation. Bringing the steering column into question is up to the manufacturer. This can indeed range from a simple part-for-part change to complete architectural modification with sheet-metal parts being affected and consequent high investments.

Restraint Systems

In our view, the dispersion of NCAP results cannot be accounted for by seat belt performance variations, and none of the other solutions relating to restraint systems, as proposed by the NHTSA, is at present applicable.

COST ESTIMATES OF VEHICLE FINAL ADJUSTMENT

We feel sure that seeking a Part 583 PASS classification in addition to compliance with FMVSS 208 will lead to at least a doubling of tests, both at the study stage and the development and certification stages. Those who have undertaken vehicle final adjustment work with a view to coming up to dummy injury criteria, during as complex a phenomenon as a front-end crash, have discovered that obtaining the result at a given speed necessitates a great number of tests and in no way guarantees success at another albeit lower speed.

Furthermore, in order to allow for par. 583.7 as proposed, the manufacturer would be induced to make additional tests at speeds greater than 35 mph, which would increase his costs.

Let us remember, finally, that compliance with injury criteria for a determined crash speed is a phenomenon extremely "sensitive" to details which differentiate the variants of the same model: 2 or 4 doors, type of engine, options and diverse equipment. Even a difference in the nature of the seat upholstery material has a not inconsiderable influence on dummy behavior, resulting in significant variations in protection criteria values.

CONCLUSION

Section 201 of the 1972 Motor Vehicle Information and Cost Savings Act commissioned the NHTSA to establish a "Crashworthiness rating system."

In a self-certification system, verification of occupant protection performance actually obtained, by using vehicles really being produced, was certainly a desirable step, and all the more so in that there was wide variation in vehicle performance and that the only criteria referred to structural performance.

The diversity of vehicles on the road at that time was likely to give rise to problems of compatibility, for some manufacturers went no further than the regulatory requirements.

The 208 Standard is a regulatory objective that permits considerable improvement in vehicle occupant protection, even if the adopted criteria and their values give rise to some opposition. In view of this, it would seem inconceivable, to say the least, that the Administration should implement a program of comparison going well beyond the regulatory objective and that it should use the results for consumer information in which it concludes that the initial regulatory objectives are inadequate.

The logical solution would have been to increase the 208 Standard regulatory test speed to 35 mph and to carry out the program on vehicles rated by manufacturers as fulfilling the requirements at this speed.

The shortcomings of the draft of Part 583 seem to us

to show that the cost-benefit ratio of this project is notoriously inadequate. The following quotation from "Car Book" is even truer than it appears: "There is no guarantee that a car that passed the test will adequately protect you in an accident."

However, should a government contemplate drawing up rules for the administrative evaluation of safety quality afforded by different models of cars, we should suggest that the following advice be taken into consideration:

—Insist on the fact that accident factors related to driver and environment behaviour largely predominate over those resulting from vehicle design, and even over those resulting from upkeep.
—Take all necessary precautions so that rating rules, necessarily simplified to give easily repeatable results, nevertheless remain in strict correlation with observations made during real accident studies; in order to do so, it is indispensable to conduct an in-depth study of the latter.
—Use the same assessment criteria as those forming a basis for regulation, while also adding other criteria. Care should be taken so that administrative rating does not produce fragmentary information about vehicles which might mislead the public.
—Give each criterion a quantified evaluation of vehicle performance, rather than a simple PASS/FAIL as decided by an arbitrarily fixed threshold.

APPENDIX 1

VALIDITY OF HIC

a) FMVSS 208 states in paragraph S 6.2:

"The resultant of acceleration at the center of gravity of the head must be such that the expression:

$$\left(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a\,dt\right)^{2.5}(t_2 - t_1)$$ does not exceed 1000, where (a) is

the resultant acceleration expressed as a multiple of g (gravity acceleration), t_1 and t_2 are two points of the value during impact."

b) FMVSS 208 requires HIC to be computed only during head impact duration, the formula remaining the same and the 1000 value being the maximum permitted.

1. (a) being always a multiple of g,
t_1 and t_2 being:
1.1 any 2 points in time during impact, or
1.2 any 2 points in time of any interval when the head is in permanent contact with a part of the vehicle other than the seat belt system when the humanoid dummy is restrained by a seat belt system.

c) In addition, the draft regulation for "uniform requirements relating to certification of occupant protection in private cars in the event of front-end collision" proposed at the ECE GENEVA (TRANS/SC1/WP 29/CRCS/R 23) specifies in its appendix 4, "BIOMECHANICAL PERFORMANCE CRITERIA":

"1. : HEAD

1.1 The criterion shall be considered as satisfied when, during the test, there is no contact of the head with any element of the vehicle.
1.2 In other cases, the resultant acceleration expressed in g and measured at the centre of gravity of the head, must be such that the expression:

$$(t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} dt\right]^{2.5}$$

does not exceed 1500 for any instants t_1 and t_2 chosen *during the duration of contact of the head with an element of the vehicle.*"

APPENDIX 2

THORAX CRITERION

There is little justification, at present, for the validity of the 60 g/3 ms criterion. It may however be noted that applying such a limit to all of the following:

1) to a passenger restrained only by his belt;
2) to a driver restrained by his belt and by contact, at stroke end, with the steering wheel;
3) to occupants restrained by air bags;

causes us to query the representativeness of the said criterion, *the loading modes and contact surfaces being extremely different in these various cases.*

It would appear that thorax deflection measurement might be more appropriate, but existing dummies do not permit this kind of investigation.

Load or pressure measurement, together with deflection measurement, seems then to be the criterion that correlates the best with biomechanics and the most common serious injury types, resulting in particular, as is the case in Europe, from restraint by means of safety belts.

However, there being no possibility of carrying out appropriate measurements, the proposed criterion would appear to be a first step and can roughly represent risks

to occupants in front-end accidents, when connected with HIC and abdominal criteria.

APPENDIX 3

CORRELATION OF TEST PROCEDURE WITH REALITY

(1) In the study report under contract with the NHTSA, FRIEDMAN states:

"Since it is clear from the FARS data results that notable differences in fatality rates exist across make model groups, *while the analysis which controls for crash severity (ΔV) shows little or no differences*, it is necessary to seek an explanation of these apparently conflicting results."

Thus, at a given ΔV, statistical analysis does not show any significant differences between vehicles. Now, the procedure followed by the NHTSA, during the NCAP, involves a crash against a fixed rigid obstacle, at a given impact speed (35 mph). *Because of this, the vehicle's ΔV is fixed.* If, as is mentioned by the NHTSA, "The tests indicated a wide range of performance among automobiles", and this is in contradiction with reality, it cannot be concluded that there is total irrelevance of the said tests.

Clearly, moreover, the differences between vehicles mentioned above by FRIEDMAN are basically caused by the differences in mass of the vehicles considered. Nobody, unfortunately, is in a position to alter the laws of mechanics that account for this phenomenon of incompatibility.

(2) Let us take note of CARLSON's statement concerning statistical analysis:

"The pilot analysis using MDAI data indicated that many of the differences between vehicle sub-groups within size class were not statistically significant."

(3) It is also interesting to examine the overall results, by class of vehicle size, of the NCAP:

CATEGORY	% of bad vehicles/vehicles tested
SUB COMPACT	84%
COMPACT	50%
INTERMEDIATE	78%
LARGE	57%

It will be noted that the percentages resulting from the tests are totally erratic and in no way show a tendency towards less safety depending on the class of vehicles in crashes against fixed obstacles. Mr. CLAYBROOK's declaration—

"But our tests also show that small cars are less safe themselves even in single vehicle collisions and in collisions between small cars."—

does not seem to be borne out by the results of the tests.

APPENDIX 4

EXTENSION OF 90° FIXED BARRIER COLLISION RESULTS TO OTHER TYPES OF CRASH

In a distributed front-end crash, is it possible to compare effectively a crash against a fixed rigid obstacle to a collision against other partners? In particular, can we assume that head-on front-end crashes between two vehicles are correctly represented by the FMVSS 208 90° front-end crash?

The whole information at our disposal shows that such a generalization of car-barrier results to include car-car collisions is very frequently false. This has been demonstrated in many documents published since 1972.

By likening a 90° fixed rigid barrier crash to a car-car crash, the NHTSA is overlooking architectural and, especially, stiffness incompatibilities. Noting the following points should be enough to be convinced about this:

"A comparison of the FIAT STRADA (passed) and the HONDA CIVIC (failed) illustrates the differences in the two structures. The Strada's (impact) duration was 150 milliseconds while the Civic's (impact) deviation was only 95 milliseconds. The Strada maximum deceleration was 26 g's and the Civic deceleration was 42 g's."

Structural stiffnesses are clearly greater for the Civic than for the Strada. A front-end crash at 70 mph between these two vehicles might result in greater structural deformation of the Strada, producing dummy results that are the exact reverse of those observed during barrier tests.

Confronted by this information, it may be concluded as follows: The front-end crash against a 90° fixed rigid barrier can only represent real collisions of the same type against a rigid obstacle. *In particular, this test can in no way be representative of car-car collisions, even if the cars are to be found in the same class of mass.*

APPENDIX 5

ANALYSIS OF "STRUCTURAL INSUFFICIENCIES" PARAMETERS

The NHTSA uses three parameters:

—impact duration

—maximum deceleration
—available crush distance

These three parameters are not entirely independent. When ΔV is fixed (35 mph to 39 mph in the NCAP cases), it is enough to give any one of the three parameters listed below for all the crash circumstances to be determined:

—impact duration
—average deceleration
—dynamic crushing

In all events, let us study the factors brought up by the NHTSA.

(1) Impact Duration

First of all, clearly at a given ΔV, the longer the crash, the less the severity for the occupant. With this theoretical point established once and for all, the second question to be answered is the following:

Does this factor vary *sufficiently*, in all crashes carried out by the NCAP, to *really influence* the results of the crash?

We estimate that, according to the experiments in our possession, the differences recorded by the NHTSA (in the order of 10 percent on average and of 35 percent between the Civic and the Strada) in no way make it possible to justify the variations observed in injury criteria.

The NHTSA itself observes this, since it states: "It should be noted that impact duration (and maximum deceleration) do not completely describe the safety performance of a vehicle. For example the values for the TOYOTA TERCEL and PLYMOUTH CHAMP indicate a very favorable environment for the occupants but the dummy readings indicate a rather "severe crash".

The NHTSA presents these exceptions as proving the rule. We think that, on the contrary, they disprove it. Considering our examination of the NCAP results, our proposal is more inclined to be the following.

Although the increase of impact duration may be a favorable circumstance for the protection of vehicle occupants, values obtained during the NCAP entitle us to think that increases realistically contemplated for a vehicle are not a decisive means of fulfilling the FMVSS requirements at 35 mph.

(2) Maximum Deceleration Recorded During A Crash

In this case, the parameter used by the NHTSA cannot be correlated with dummy readings, because of the following points:

—The vehicle restraint system-occupant group is far too often involved for a peak deceleration not to be filtered by the chain described. In other words, a maximum deceleration on a vehicle, which might be the result of a brief impulse (the NHTSA does not in any case state how it measures the said maximum deceleration), will not be noticed in the results recorded for the occupant.
—What has just been mentioned is even truer when it is realised that such a peak deceleration can be recorded early on in the progress of the crash, at a moment when the occupant is still in "free flight" as compared with his vehicle (cf. for example the Chevrolet Citation, the VW Rabbit or the Ford Fiesta).

(3) Available Crush Distance

This parameter does not seem to be a good working tool for the prediction of a vehicle's potential in FMVSS 208 matters. In fact, although a good number of vehicles considered as PASS are to be found above the average of 25.2 in., others, such as the Strada, are to be found below it. By contrast, vehicles such as the Fiesta, the Datsun 310, the Audi 4000 and the Datsun 200 SR, considered as FAIL are to be found above this average. This classification criterion is, in our view, totally artificial (the NHTSA, in addition, does not precisely indicate how it evaluates it) since it is not related in fact to dynamic crushing (only important value) actually measured during the crash.

In all events, if Standard 208 is used to determine a vehicle's capacity to protect its occupants by means of protection criteria, it is unnecessary to add structural performance considerations which have no correlation with these criteria.

This is a very dangerous approach which might freeze vehicle construction by conserving structures giving the best mechanical results during crashes against 90° fixed barriers, whereas it would be desirable to develop them to obtain better compatibility for vehicles compared to one another and from which the only progress for occupants will result.

Technical Session No. 6

Accident Avoidance and Driver/Vehicle Interaction

Mr. Franco Roberto Rossi, Chairman, Italy

Recent Trends in Handling, Stability and Braking Performance of Japanese Passenger Cars

AKIRA AOKI
TOMO-O NISHIMI
Japan Automobile Research Institute, Inc.

ABSTRACT

This paper reviews the recent trends in handling, stability and braking performance of Japanese passenger cars sold on market in the last ten years based on the running tests conducted on about ninety models.

Steady state cornering, pulse and step steering, frequency response, braking effectiveness, etc. were tested. It is shown that models with slighter understeer, and smaller steering effort have been increasing in number during the last ten years. Their roll angle and brake pedal force are also getting smaller.

INTRODUCTION

The evaluation of handling, stability and braking performance in development of vehicles consists of that of marketability and that of safety. The former relates to the "user's choice" on the handling, stability and braking performance, and the latter relates to the accident avoidance capability. In evaluating these aspects of vehicles, it often becomes necessary to grasp relations between the vehicle specifications (design parameters) and drivers' subjective evaluations and control performance. The driver-vehicle system, however, constitutes a complicated closed system, and it is difficult to combine them directly. Thus, it is usual to examine vehicle responses (response parameters) of open-loop system to associate them with design parameters with the use of mathematical models, etc. (1)

Examinations of correlations between the response parameters and drivers' various subjective evaluations and control performance will lead, indirectly though, to grasping the relations between the evaluation of handling, stability and braking performance and design parameters.

On the other hand, objectives of designs of individual vehicles must be reflected in response parameters used for evaluation, and it is of interest to investigate the values, distributions, and recent trends of response parameters of currently mass-produced vehicles.

This report determines various response parameters, their distributions and their recent trends through running tests to clarify the handling, stability and braking performance of Japanese passenger cars sold on market in the last 10 years.

TEST METHODS

About 90 models of Japanese passenger cars marketed during the past 10 years starting in 1972 were used as test vehicles. The series of tests on each car was conducted within one to two months from the first day of its marketing.

The tests conducted on cars related to the handling, stability and braking performance of open-loop system, and the basic testing conditions included that the vehicle runs on a flat and dry road at a constant speed.

Test items included the steady state cornering test, pulse steering input test, step steering input test, frequency response test, brake effectiveness test, etc., and these test items are listed in Tables 1 and 2.

Measuring parameters of the handling and stability tests were steering wheel angle (δ_{sw}), steering wheel torque (τ), yawing angular velocity (r), roll angle (ϕ), lateral acceleration ($\ddot{Y}$), and vehicle velocity (V). Note that the

Table 1. Main items of road test concerning handling and stability.

Items	Main purpose	Test procedures	Measuring parameters
1. Steady state cornering test	Understeer/Oversteer Steering effort Vehicle roll	Steady state turning R=30 m 1 m/s^2 < $\ddot{Y}$ < 8 m/s^2	δ_{SW}, τ, r ϕ, $\ddot{Y}$, V
2. Frequency response test	Steering effort	Oscillatory steering f=0.33 Hz V=50, 100 km/h δ_{SW}=15° ∿ max	δ_{SW}, τ, r $\ddot{Y}$, V
3. Pulse steering input test	Transient response	Pulse steering Duration: 0.3 ∿ 0.4s V=50, 100 km/h $\ddot{Y}$ peak = 2 ∿ 3 m/s^2	δ_{SW}, τ, r ϕ, $\ddot{Y}$, V
4. Step steering input test	Transient response Understeer/Oversteer	Ramp-step steering V=40, 50, 60, ..., 120 km/h $\ddot{Y}_{ss}$=2 ∿ 3 m/s^2	δ_{SW}, τ, r ϕ, $\ddot{Y}$, V
5. Random steering input test	Transient response	Random steering V=100 km/h $\ddot{Y}$ < 3 m/s^2	δ_{SW}, τ, r ϕ, $\ddot{Y}$, V
6. Returnability test	Steering returnability	Releasing steering wheel in steady state turning V=40, 80 km/h $\ddot{Y}_0$=3.92 m/s^2	r, $\ddot{Y}$, V

Table 2. Main items of road test concerning braking performance.

Items	Main purpose	Test procedures	Measuring parameters
1. Effectiveness test	Brake effectiveness	V_0=50, 100 km/h $\ddot{X}$=2 ∿ 8 m/s^2 Normal operational system Booster failure	$\ddot{X}$, F_B, V θ_i
2. Fade and recovery test	Effectiveness in repeating braking	Fade: V_0=100 km/h 10 times Recovery: V_0=50 km/h 12 times	$\ddot{X}$, F_B, V θ_i
3. Water recovery test	Effectiveness in wet brake condition	Braking after entering in water course of 0.15 m deep V_0=50 km/h 15 times	$\ddot{X}$, F_B, V θ_i
4. Spike stop test	Stopping distance in locking of wheels	V_0=50, 100 km/h	$\ddot{X}$, X, F_B V, θ_i
5. Parking brake test	Operational force of parking brake on a slope	30% slope uphill downhill	F_P

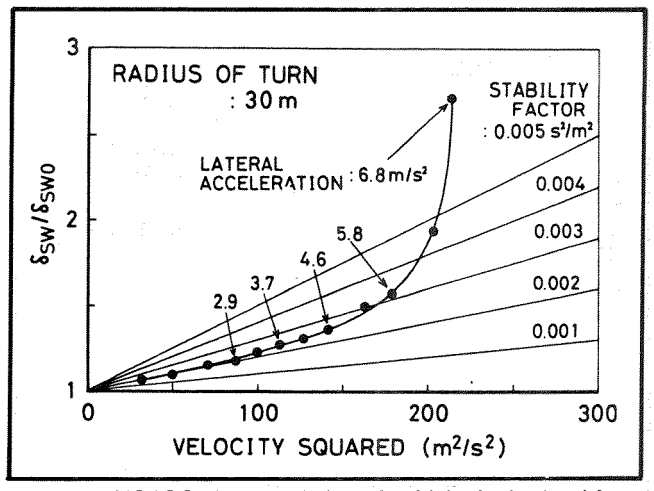


Figure 1. US/OS characteristics of vehicle A obtained from steady state cornering test.

lateral acceleration here does not include that which comes from rolling of vehicle body near the center of gravity.

These parameters were measured using the measuring equipment of steering wheel angle and torque of substeering wheel type, rate gyroscope, free gyroscope, accelerometer (on stable platform) and fifth wheel.

The measuring parameters of the brake performance test were the brake pedal force (F_B), deceleration ($\ddot{X}$), stopping distance (X), vehicle forward velocity (V), and brake temperature of each wheel (θ_i).

These parameters were measured using the pedal force gage, accelerometer, fifth wheel, and thermocouples. The vehicle weight was adjusted in testing to the gross vehicle weight of each car. The high speed circuit and the steering & handling test ground of JARI (Japan Automobile Research Institute, Inc.) were used as testing courses.

TEST RESULTS AND SOME DISCUSSION

Steering Responses. Lateral motion of vehicle is controlled through the steering wheel angle and the steering wheel torque. The responses in the yawing angular velocity to the steering wheel angle are called the yaw responses, and the yaw responses consists of the steady state response and transient response.

The steady state yaw response corresponds to the so-called understeer/oversteer (US/OS) characteristics. That is, the steady state yaw response is represented by the ratio of turning radii (in steady state turning at fixed steering wheel angle) or the ratio of steering wheel angles (in steady state turning at fixed radius) between very low speed driving assuming that the vehicle conforms to the Acherman geometry and driving at a certain speed. An example of the result of US/OS test for steady state turning at low to intermediate velocities is shown in Figure 1. In this figure, theoretical values are also presented in linear lines for different stability factors (K) which represent the US.

The stability factor is defined by the expressions given below through linear analysis, and the vehicle is US, OS, or NS (neutral steer) depending on whether K is positive, negative, or zero, respectively.

$$\frac{\delta_{sw}}{\delta_{swo}} = \frac{\delta_{sw}}{(r\ell\eta/V)} = 1 + kV^2 \text{ or } \frac{r\ell}{(\delta_{sw}/\eta)} = \frac{V}{1 + kV^2}$$

where δ_{swo} is the steering wheel angle in turning at very low speed, ℓ is the wheelbase, η is the overall steering ratio, and V is the vehicle forward velocity.

In the example of Figure 1, the change in US becomes greater at lateral accelerations ($\ddot{Y}$) exceeding 3 m/s^2. It should be noted, however, that the profile of change in US (or the value of K) with respect to the lateral acceleration changes considerably from model to model.

Figure 2 shows a result of US/OS values obtained by the step steering input test extending to high velocity regions.

The step steering angle input used in the test was adjusted to achieve steady lateral acceleration of 2 to 3 m/s^2 in order to see the US/OS in the range where linearity in lateral motion is maintained. Theoretical values for different values of K are also presented in solid lines in Figure 2. The figure indicates that the vehicle has a US characteristic of about $K = 2 \times 10^{-3}$ s^2/m^2 and it is consistent with the steady steering characteristic for $\ddot{Y} < 3$ m/s^2 of Figure 1.

The value of K obtained from the steady turning test is not necessarily consistent with that obtained from the step steering input test for different velocities and radii of turning even in the range of $\ddot{Y} < 3$ m/s^2 due to nonlinearity in the steering system, etc.

Figure 3 shows relations between the stability factor and the lateral acceleration for vehicles with different US/OS characteristics. The figure indicates that the range of

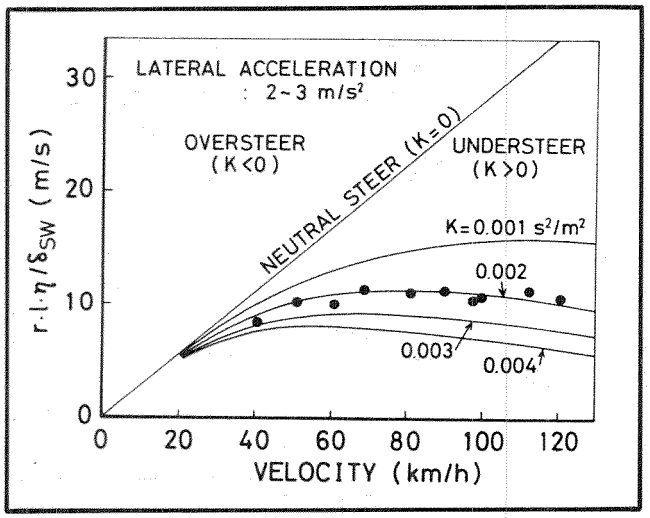


Figure 2. US/OS characteristics of vehicle A obtained from step steering input test.

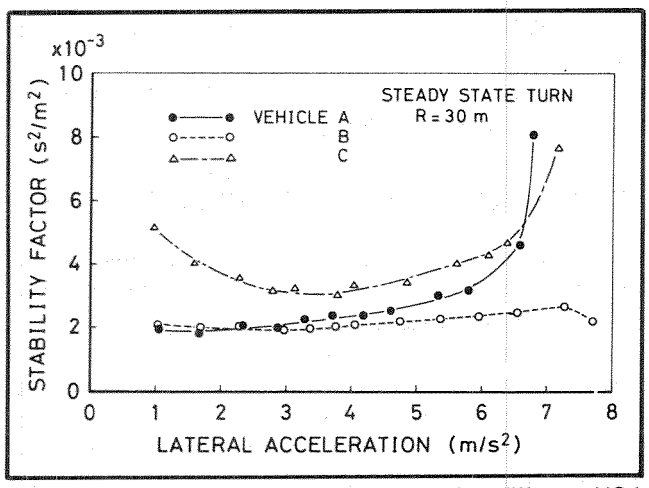


Figure 3. Comparison of the vehicles having different US/OS characteristics.

linear region in the lateral acceleration depends much on models.

Figure 4 shows two histograms which indicate relations between the occurrence of vehicles and the stability factor obtained from the steady turning test at $\dot{Y} = 2.94$ m/s².

One of the histograms is for vehicles which appeared on market in the last 3 years, and the other is for those which appeared on market in the last 10 years.

The mean values and standard deviations of the stability factor for these cases are $K = 2.58 \pm 0.86 \times 10^{-3}$ S²/m² for the last 3 years (n = 34) and $K = 3.19 \pm 1.01 \times 10^{-3}$ S²/m² for the last 10 years (n = 89).

It can be said from these values that vehicles with smaller stability factor are increasing in recent years.

Figure 5 shows the range of the stability factor dividing vehicles into three periods. The figure also indicates that

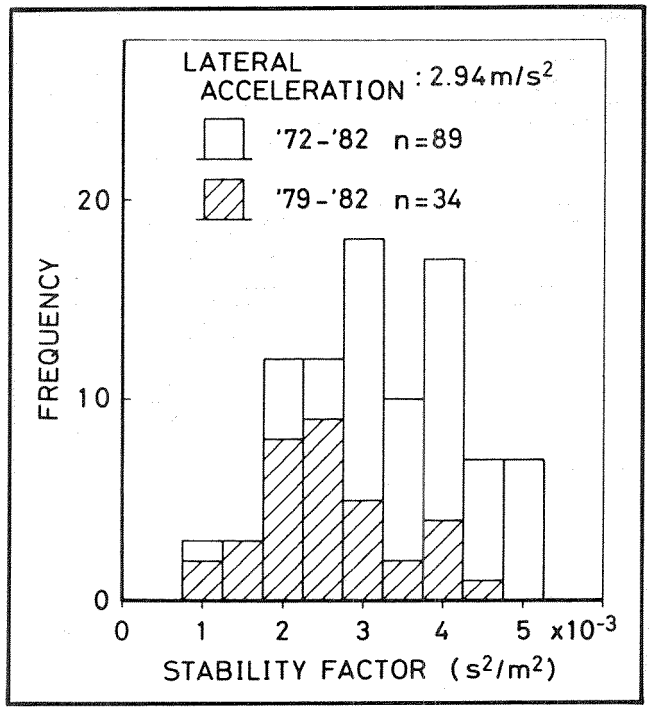


Figure 4. Histogram of stability factor obtained from steady state cornering test.

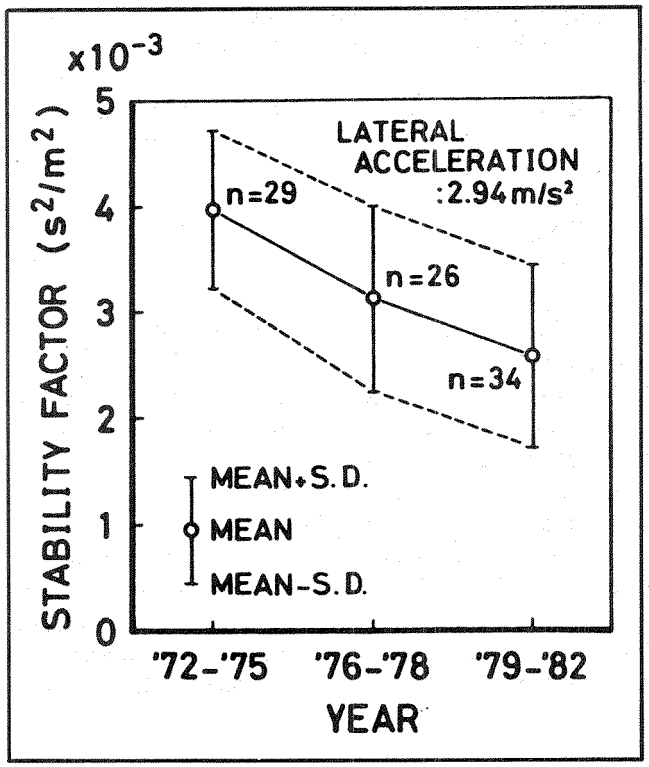


Figure 5. Transition of stability factor obtained from steady state cornering test.

the value of stability factor is steadily decreasing in the last 10 years, and vehicles of lower understeer are increasing.

The transient yaw response can be obtained from observing real time responses of yawing angular velocity (r) upon the steering wheel angle input. What is considered here, however, is the frequency response characteristics of r/δ_{sw} in the linear region ($\ddot{Y} < 3$ m/s^2) of lateral motion.

Figure 6 shows an example of the frequency response characteristics determined from the transient response (pulse and step steering input) test.

Response parameters used are the resonant frequency of yawing (f_c), the index of resonance of yawing (D), and the phase lag at 1 Hz (θ_{f1}).

Figure 7 shows histograms of recent Japanese cars on the three response parameters of transient yaw response described above. The mean values and standard deviations for these response parameters are $f_c = 1.16 \pm 0.14$ Hz, $D = 2.51 \pm 1.24$ dB and $\theta_{f1} = -27.4 \pm 8.2°$.

Steering Effort Properties. Responses of vehicles to the steering wheel torque are discussed below.

Figure 8 shows the relation between the steering effort (T_{ss}, force acted on steering wheel in the tangential direction) and the lateral acceleration in steady turning for test vehicles of the last 3 years.

Figure 9 shows the relation similar to that of Figure 8 in the frequency of steer of 0.33 Hz. The lateral accelerations and the steering efforts used in the figure are averages of peak values observed in their 0.33 Hz waveforms. Note that Figures 8 and 9 include data on vehicles with power steering system. The steering effort in steady turns is somewhat greater on the average than that in the oscillatory steering, but their standard deviations are similar in size.

Figure 10 shows histograms which indicate relations between the number of cars (frequency) and the steering effort in steady turns and oscillatory steering at $\ddot{Y} = 2.94$ m/s^2. The mean values and standard deviations for these histograms are $T_{ss} = 24.0 \pm 7.6$ N and $T_{fr} = 28.1 \pm 7.7$ N for vehicles of the last 3 years (n = 34), and $T_{ss} = 25.7 \pm 7.4$ N and $T_{fr} = 30.8 \pm 8.5$ N for vehicles of the last 10 years (n = 89 and 84), and it can be said that the number of cars with lighter steering effort are increasing recently. One of the causes of this phenomenon is the fact that vehicles with manual steering system which gives heavier steering effort are decreasing while those with power steering system which gives lighter steering effort are increasing.

Figure 11 shows how the steering effort has changed in the last 10 years dividing the period into three periods. In addition to the mean values for all vehicles, averages for vehicles with and without power steering system are also presented in the figure. As seen in the figure, the number of vehicles (n) with power steering system increased greatly in the period of 1979-1982. It should be noted in addition that the steering effort of vehicles with power steering system increased steadily in the last 10 years.

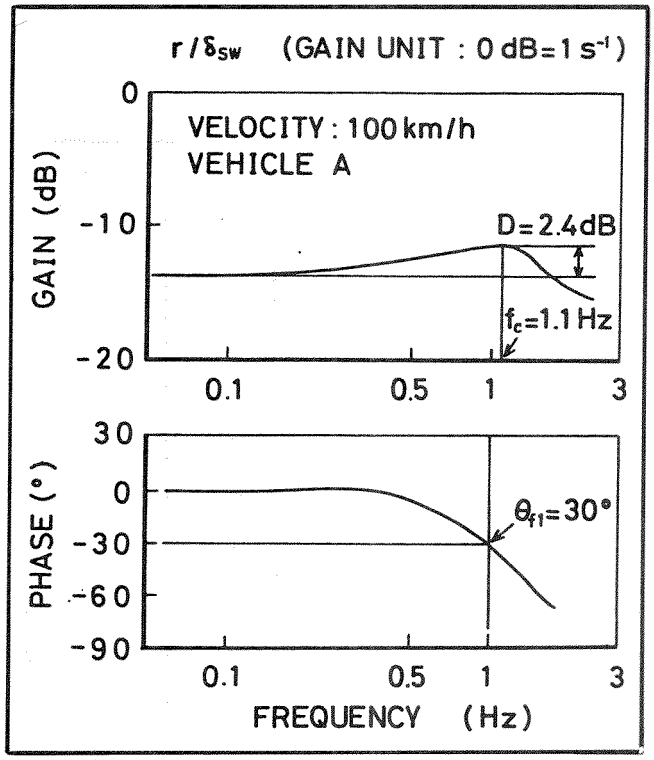


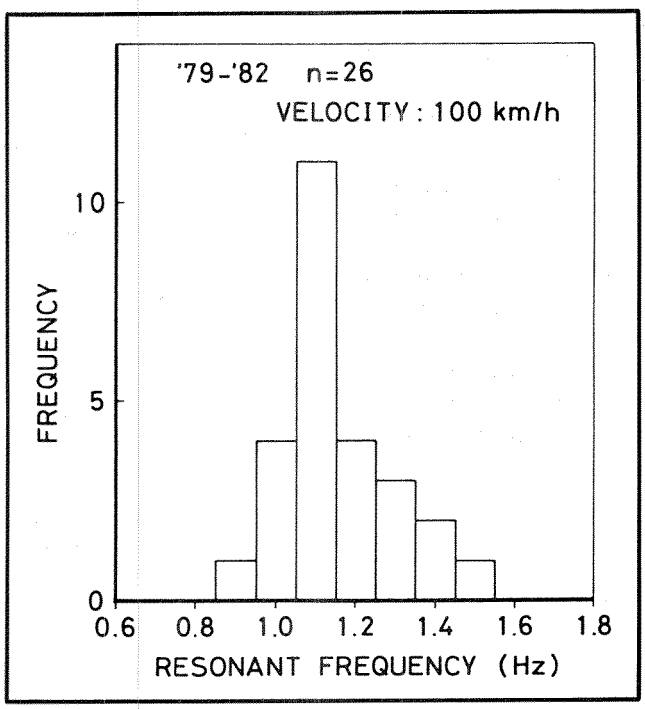
Figure 6. Frequency response characteristics of vehicle A obtained from pulse and step steering input test.

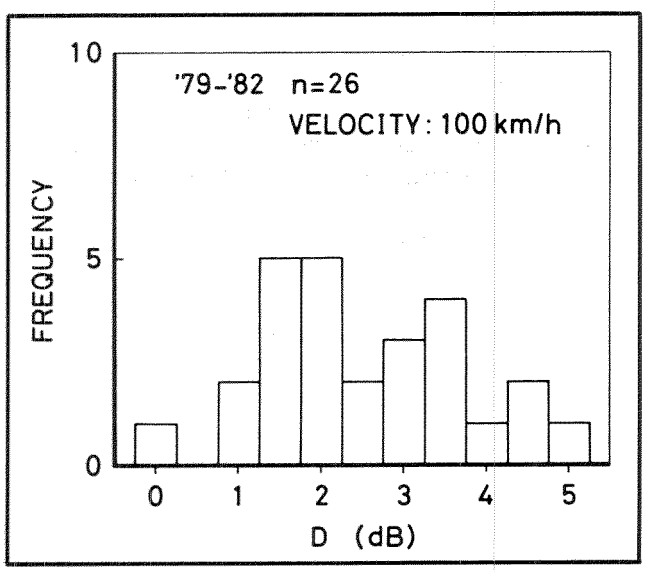
Figure 12 gives graphs similar to those of Figure 11 for the case of oscillatory steering.

Rolling Characteristics. The roll angle (ϕ_G) in steady turns at a lateral acceleration of 4.9 m/s^2 is used as an index for indicating the degree of rolling in steady turns. Figure 13 shows histograms which give the relation between the number of cars and such roll angle. The mean values and standard deviations for the histograms are $\phi_G = 4.05 \pm 0.71°$ for the last 3 years (n = 42) and $\phi_G = 4.24 \pm 0.67°$ for the last 10 years (n = 98), and it can be said that vehicles with smaller roll angle are increasing recently. Figure 14 presents values of ϕ_G dividing into 3 periods. The figure also indicates the trend that the value of ϕ_G is steadily decreasing for the last 10 years.

Braking performance. The longitudinal motion of vehicles is controlled through the accelerator pedal and the brake pedal. The motion of vehicle becomes very complicated when the control of longitudinal motion is combined with that of lateral motion. The braking performance of vehicles in straight motion is mainly discussed in this paragraph.

Figure 15 shows the relation between the brake pedal force and the deceleration for Japanese cars marketed in the last 3 years. Figure 15 shows the braking performance of vehicles with initial velocity of 50 km/h. The trend is





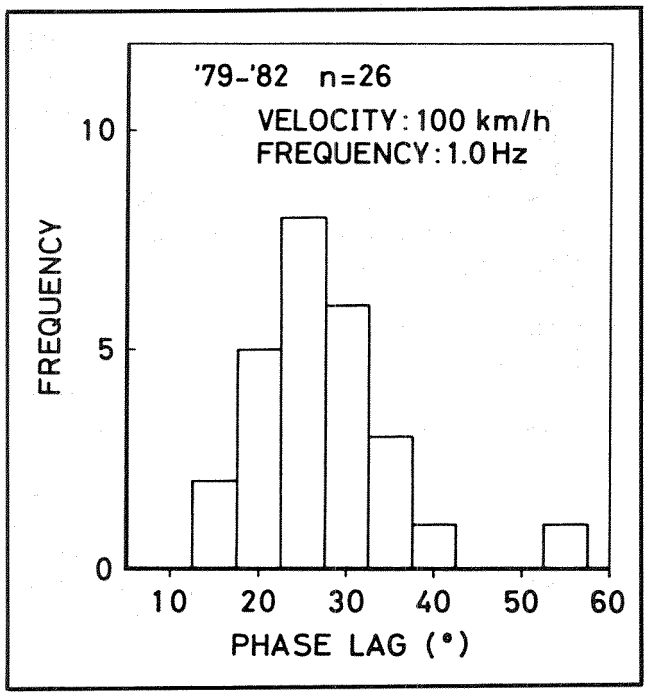


Figure 7. Histogram of transient response obtained from pulse and step steering input test.

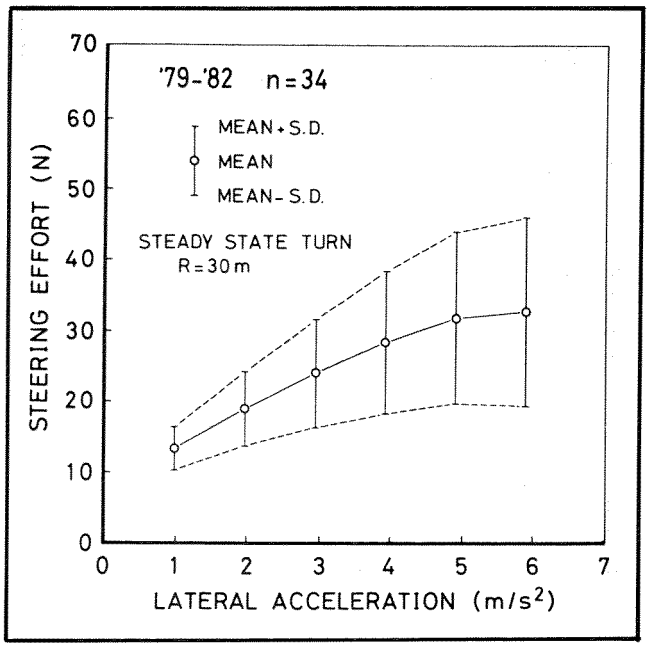


Figure 8. Mean values and standard deviations of steering effort obtained from steady state cornering test.

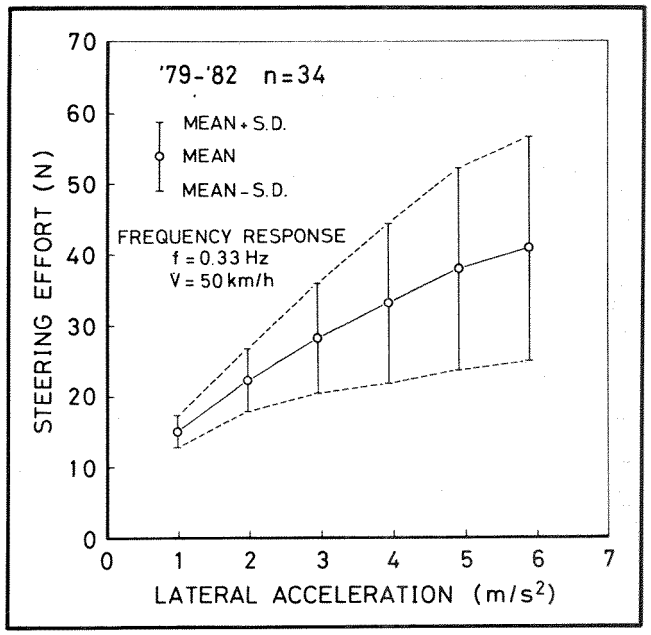


Figure 9. Mean values and standard deviations of steering effort obtained from frequency response test.

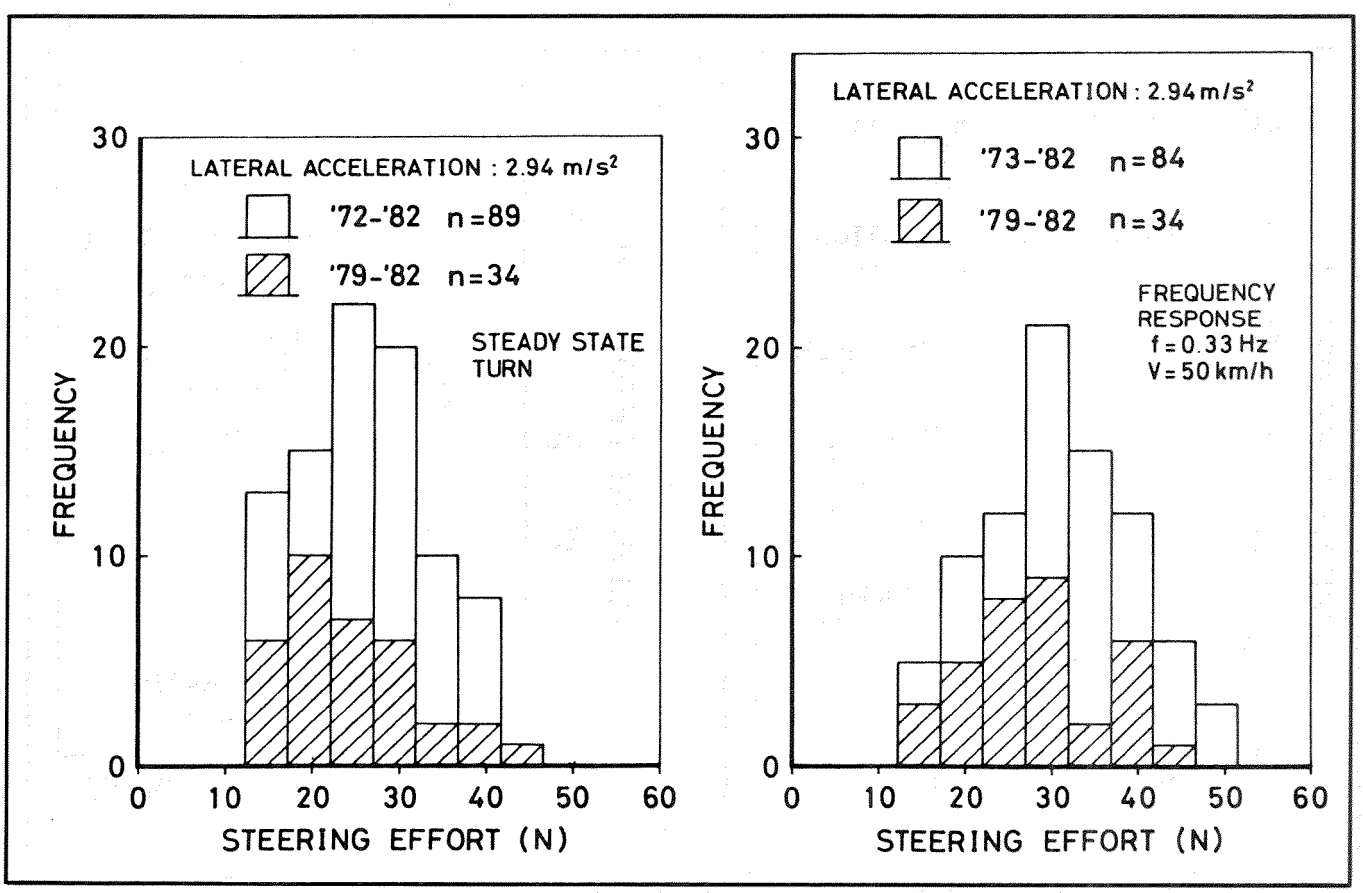


Figure 10. Histogram of steering effort.

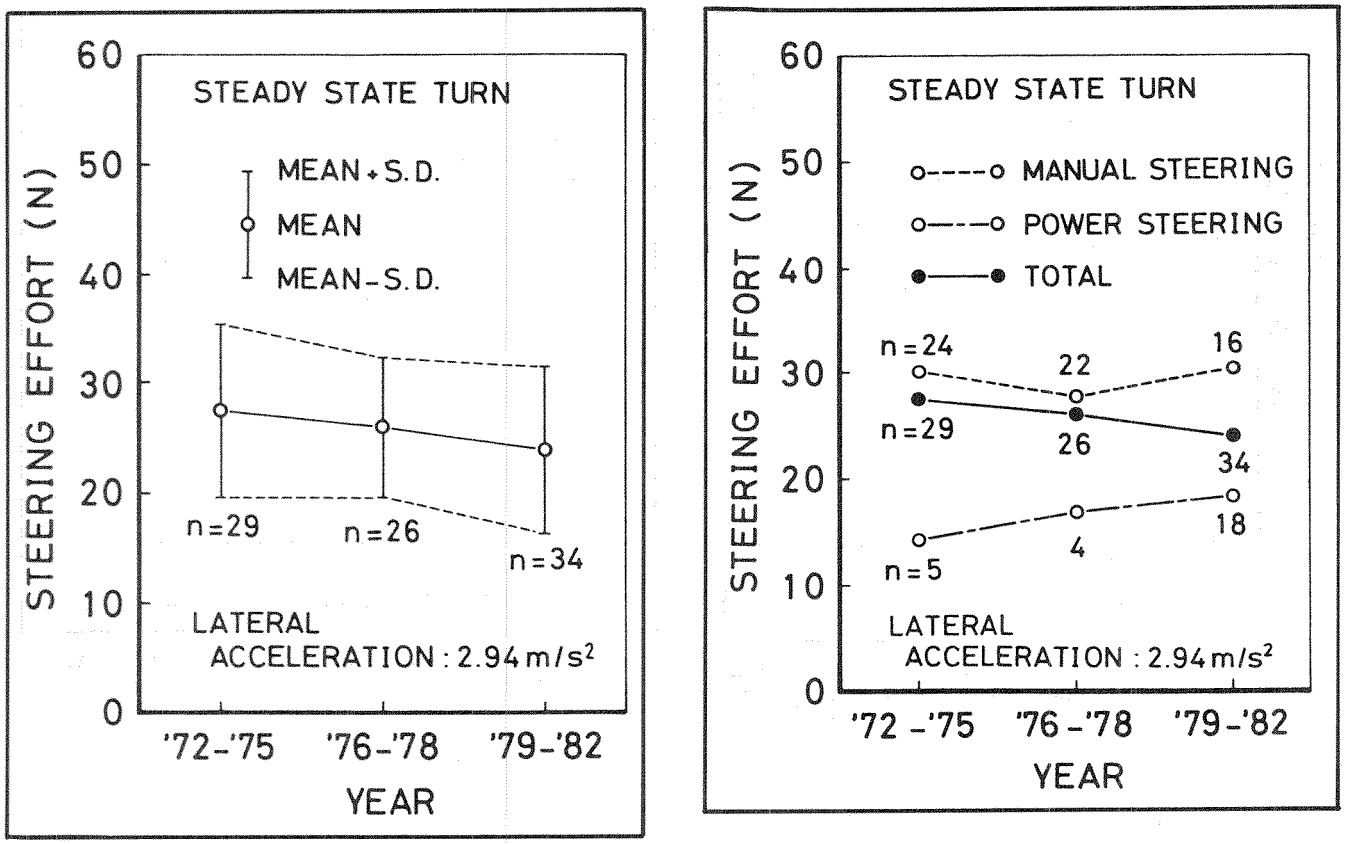


Figure 11. Transition of steering effort obtained from steady state cornering test.

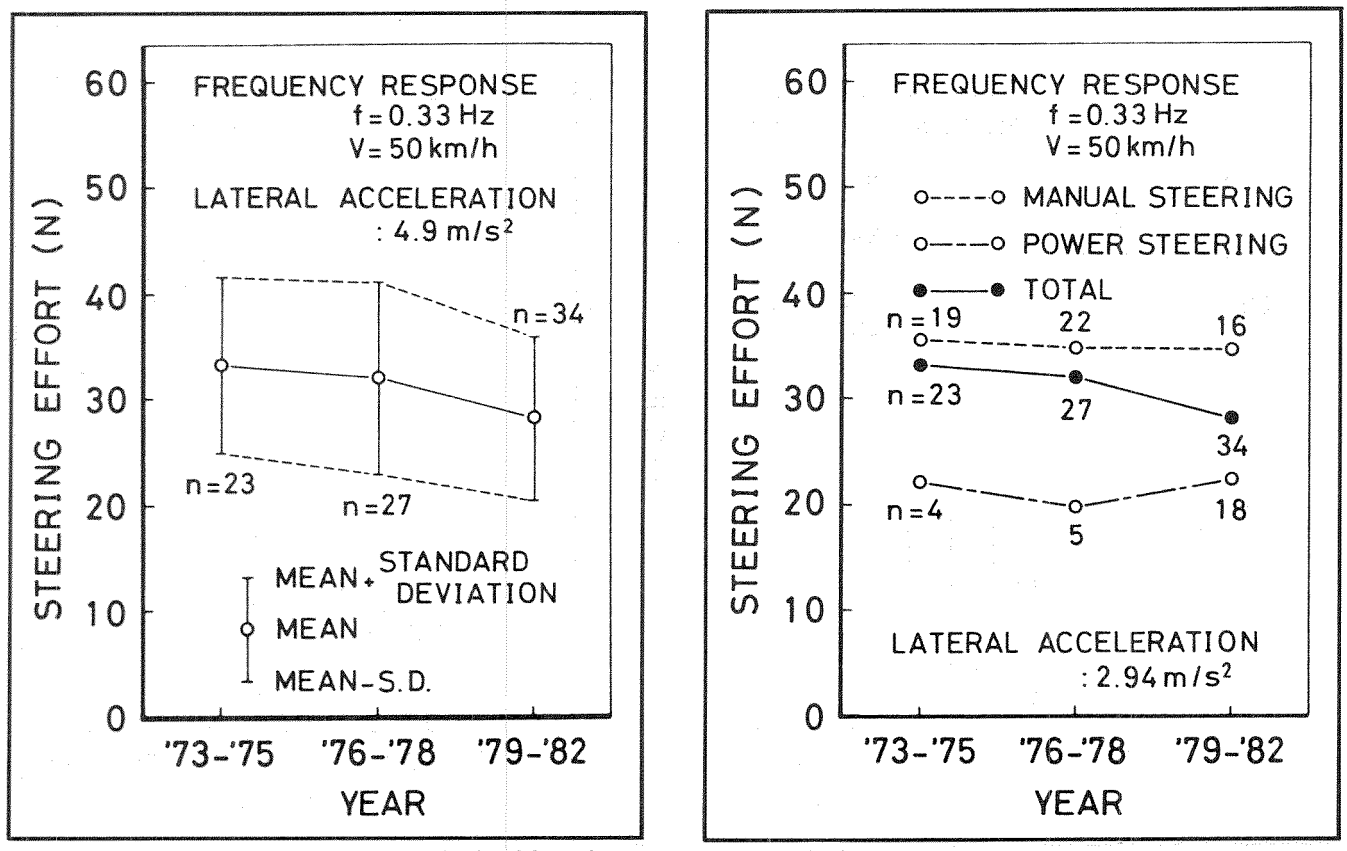


Figure 12. Transition of steering effort obtained from frequency response test.

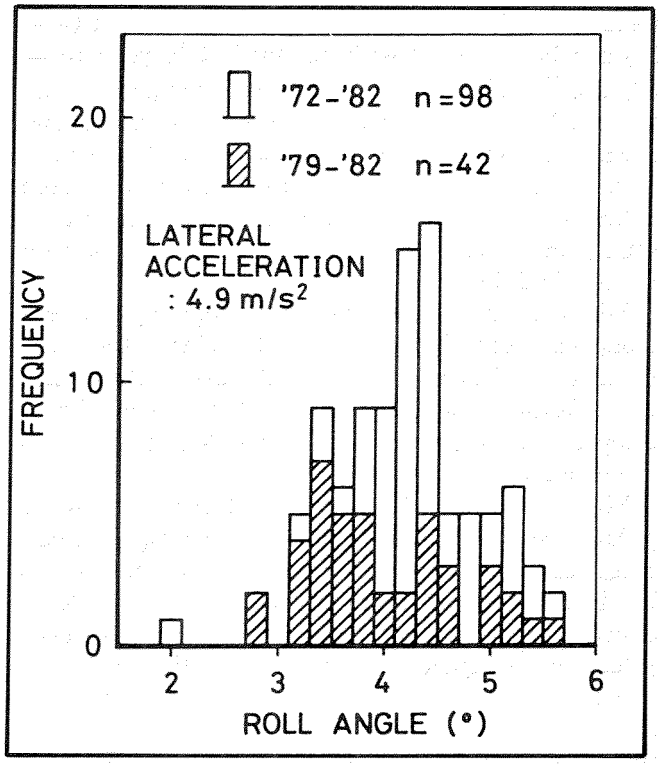


Figure 13. Histogram of vehicle roll obtained from steady state cornering test.

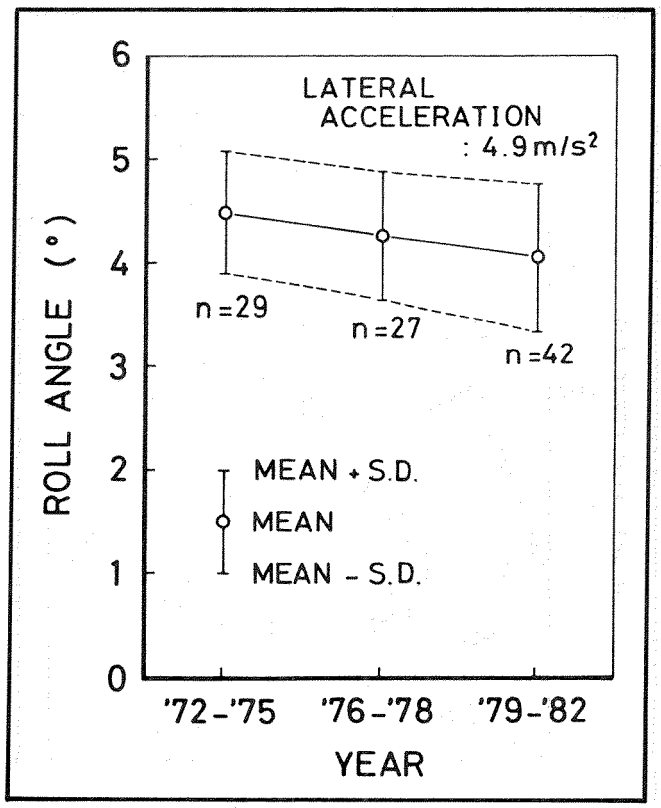


Figure 14. Transition of vehicle roll obtained from steady state cornering test.

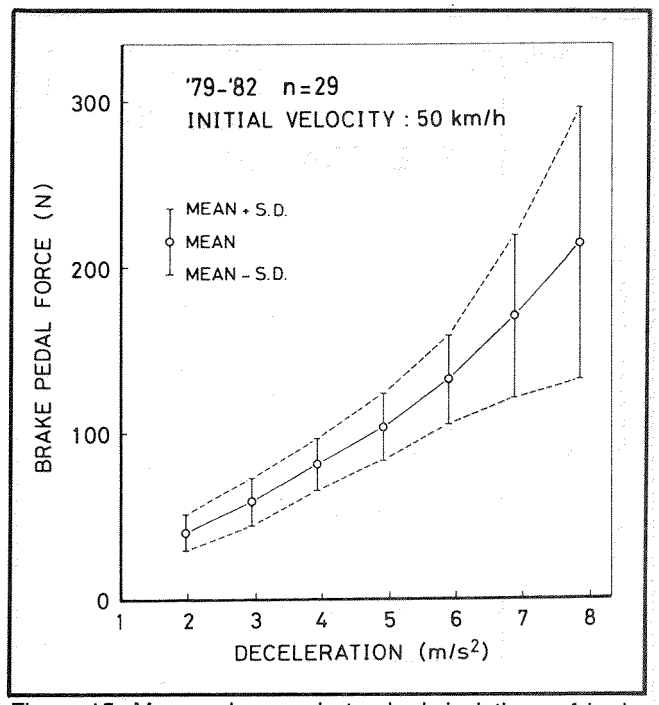


Figure 15. Mean values and standard deviations of brake pedal force obtained from effectiveness test.

mostly the same, however, when tested with initial velocity of 100 km/h in the deceleration range of up to 6 m/s². Figure 16 gives histograms which show relations between the frequency (number of cars) and the brake pedal force (F_B) at a deceleration of 5.88 m/s². The mean values and standard deviations obtained from these his-

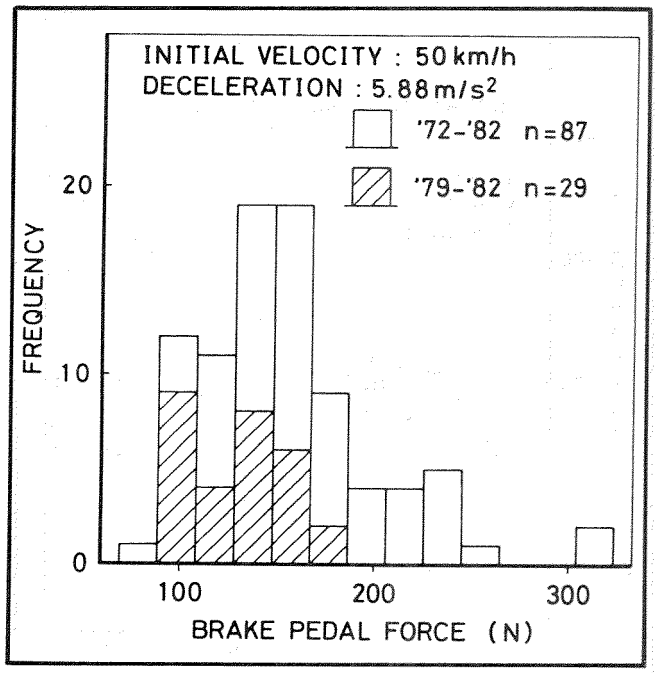


Figure 16. Histogram of brake pedal force obtained from effectiveness test.

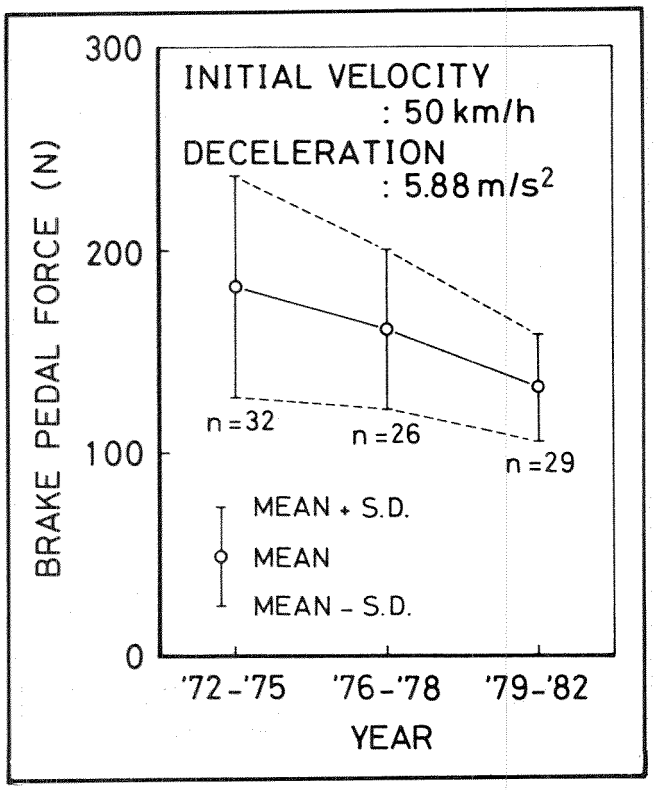


Figure 17. Transition of brake pedal force obtained from effectiveness test.

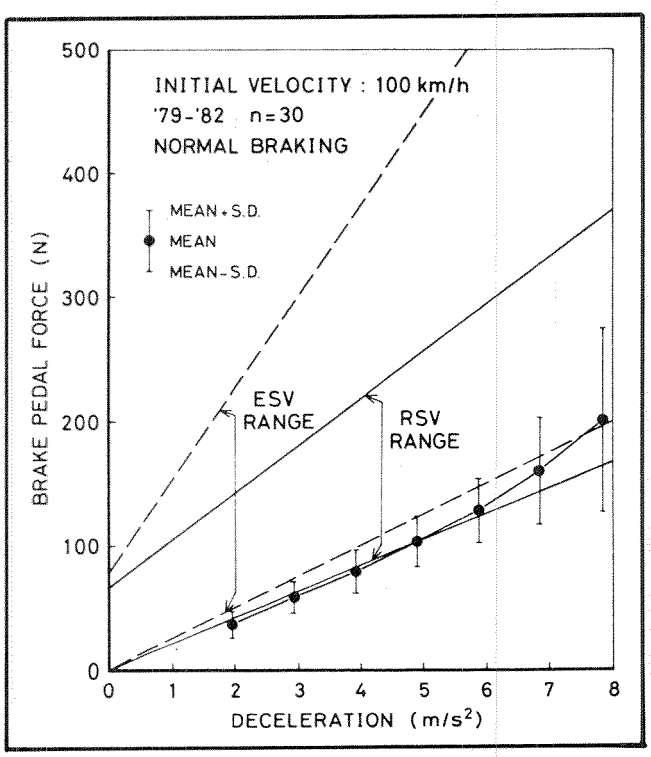
tograms are $F_B = 132 \pm 27$ N for the last 3 years (n = 29) and $F_B = 159 \pm 47$ N for the last 10 years (n = 87), and it can be said that vehicles which require smaller brake pedal force are increasing recently. Figure 17 shows mean values and standard deviations of the brake pedal force for test vehicles dividing into 3 periods. The figure indicates that the brake pedal force has been getting smaller in the last 10 years, and the same is true with the standard deviation.

The brake effectiveness in straight running has been examined as one of the test items of Accident Avoidance Capabilities of ESV (Experimental Safety Vehicle) and RSV (Research Safety Vehicle), and it is of interest to compare their specifications with trends in that of Japanese passenger cars.

Figure 18 compares the relation between the brake pedal force and the deceleration of recent Japanese passenger cars decelerated from the initial velocity of 100 km/h and those for ESV and RSV specifications decelerated from the initial velocity of 96 km/h. The mean values for the Japanese passenger cars of the last 3 years mostly coincide with the lower boundary of the RSV specifications for decelerations below 6 m/s² although there is a small difference in the initial velocities.

In the condition of booster failure, the mean values fall in the middle of the upper and lower boundaries of the ESV and RSV specifications.

The parking brake tests were conducted on 30% slopes, which is the same condition as that of the method of



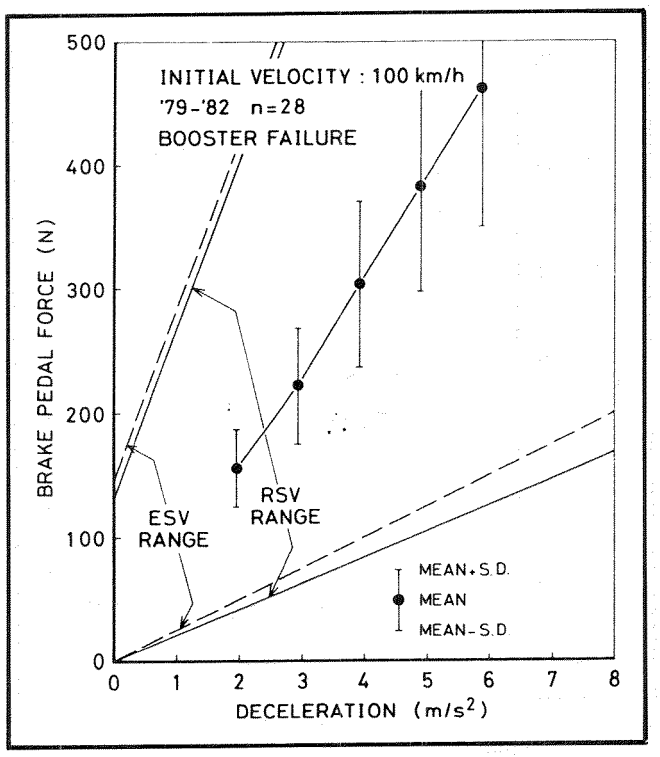


Figure 18. Comparison of brake pedal force of recent Japanese passenger cars and ESV/RSV specifications.

testing for ESV and RSV. Figure 19 shows the distribution of vehicles of the last 3 years as to their parking brake operating force (F_p). Parking brakes of most Japanese cars are of manual operation type, and $F_p = 293 \pm 64$ N on 30% uphill slopes and $F_p = 267 \pm 62$ N on 30% downhill slopes. The ESV and RSV specification on this parameter is $F_p < 400$ N, and most of the Japanese passenger cars meet the specification.

CONCLUDING REMARKS

The handling, stability and braking performance of recent Japanese passenger cars were discussed in this report as to the distribution and trend of values of response parameters.

The major results can be summarized as follows:

1. Japanese passenger cars tend, for the last 10 years, to have smaller steering effort and slighter understeer. Vehicles which have smaller roll angle and smaller brake pedal force are increasing.
2. Vehicles with power steering system increased more than those with manual steering system in the period of 1979-1982, and the average value of steering effort decreased accordingly.
3. The brake effectiveness of Japanese passenger cars of last 3 years was compared with the ESV and RSV specifications in the normal condition and the booster failure condition. The comparison revealed that the average values for vehicles marketed in the last 3 years match the lower boundary of RSV specifications for vehicles of normal condition.

LIST OF SYMBOLS

D	:	Index of resonance of yawing
f	:	Frequency of steering input in frequency response test
f_c	:	Resonant frequency of yawing
F_B	:	Brake pedal force
F_p	:	Operational force of parking brake
K	:	Stability factor
ℓ	:	Wheelbase
n	:	Number of data
NS	:	Neutral steer
r	:	Yawing angular velocity
R	:	Turning radius
S.D.	:	Standard deviation
T_{fr}	:	Steering effort in frequency response test, which is the value obtained by dividing steering wheel torque by effective steering wheel radius
T_{ss}	:	Steering effort in steady state cornering test, which is the value obtained by dividing steering wheel torque by effective steering wheel radius
US/OS	:	Understeer/Oversteer
V	:	Vehicle forward velocity
V_0	:	Initial velocity in braking
X	:	Stopping distance
$\ddot{X}$	:	Deceleration
$\ddot{Y}$	:	Lateral acceleration of vehicle center of gravity
δ_{sw}	:	Steering wheel angle
δ_{sw0}	:	Steering wheel angle in turning at very low velocity, which is defined by $\ell\,\eta/R$
η	:	Overall steering ratio
θ_{f1}	:	Phase lag at 1 Hz

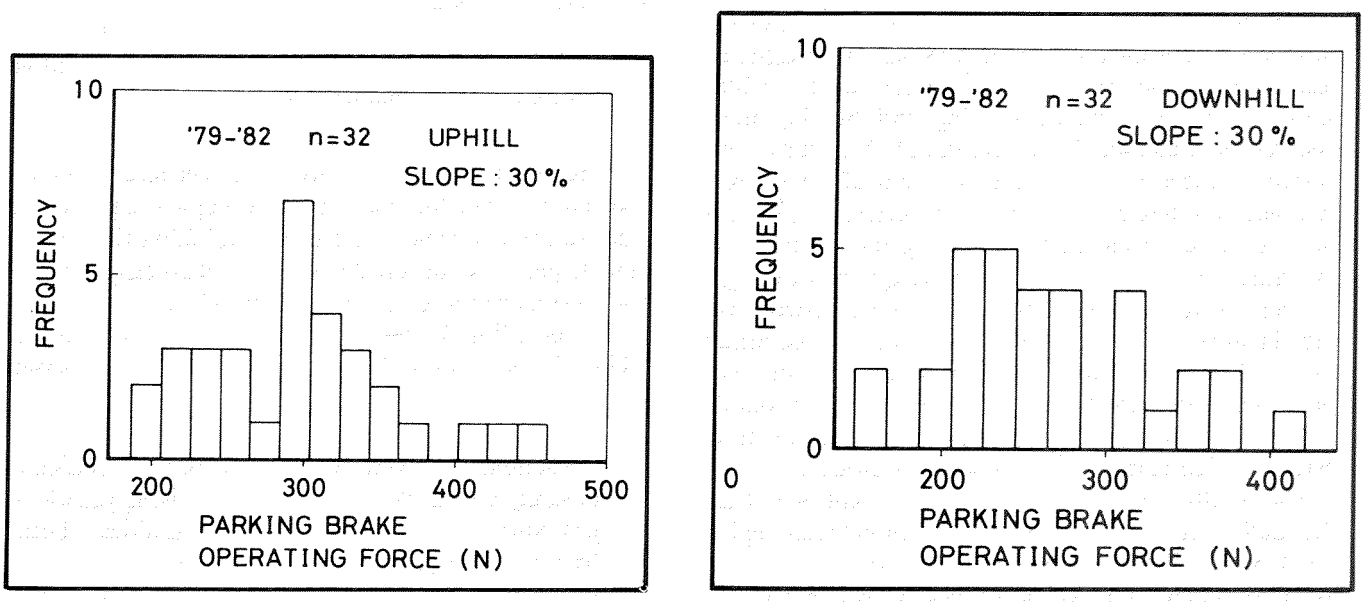


Figure 19. Histogram of operational effort obtained from parking brake test.

θ_i : Temperature of brake pad and/or lining, where i expresses each wheel and i = 1, 2, 3, 4
τ : Steering wheel torque
ϕ : Roll angle
ϕ_G : Roll angle, defined for $\ddot{Y} = 4.9$ m/s^2

REFERENCES

1. Sano, S., "Evaluation of Motor Vehicle Handling", JSAE Review No. 4, March 1981.
2. Linke, W., Richter, B., Schmidt, R., "Simulation and Measurement of Driver Vehicle Handling Performance", SAE Paper No. 730489, May 1973.
3. Kohno, T., Tsuchiya, S., Komoda, N., "On the Vehicle Dynamic Response to the Steering Control", SAE Paper No. 690488, May 1969.
4. Motor Fan Road Test, Feb. 1972-Sep. 1982, Sanei Shobo (Tokyo).

Variation Ranges for the Handling Characteristics of Today's Passenger Cars

KLAUS ROMPE
EDMUND DONGES
Institute for Traffic Safety
TÜV Rheinland e. V., Cologne

ABSTRACT

So far the handling characteristics of passenger cars have mainly been designed on the basis of subjective criteria. It will only be possible to make well-founded statements when we have succeeded in correlating accident frequency and vehicle handling characteristics. Before we can do so, however, we must be able to give objective descriptions of the handling characteristics. The aim of the investigations described here, which were carried out under commission to the German Federal Ministry for Research and Technology, is to give a quantifiable description of the handling characteristics of 15 different passenger vehicles in 7 test procedures during which steady-state and dynamic steering and braking manoeuvres were measured. The results of these tests show variation ranges for the evaluation criteria of the different tests and at different initial conditions, such as the loading or road surface friction. By observing the behaviour of individual cars within the variation ranges and throughout all the tests, correlations can be seen between the individual test procedures and conclusions can be drawn as to whether the handling characteristics in one test procedure necessarily have an influence on the vehicle behaviour in another test procedure. The influence of certain design parameters also becomes clearer.

The resulting ranges of variation represent one of the foundations for studying the connection between vehicle handling characteristics and accident occurrence. They are also suitable for evaluating new vehicle categories, such as research vehicles.

INTRODUCTION

So far the design and evaluation of vehicle handling characteristics have mainly been based on the subjective assessment of experienced test engineers. The aim of this investigation, carried out under commission to the German Federal Ministry for Research and Technology, was to record the resulting handling characteristics of today's passenger cars and define ranges for quantifiable evaluation factors to describe the vehicle behaviour. The purposes of doing so were

—to be able to make comparative evaluations of new vehicles and components
—to gain more profound knowledge on the connection between test procedures, evaluation factors and design parameters
—to create quantified values as a basis for determining the connection between accident occurrence and vehicle handling characteristics.

The results of the measurements can also be of importance within the context of developing experimental and research vehicles since merely fulfilling the requirements placed so far on the handling characteristics does not necessarily lead to safe performance [1].

In compiling the test programme to describe the handling characteristics, the following selection criteria were applied:

—the simulated driving situations were to be relevant to safety and as close as possible to driving practices
—procedures were to be used which had already been tried and had proved to give reproducible results
—manoeuvres representative of the main driving situations were to be carried out in each case, these

being straight course, turning, transition and alternating bends

—the measurements were to refer not only to normal driving situations with forward and lateral accelerations up to 3-4 m/s², but also to situations approaching the handling limits.

Based on the experience available with different test procedures, a comprehensive literature research and our involvement with the ISO Committee dealing with this subject, the 7 test procedures compiled in Figure 1 were selected:

1. Straight line braking at v_{xo} = 50 and 100 km/h
2. Steady-state turning on a constant radius R_o = 40 m, at different speeds
3. Turning with steering wheel fixed, R_o = 40 m, over a single bump 40 mm high and 400 mm wide placed at right angles to the path at different speeds
4. Power-off during steady-state turning, R_o = 40 m, at different initial speeds
5. Braking in a turn, R_o = 40 m, starting at a lateral acceleration of a_{yo} = 5 m/s² with different braking forces
6. Step-steering input on a straight course at v_x = 100 km/h, attaining a lateral acceleration of 4 m/s²
7. Sinusoidal-steering input at v_x = 100 km/h with frequencies of 0,2 - 2 Hz with a steady lateral acceleration of 4 m/s²

A main feature in the performance of the test programme was the adherence to reproducible and constant test conditions relating to the measuring processes and test road surfaces as well as the vehicles and their equipment.

Within the 15 test vehicles used (14 passenger cars and 1 van), there were 8 vehicles with front-wheel drive, 5 with rear-wheel drive and 2 with rear-wheel drive and rear engine. The maximum permissible weight of the vehicles was between 1140 and 2310 kg with a specific engine power of between 22 and 92 kW per 1000 kg.

The vehicle types were selected to conform, on the one hand, with highest registration frequency and, on the other hand, to cover a broad spectrum of handling characteristics. All the measurements were carried out at test weight (driver plus measuring equipment), G_{test} and at maximum permissible weight with the permissible rear axle loading, G_{max}.

The measuring equipment consisted of a measurement steering wheel, a gyro-stabilised platform to measure accelerations and roll angles, a yaw velocity sensor and recorders for the forward and lateral velocities, and included indicators and aids for the driver. The total equipment weighed about 80 kg and was installed in place of the front passenger seat. The measurement recordings were evaluated according to various criteria by means of specially developed computer programs.

Each individual test was repeated at least 5 times.

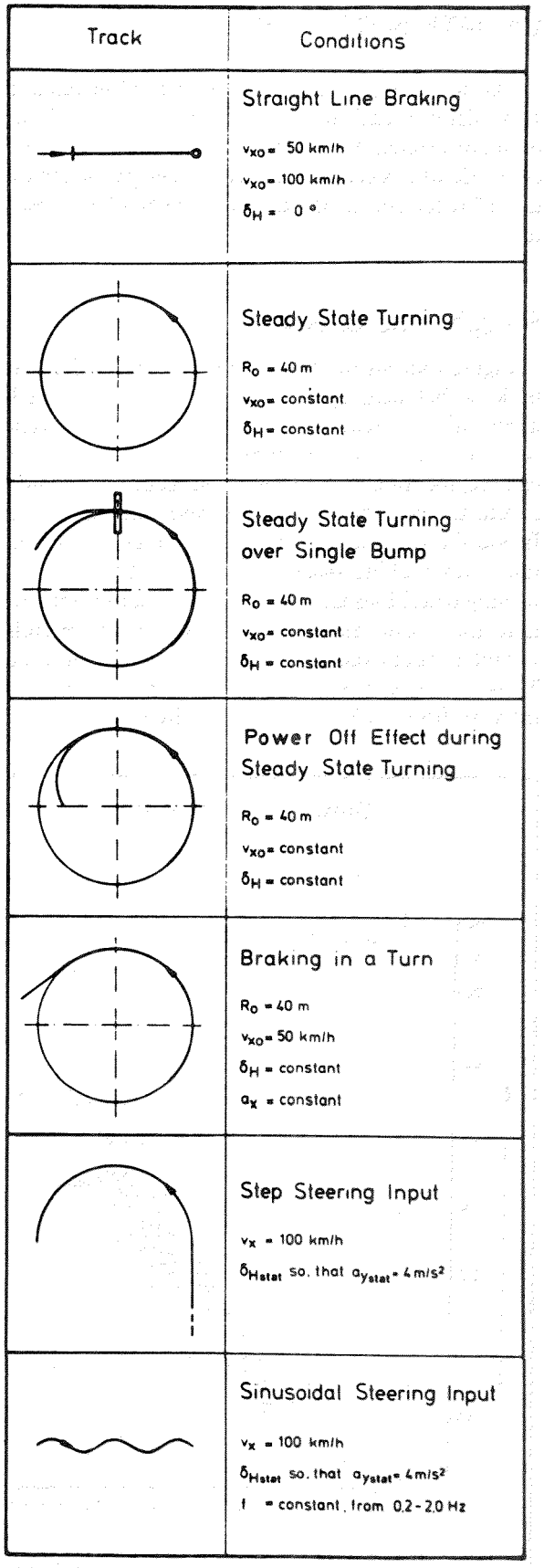


Figure 1. List of the seven test procedures illustrating the track and stating the test conditions.

VARIATION RANGES

The following figures show the variation range of all 15 vehicles in each test procedure as an example of one or more evaluation factors. In order to illustrate characteristic differences in the vehicle design, in some cases the reference curves of individual vehicles have been plotted in addition.

Straight Line Braking

Figure 2 shows the range of distribution of the recorded braking distances s as a function of the speed at brake application v_o between 50 and 100 km/h. The parameters plotted are the curves of constant deceleration a_x. As you can see, the minimum mean decelerations are about 6 m/s^2 and the maximum mean decelerations about 9 m/s^2. Inside the distribution range the curves are plotted for the mean braking distance $\bar{s}$ for all 15 vehicles in the loading conditions G_{test} and G_{max}. We can see clearly here that the mean deceleration at maximum permissible weight is about 0,6 - 0,7 m/s^2 less than at test weight. Thus at a velocity of 100 km/h the mean braking distance increase from 48,7 to 52,6 m, i.e., by about 4 m.

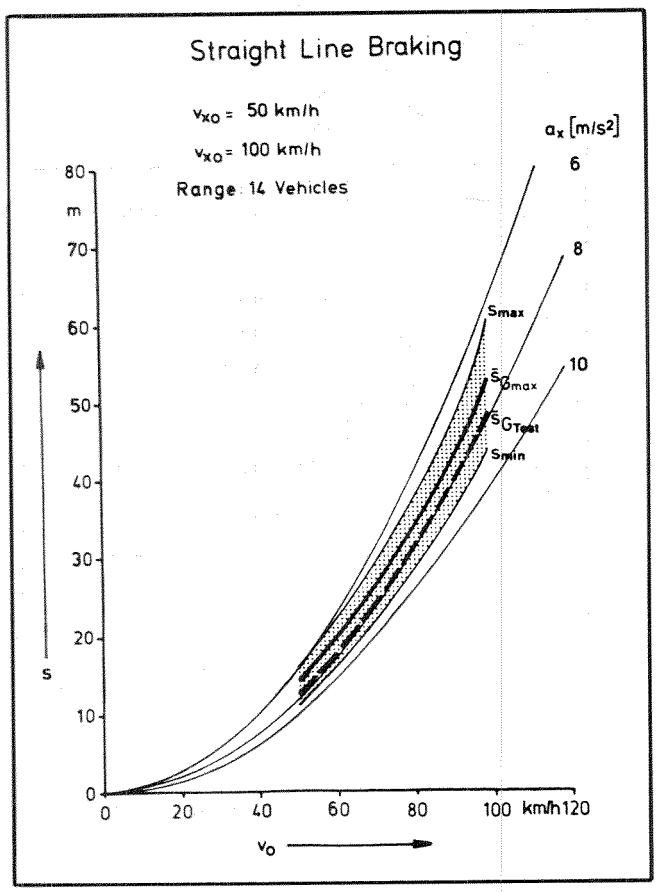


Figure 2. Distribution range of the braking distance s at speeds of v_{xo} = 50 to 100 km/h.

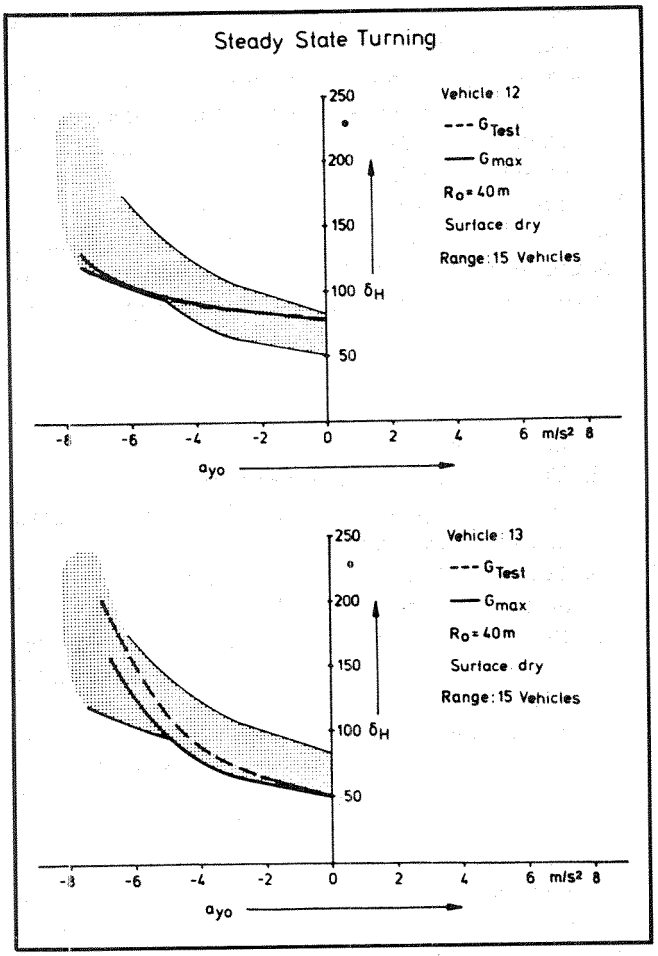


Figure 3. Distribution range of the steering wheel angle δ_H as a function of the lateral acceleration a_{yo} with the reference curves for vehicle 12 (top) and vehicle 13 (bottom).

Steady-state Turning

Figure 3 shows the distribution range of the necessary steering wheel angle δ_H during steady-state turning on a 40 m radius with increasing lateral acceleration a_{yo}. In the top graph inside the marked range you can see the reference curves for one vehicle with a relatively low increase in the steering wheel angle and only slight differences between the loading conditions G_{test} and G_{max}, and in the bottom graph the reference curves for a vehicle with a greater increase in the steering wheel angle at the handling limits and with a greater dependency on the loading condition.

A common feature of all the steering wheel angle reference curves is the initial linear, then progressive increase in the steering wheel angle with increasing lateral acceleration, i.e., all the vehicles under investigation showed design-dependent understeering.

The linear rise of the reference curves is characterized by the steering wheel angle-lateral acceleration-gradient

with a value of between 2,0 and 8,6 degrees/m/s^2 for the tested vehicles. With an increase in the lateral acceleration from 0 to 6 m/s^2, the necessary increase in the steering wheel angle was between 25 and 85 degrees. The maximum lateral accelerations achieved on a dry road surface were between 6,1 and 8,2 m/s^2.

Steady-state Turning Over a Single Bump

In the evaluation of turning with steering wheel fixed over a single bump which, according to Reference [2], is suitable for assessing the influence of uneven road surfaces on the vehicle's ability to maintain course, it is possible to use various rating factors. As an example, Figure 4 shows the distribution range for the change in yaw velocity when driving over the bump $\dot{\Psi}/\dot{\Psi}_o = (\dot{\Psi}_{max} - \dot{\Psi}_{min})/\dot{\Psi}_o$ with increasing lateral acceleration a_{yo} in the top graph and in the bottom graph we see the distribution range for the course deviation out of the circle caused by the bump and measured 1 s after driving over it. Additionally, the reference curves of 2 vehicles are plotted in both graphs. Referring to the change in yaw velocity in the top graph, the two vehicles show a tendency towards opposite behaviour, whereas referring to the sideward course deviation due to the bump in the bottom graph, they show a similar tendency.

With a lateral acceleration before driving over the bump of a_{yo} = 6 m/s^2, the tested vehicles showed changes in the yaw velocity caused by the bump of between 30 and 100% and sideward course deviations 1 s after driving over the bump of 0,1 to 0,5 m. The loading condition did not appear to have a significant effect.

Power-off During Steady-state Turning

Power-off is understood to be a sudden release of the accelerator pedal during steady-state turning. With increased lateral acceleration and velocity v_{xo} the course deviation and the yaw motion of the vehicle are observed. Showing the reference curves of 2 vehicles differing greatly in their behaviour, Figure 5 demonstrates how wide the distribution range is for the course deviation of the path of the centre of gravity towards the centre of the circle with increasing speeds.

The vehicle represented in the top graph, continuing for a further quarter circle after power-off at the highest possible test speed, shows a sideward deviation towards the centre of the circle of up to 15 m, the effect being only very slightly dependent on the loading condition. In contrast, the vehicle in the bottom graph shows at approximately the same speed course deviations of 25 m and more. At test weight (G_{test}) the vehicle turns 180 degrees. This behaviour was also observed in two other vehicles. It is worth noting here that the two vehicles illustrated hardly differ in their behaviour up to a speed

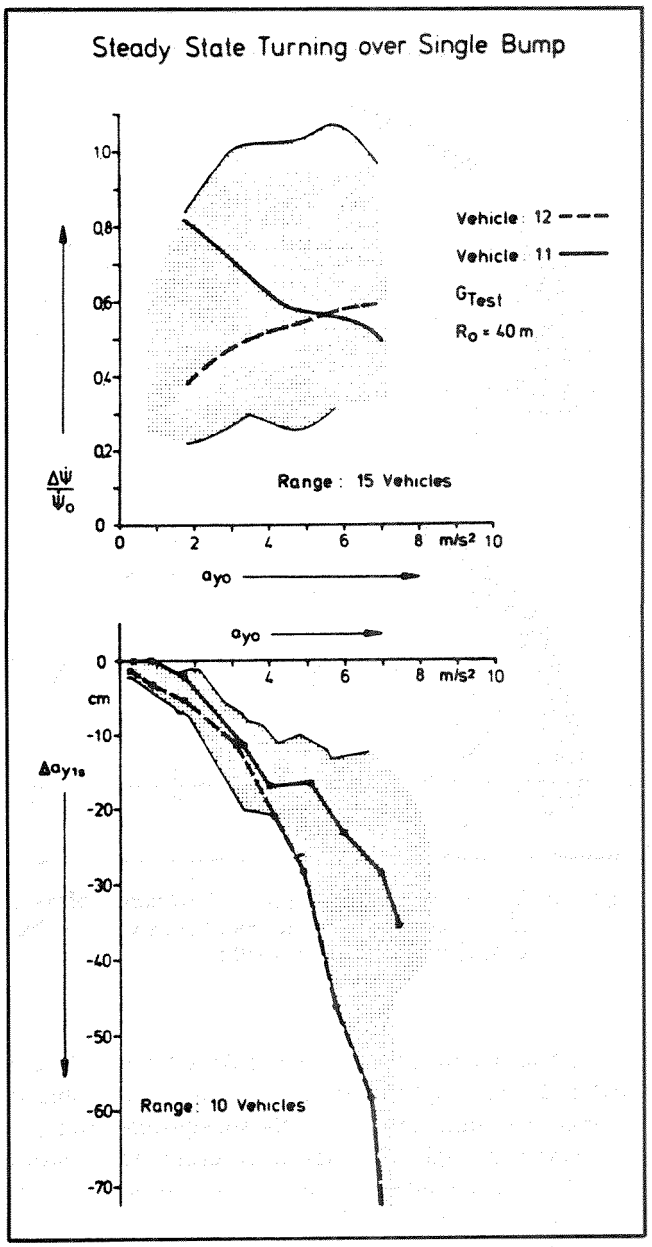


Figure 4. Distribution range for the evaluation factors, referred change in jaw velocity $\Delta\dot{\Psi}/\dot{\Psi}_o$ and sideward course deviation 1 s after driving over the bump Δy_{1s} versus the steady-state lateral acceleration a_{yo}.

of 60 km/h (a_{yo} = 7 m/s^2). That means that the critical situation only arises at the extreme handling limits at lateral accelerations of almost 8 m/s^2 and is generally more noticeable at test weight than at maximum permissible loading.

Braking in a Turn

The test procedure braking in a turn was carried out in accordance with Reference [3] at a lateral acceleration

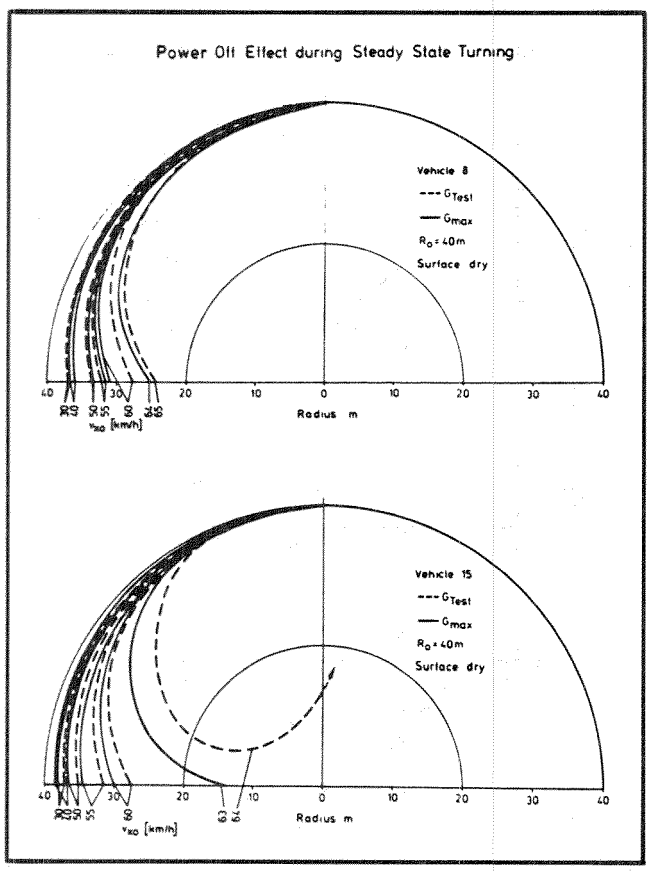


Figure 5. Course deviation of the path of the centre of gravity at power-off and at different speeds v_{xo} for vehicle 8 (top) and vehicle 15 (bottom).

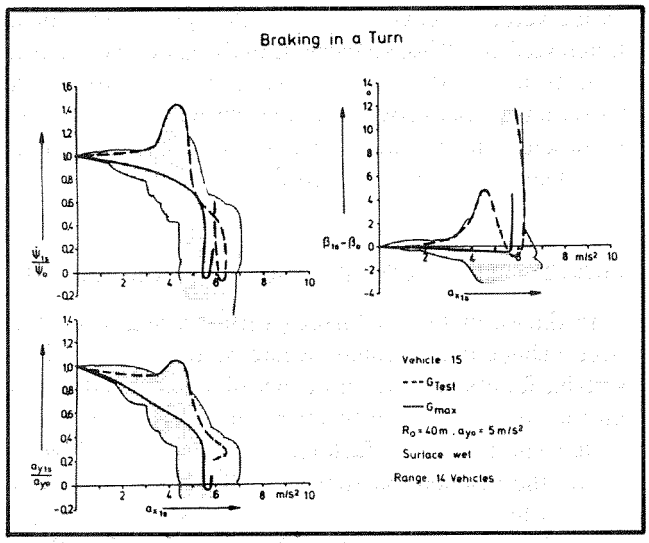


Figure 6. Distribution range of the evaluation factors 1 s after brake application, referred yaw velocity $\dot{\Psi}_{1s}/\dot{\Psi}_o$, referred lateral acceleration a_{y1s}/a_{yo} and side slip angle difference $\beta_{1s} - \beta_o$ each as a function of the deceleration a_{x1s} on a wet road surface with the reference curves for vehicle 15 at loading conditions G_{test} and G_{max}.

a_{yo} of 5 m/s² and with different braking forces. The evaluation factors applied here are the yaw velocity and the lateral acceleration, relative to the steady-state values, and the side slip angle. The values recorded are measured 1 s after brake application taking account of the driver's possible reaction time. Figure 6 shows the distribution range for these three factors as a function of the deceleration 1 s after brake application. The graph is valid for a 40 m radius and a wet road surface. The reference curves of a vehicle with relatively large dependency on the loading condition are plotted inside the distribution range. Due to an unfavourable ratio of braking force to wheel load at the rear axle in the loading condition test weight, this vehicle has a relative yaw stability at medium deceleration of 4-5 m/s² which is demonstrated by the peaks for the three evaluation factors. A similar behaviour was observed with one other vehicle.

Step-steering Input

The steering wheel angle for the step-steering input at v_x = 100 km/h (62 mph) was chosen to ensure that a steady lateral acceleration of $a_{y\ stat}$ = 4 m/s² would result.

Figure 7 shows the distribution ranges of the reference curves for the lateral acceleration and the yaw velocity, relative to the steady-state values which ensure as a reaction to the step steering input. Additionally, the reference curves of 2 vehicles with quite different designs are plotted. To evaluate the vehicle reaction, the 90% response times and the overshooting, expressed as the quotient of the maximum and the steady-state values are calculated. For the yaw velocity this response time $T_{90\%}$ was between 0,08 and 0,20 s and the overshooting factor Ü was between 1,1 and 1,8. The TB value developed by Reference [4] as the product of the response time of the yaw velocity up to the first peak and the steady-state side slip angle was between 0,11 and 0,91 s x degrees.

Sinusoidal-steering Input

The sinusoidal-steering input, as it is applied here, serves to describe the dynamic steering behaviour of the test vehicles using frequency response functions. The amplitude of the steering wheel angle is determined so as to lead to a lateral acceleration of 4 m/s² during turning at a speed of 100 km/h. The given frequency of the steering wheel angle ranges from 0,2 to 2 Hz. Figure 8 shows the distribution ranges for the derived frequency response functions in amplitude (top) and phase (bottom) for the lateral acceleration (left) and the yaw velocity (right). Additionally, the functions for 2 vehicles are plotted. In order to characterize these frequency response functions, the frequency at which the lateral acceleration is reduced

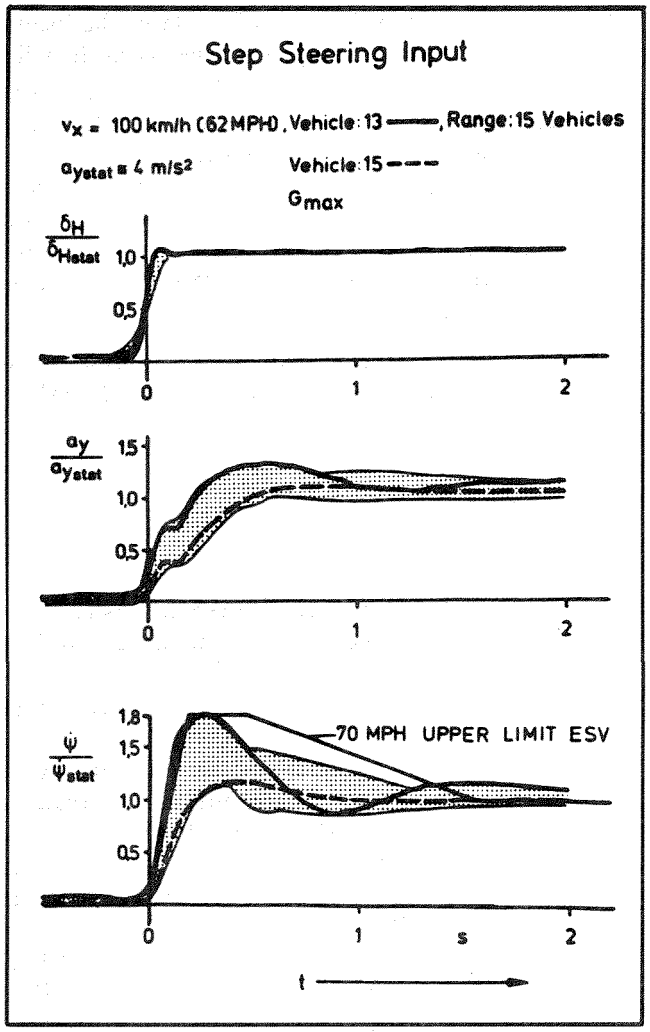


Figure 7. Distribution range of the lateral acceleration and the yaw velocity referring to the steady-state value with the reference curves of vehicles 13 and 15.

by 3 dB (f_{ay-3dB}) and the frequency at which the yaw velocity shows a resonant peak ($f\dot{\Psi}_{reson}$) are used. For the 15 test vehicles the 3 dB limit frequency for the lateral acceleration was between 0,7 and 1,6 Hz and for the yaw resonance between 0,6 and 1,5 Hz. To identify the time history, the equivalent reaction time T_{eq} of the yaw velocity is also applied. This value is defined as the reciprocal value of the angular frequency at which the phase angle reaches 45 degrees. T_{eq} resulted in a value of between 0,11 and 0,23 s.

APPLICATION POSSIBILITIES

Due to the large number of measurements taken under comparable conditions, comparisons and correlation calculations can be made

—to determine the most valid evaluation factors within one test procedure

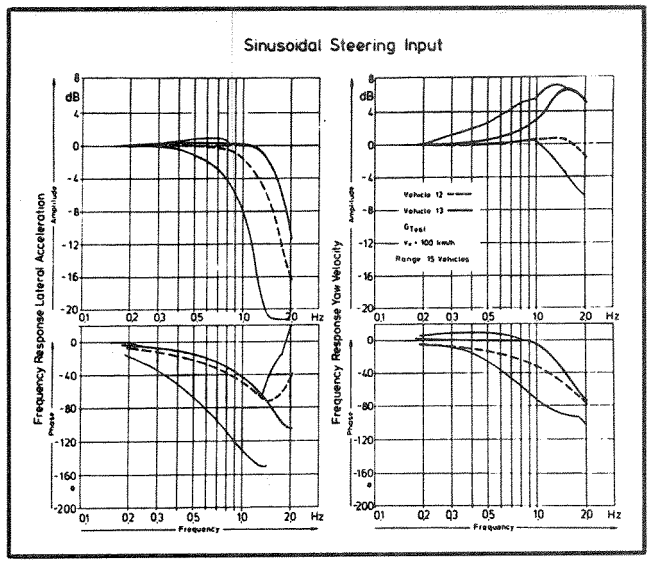


Figure 8. Distribution range of the frequency response function of the lateral acceleration and the yaw velocity with the reference curves of vehicles 12 and 13.

—to elucidate the correlations between different test procedures

—to examine the possibilities of determining integral evaluation factors from several test procedures.

As an example of application Figure 9 demonstrates the correlation between the equivalent response time of the yaw velocity from the test procedure sinusoidal-steering input and the steering wheel angle-lateral acceleration-gradient from the test procedure steady-state turning.

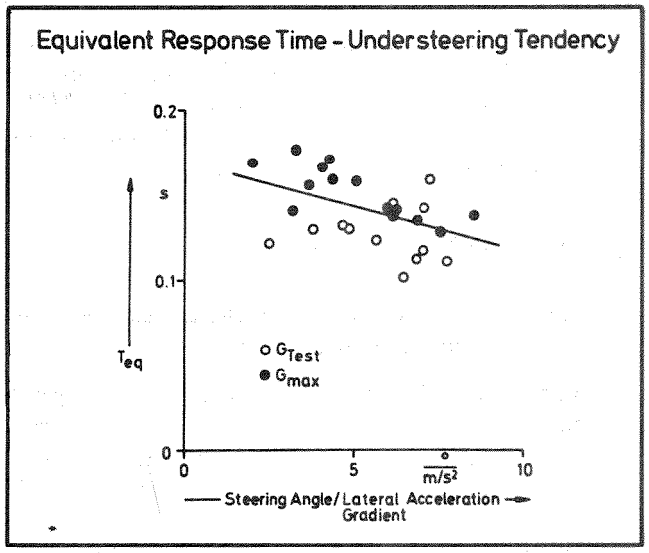


Figure 9. Correlation between the equivalent response time T_{eq} and the understeering tendency for 14 test vehicles. Because of its special dimensions of mass and inertia moment the van is excepted in this graph.

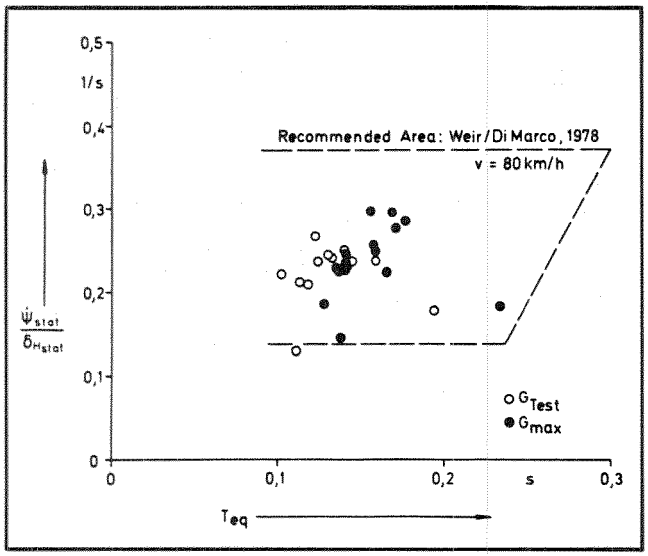


Figure 10. Correlation between the yaw increase factor $\dot{\Psi}_{stat}/\delta_{H\ stat}$ and the equivalent response time T_{eq} for the test vehicle.

From the linear theory of the handling characteristics it follows that the vehicle has a shorter response time the larger this gradient is, i.e., the greater the understeering. The measurements tended to confirm this correlation. However, other design parameters, such as the vehicle weight, also proved to have an even stronger influence.

For the correlation between the yaw amplification factor $\dot{\Psi}_{stat}/\delta_{H\ stat}$, for example as determined in the test procedure step-steering input, and the equivalent response time T_{eq} from the test procedure sinusoidal-steering input, Reference [5] gives a design recommendation for the speed 80 km/h. If we plot the results of the measurements taken at 100 km/h in this recommended area, which is shown in Figure 10, we can see that 13 vehicles have very similar values within this area. Thus the subjective evaluation by the test engineers led to a very similar design.

Further analyses of the correlations have either already been done or are still being undertaken.

CONCLUSIONS

If we sumamrize the results of the measurements we can draw the following conclusions:

—For most of the vehicles, the distribution ranges of the evaluation factors applied cover roughly the same area, thus they are similar in the design of their handling characteristics. The range of the total distribution is determined by only a few vehicles, but these are not the same ones for each test procedure.

—Driving conditions which were more difficult to control only arose for some vehicles when approaching the handling limits in the test procedures power-off and braking during steady-state turning.

—For some vehicles in some of the tests, the loading can have a relatively large influence on the handling characteristics. In contrast, other vehicles showed handling characteristics in some tests which were almost totally independent of the loading.

—Although the theoretical correspondence between the evaluation factors and the test procedures could be verified to a certain extent, it could also be seen that with certain suspension designs this correspondence is less recognizable.

Carrying out further evaluations and analyses of the available data should lead to more profound knowledge on the test procedures and the evaluation factors.

REFERENCES

1. Zomotor, A., Nitz, J., Ruf, G.: Results of Handling, Stability, and Braking Tests of the Minicars RSV. Report of the 8th International Conference on ESV, p 77-87, 1980
2. Bergman, W.: Measurement and Subjective Evaluation of Vehicle Handling. SAE 730492, 1973
3. Rompe, K.: Vehicle Handling Characteristics During Braking in a Turn. Report of the 8th International Conference on ESV. p 1056-1064, 1980
4. Lincke, W., Richter, B., Schmidt, R.: Simulation and Measurement of Driver Vehicle Handling Performance. SAE 730489, 1973
5. Weir, D. H., DiMarco, R. J.: Correlation and Evaluation of Driver/Vehicle Directional Handling Data. SAE 780010, 1980

LIST OF SYMBOLS

a_x	Forward acceleration
a_y	Lateral acceleration
a_{y1s}	Lateral acceleration 1 s after brake application
f	Frequency
s	Braking distance
t	Time
v_x	Forward velocity
G_{test}	Test weight (driver plus measuring equipment)
G_{max}	Maximum permissible weight
R_o	Initial path radius
T_{eq}	Equivalent response time
β_{1s}	Side slip angle 1 s after brake application
δ_H	Steering wheel angle
$\dot{\Psi}_{1s}$	Yaw velocity 1 s after brake application
$\Delta\dot{\Psi}$	Change in yaw velocity ($\dot{\Psi}_{max} - \dot{\Psi}_{min}$)
Δy_{1s}	Sideward course deviation 1 s after driving over the bump
Indices	
o	Initial value
stat	steady-state value

The Driver Related Steering Characteristics of the New Volvo 760 GLE

FRIEDRICH O. JAKSCH
Volvo Car Corporation, Gothenburg, Sweden

ABSTRACT

Steering characteristics of cars have been improved during the past years, but investigations show that there is still a need for more driver adapted steering systems to reach a higher level of controllability of the driver/vehicle system. Research within the Volvo Concept Car project showed the possibility of increasing steering controllability.

Modern passenger cars are almost similar to each other with respect to vehicle handling during normal driving. At the limit of the tyre side force capability, cars can still react very different and sometimes require a great deal of driver adaptation to secure a high level of controllability of the driver/vehicle system.

This paper reports how the high level of controllability of the steering system has been reached in the Volvo 760 GLE without sacrificing either stability or manoeuvreability. Furthermore, the technical solution of the different vehicle subsystems influencing the steering characteristics are described.

INTRODUCTION

The Volvo 760 GLE, which is shown in Figure 1, incorporates design features which are a direct result of ongoing research activities in the Volvo Car Corporation. Many of the subsystems have been successfully tested in the Volvo Concept Car project (ref. 1).

The aim of this paper is to describe the influence of different vehicle parameters on steering characteristics, as well as the development of the steering characteristics for the Volvo 760 GLE.

Furthermore, the paper also reports on the most important requirements on steering characteristics with the help of earlier defined measuring methods (refs. 2 and 3).

Figure 1. The new Volvo 760 GLE, a result of several research activities in the Volvo Car Corporation.

REQUIREMENTS ON STEERING CHARACTERISTICS RELATED TO THE DRIVER'S BEHAVIOUR

Earlier published investigations (ref. 2, 3, 4, 5, 6 etc.) indicate that vehicle parameters like

—Steering wheel angle
—Steering wheel torque
—Lateral acceleration
—Yaw velocity
—Vehicle side slip angle

as well as different forms of their combinations and time relation are of fundamental importance for the controllability and stability of the driver/vehicle system.

Inverse Lateral Acceleration Gain versus Lateral Acceleration Response Time

The lateral acceleration gain of a vehicle can be measured in different ways. Using a sinusoidal steering wheel angle input, the gain in terms of lateral acceleration can be measured with different steering wheel angle amplitudes and different steering wheel angle frequencies during straight line driving (ref. 1 and ref. 2). This measuring method is useful especially if the test track is limited in width.

It is also possible to measure the lateral acceleration gain due to steering wheel angle inputs on a circular path using different steering wheel angle frequencies and amplitudes at different steady state lateral accelerations.

Like in classical control theory, with respect to steering controllability and stability, it seems to be important to measure the gain and response time in the steering system at different input frequencies. Figure 2 shows the time history of a typical measurement sequence with steering wheel angle input and lateral acceleration response.

In order to get a more complete picture of a vehicle's response to steering wheel angle inputs, the inverse lateral acceleration gain has to be plotted as a function of the lateral acceleration response time for different steering wheel angle frequencies and different levels of lateral acceleration, which is exemplified in Figure 3. The boundaries of the highest and lowest steering frequency as well as the boundaries of the highest and lowest lateral ac-

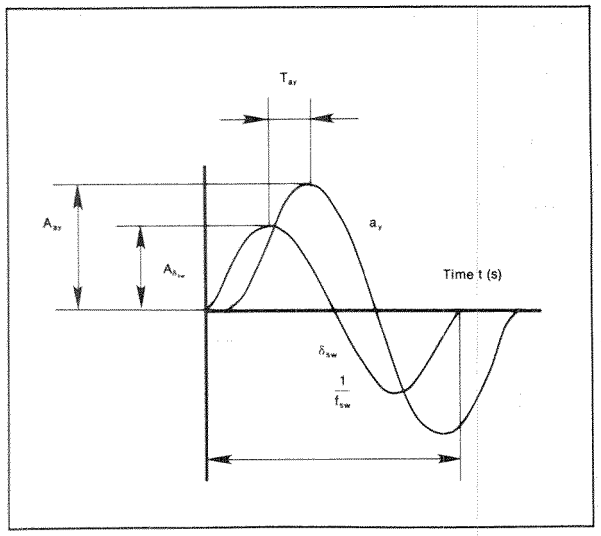


Figure 2. Time histories of a typical measuring sequence showing steering wheel angle input δ_{sw} and lateral acceleration response a_y.

δ_{sw}	Steering wheel angle
a_y	Lateral acceleration
$A_{\delta_{sw}}$	Amplitude of steering wheel angle
A_{ay}	Amplitude of lateral acceleration
T_{ay}	Time lag
f_{sw}	Input frequency
t	Time

$$G_{\delta_{sw}}^{a_y-1} = \frac{A_{\delta_{sw}}}{A_{ay}}$$

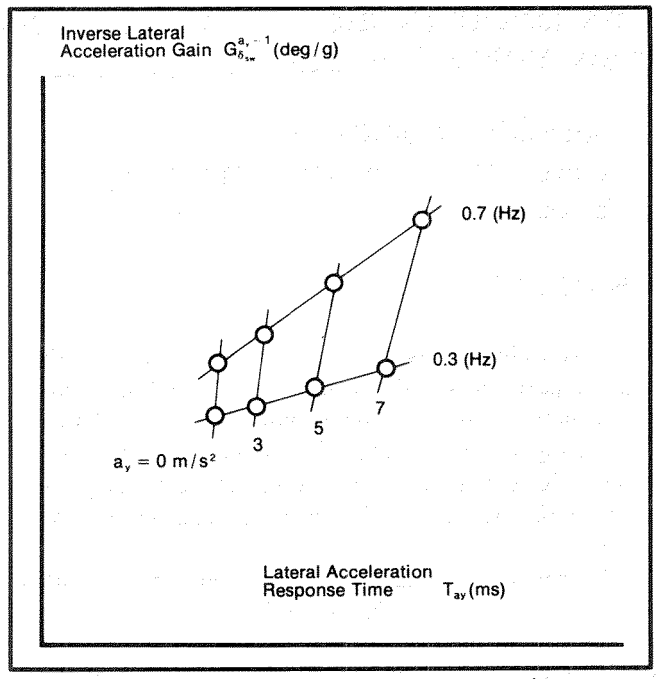


Figure 3. Inverse lateral acceleration gain $G_{\delta_{sw}}^{a_y-1}$ (deg/g) versus lateral acceleration response time T_{ay} (ms) at different levels of lateral acceleration a_y (m/s²) and different steering wheel angle frequencies f_{sw} (Hz) measured with sinusoidal steering wheel angle input.

celeration indicate how much adaptation is needed from the driver in order to control the vehicle safely within the measured ranges of the steering frequency and lateral acceleration.

Evaluation of test vehicles and subjective rating indicate (ref. 1 and ref. 2) that this area within the boundaries should be as small as possible and within a certain range of inverse lateral acceleration gain values in order to get a predictable steering behaviour for passenger cars.

Steering Wheel Torque Gradient versus Vehicle Speed

During straight line driving, steering wheel angle movements are often very small, which means that the steering wheel angles used in order to keep the vehicle on a straight line can be close to or below the driver's threshold. In those cases, the feedback force at the steering wheel rim will play a major role in the steering control of the vehicle.

The feedback force at the steering wheel rim can be determined by measuring the steering wheel torque with sinusoidal steering wheel angle input during straight line driving taking the steering wheel radius into consideration. The steering wheel angle input should not exceed an amplitude corresponding to ± 0.3 g of lateral acceleration. Since the steering wheel radius is very much the same in different cars, steering wheel torque can be used instead of steering wheel rim force.

The steering wheel torque gradient; i.e., quotient of steering wheel torque and lateral acceleration, should be kept within certain limits and can be obtained from the time histories of steering wheel torque and lateral acceleration (ref. 1).

Figure 4 shows a typical diagram of steering wheel torque versus lateral acceleration which can be used for the determination of the steering wheel torque gradient. The diagram also shows a hysteresis partly depending on a time delay between the two signals but also depending on friction forces between steering wheel and front wheels. Friction forces should generally be limited, but a certain amount can be necessary as a damping in the steering system if no other damping forces are existing.

It is also an advantage for the driver if the vehicle indicates lower friction between tyre and road with lower steering wheel torque gradients in order to give the driver an early warning signal.

Figure 5 shows a typical range for the inverse lateral acceleration gain at different vehicle speeds measured on 13 different cars. Note the clear tendency of reduced inverse gain at increased vehicle speed. Figure 6 shows a typical range for the steering wheel torque gradient at different speeds for the same car population. The torque

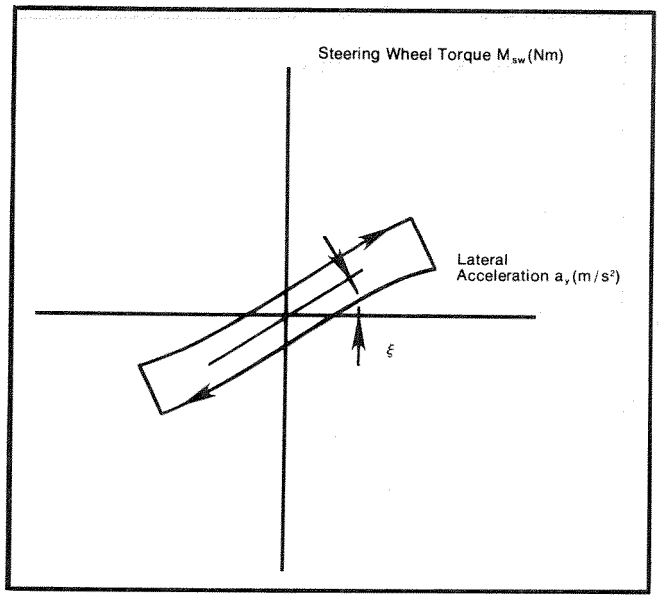


Figure 4. Steering wheel torque M_{sw} (Nm) versus lateral acceleration a_y (m/s²) derived from the time history of the two signals measured with sinusoidal steering wheel angle input.

$$\zeta = \left(\frac{M_{sw}}{a_y}\right) = \text{Steering wheel torque gradient (Nm/g)}$$

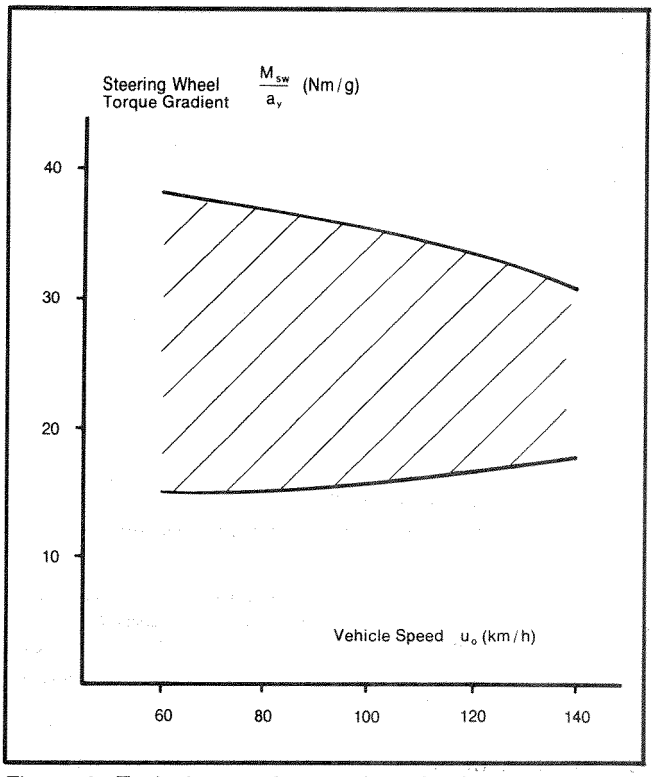


Figure 6. Typical range for steering wheel torque gradient (M_{sw}/a_y) (Nm/g) at different vehicle speeds u_o (km/h) for 13 different cars measured on high friction surface with sinusoidal steering wheel angle input during straight line driving.

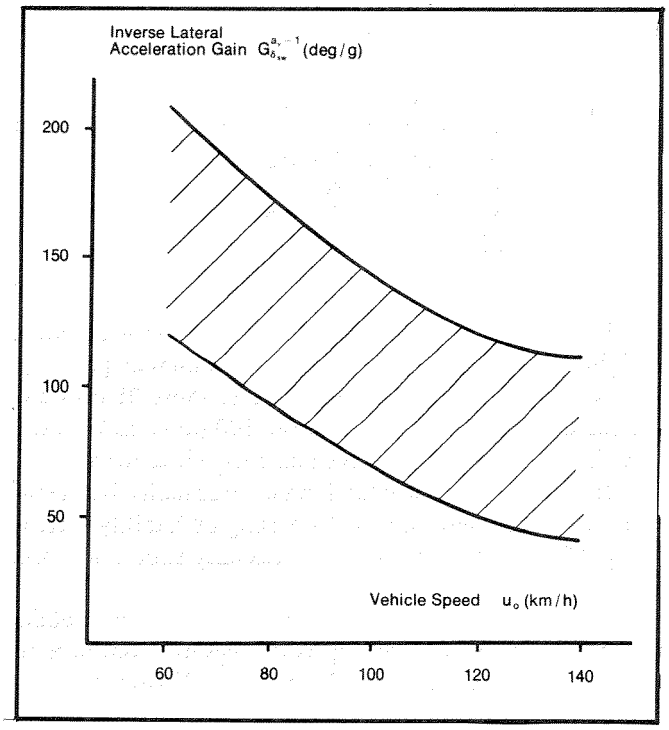


Figure 5. Typical range for inverse lateral acceleration gain $G_{\delta_{sw}}^{a_y^{-1}}$ (deg/g) at different vehicle speeds u_o (km/h) for 13 different cars measured on high friction surface* with sinusoidal steering wheel angle input during straight line driving.

* High friction surface means a friction level of at least skid number SN 80 according to the ASTM friction measuring method.

gradient seems to be more constant when vehicle speed is increasing.

Due to the fact that the inverse lateral acceleration gain always is decreasing when vehicle speed is increasing, it is even more important at higher vehicle speeds to keep the steering wheel torque gradient above a certain limit. Also here, evaluation of test vehicles and subjective rating performed by test drivers indicate (ref. 1 and ref. 2) that this torque gradient should not be below 15 (Nm/g).

Vehicle Side Slip Angle Gain versus Lateral Acceleration

The vehicle side slip angle and especially the vehicle side slip angle gain is of great importance for the stability of the driver/vehicle system at higher lateral accelerations. Near the side force limit, a vehicle with high side slip angle gain has a bigger potential to reach instability irrespective of the level of friction between tyre and road.

Figure 7 shows the measured vehicle side slip angle gain at different lateral accelerations for 13 different passenger cars on high friction surface. In order to reach acceptable stability in the driver/vehicle system, the side slip angle gain in this diagram should not exceed 0.08

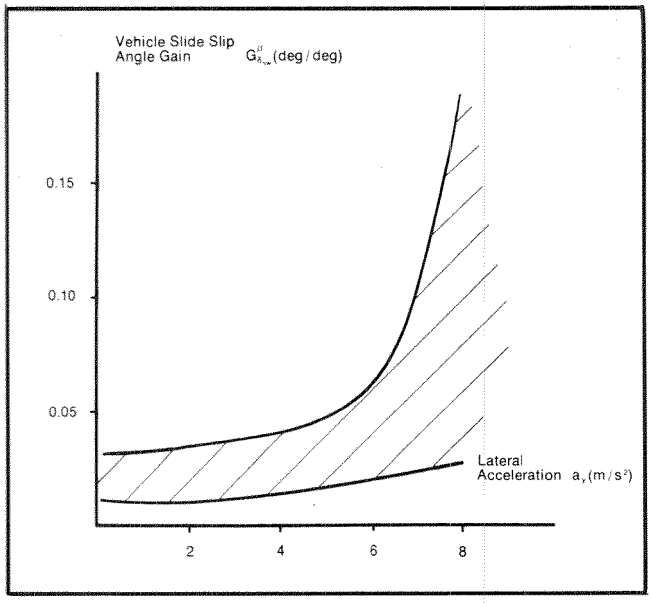


Figure 7. Vehicle side slip angle gain $G^{\beta}_{\delta sw}$ (deg/deg) versus lateral acceleration a_y (m/s²) for 13 different vehicles measured on high friction surface with sinusoidal steering wheel angle input at a frequency of f_{sw} = 0.3 (Hz).

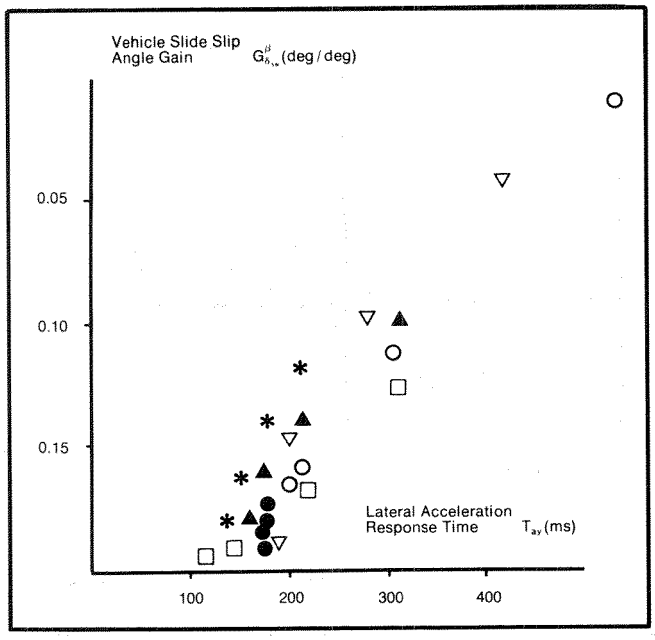


Figure 8. Vehicle side slip angle gain $G^{\beta}_{\delta sw}$ (deg/deg) versus lateral acceleration response time T_{ay} (ms) for 6 different cars measured on high friction surface with sinusoidal steering wheel angle input at a steering frequency of f_{sw} = 0.3 (Hz). Peak lateral acceleration for the different vehicles in increasing order.

(deg/deg) in the region of 7 to 8 (m/s²) of lateral acceleration.

The limitation for the individual driver is dependent on the driving experience with high side slip angles. The general motorist has very limited experience in driving with high vehicle side slip angles. This has been found and reported earlier (ref. 2, 5 and 7).

There are more reasons why the vehicle side slip angle should be held down for a passenger car for road transportation. Figure 8 shows the relationship between vehicle side slip angle gain and lateral acceleration response time for 6 different passenger cars in the curb weight range between 800 (kg) and 1400 (kg) representing both front wheel drive and rear wheel drive. The diagram indicates an increase in lateral acceleration response time when side slip angle gain is increasing.

Both long response time and high side slip angle or side slip angle gain increase the risk for instability in the driver/vehicle system.

Lateral Manoeuvreability versus Lateral Acceleration Response Time

In the foregoings, it has been shown that low vehicle side slip angle or short lateral acceleration response time is necessary for high stability in the driver/vehicle system.

Very short response time and very low vehicle side slip angle can, however, limit the vehicle's ability to move laterally during a steering manoeuvre, which is, in this report, called lateral manoeuvreability.

a_y (m/s²)

○	3.0	5.0	7.0	8.0	RWD
●	2.5	4.5	6.5	7.0	RWD
▲	3.3	4.8	7.3	9.0	RWD
▽	2.5	5.3	7.5	8.3	RWD
★	3.2	4.7	7.0	8.8	FWD
□	2.3	4.5	6.6	8.4	FWD

Figure 9 shows a typical range of lateral manoeuvreability performance measured on 25 different passenger cars. Marked in the diagram are 6 of those 25 cars covering a curb weight range between 800 (kg) and 1400 (kg) with both front wheel drive and rear wheel drive.

It can be seen that lateral manoeuvreability is decreasing when response time is decreasing or stability increasing. Maximum lateral manoeuvreability should not drop below 3 (m).

Also Figure 10 indicates that lateral manoeuvreability is decreasing when side slip is decreasing, even here for the same 6 vehicles as in Figure 8 and Figure 9.

STEERING CHARACTERISTICS OF THE VOLVO 760 GLE

Some of the targets for the Volvo 760 GLE, with respect to steering characteristics were:

—to improve the steering comfort and steering preci-

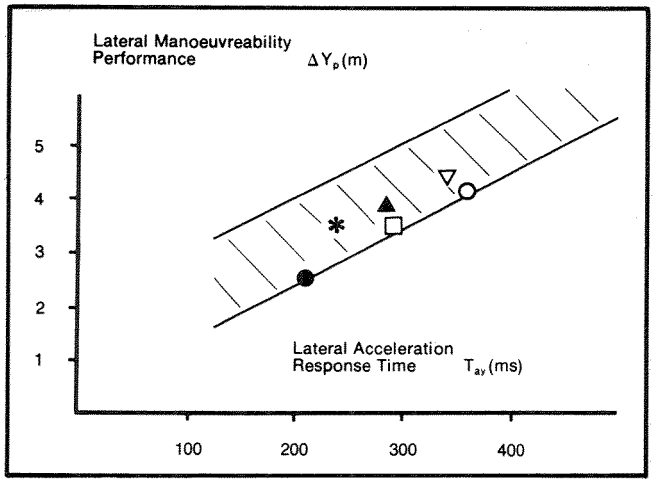


Figure 9. Typical range of lateral manoeuvreability performance ΔY_p (m) versus lateral acceleration response time T_{ay} (ms) at maximum lateral acceleration a_{ymax} (m/s²), a steering frequency of f_{sw} = 0.7 (Hz) and a vehicle speed of u_o = 80 (km/h) for 25 different passenger cars measured on high friction surface.

sion which means to reduce the inverse lateral acceleration gain and the lateral acceleration response time in the range of the low lateral accelerations;

—to improve the predictability of the steering control system, which means to reduce the inverse lateral acceleration gain and the lateral acceleration response time considerably in the range of high lateral accelerations;

—to increase the margin of yaw stability, which means to reduce the vehicle side slip and side slip angle gain at the side force limit;

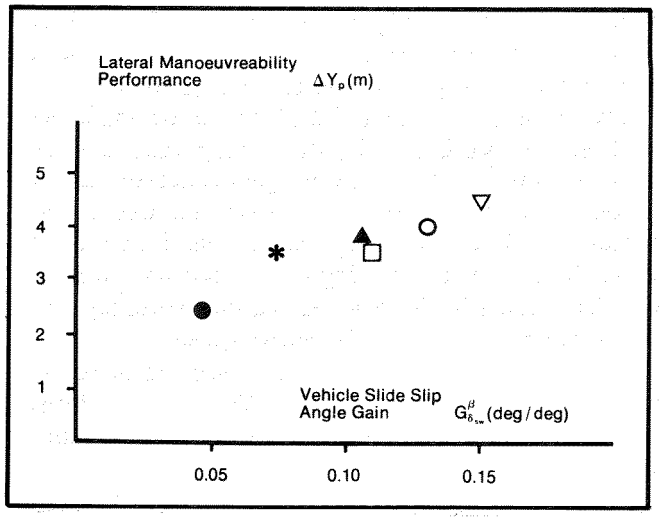


Figure 10. Lateral manoeuvreability performance ΔY_p (m) versus vehicle side slip angle gain $G^{\beta}_{\delta_{sw}}$ (deg/deg) measured with sinusoidal steering wheel angle input at maximum lateral acceleration a_{ymax} (m/s²), a steering frequency of f_{sw} = 0.7 (Hz) and a vehicle speed of u_o = 80 (km/h) on high friction surface.

—to increase the lateral manoeuvreability performance, which means to reach higher lateral accelerations;

compared to the Volvo 264 GLE.

The Development of the Steering Characteristics of the Volvo 760 GLE

To show how the steering characteristics of the new Volvo 760 GLE have been improved in relation to the Volvo 264 GLE, which the 760 GLE replaces, the influence of different subsystems on steering characteristics will be shown by calculating the different characteristics using a mathematical model. This mathematical model, which has been used in other investigations (ref. 1, 8, 9 and 10) and is described in the Appendix, is advantageous here because the influence of different subsystems on control and stability is very easy to overview.

The development of the steering characteristics will be shown using the inverse gain/response time characteristic which can be seen in Figure 3. This type of characteristic is very useful because it gives a very good indication of controllability, stability and manoeuvreability at the same time.

Figure 11 shows the calculated results of the inverse gain/response time characteristic of the former production Volvo covering the steering wheel input frequencies between f_{sw} = 0.3 (Hz) and f_{sw} = 0.7 (Hz) as well as the steady state lateral accelerations between a_{yss} = 0 (m/s²) (straight line driving) and a_{yss} = 7 (m/s²). This

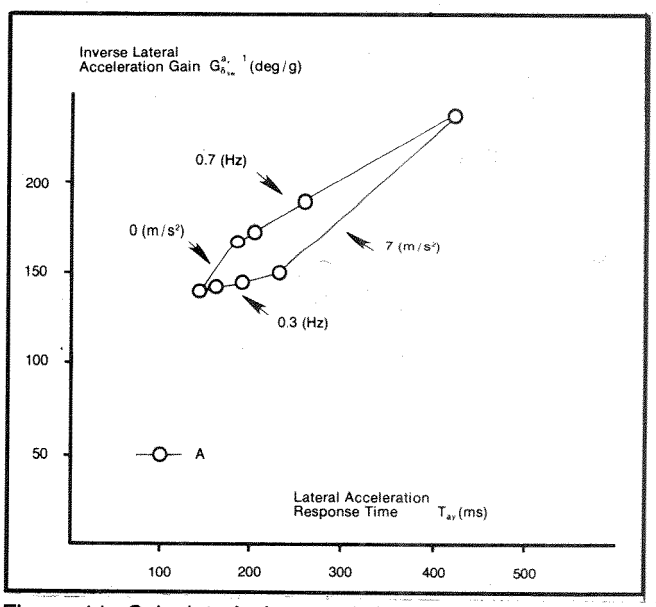


Figure 11. Calculated characteristic of inverse lateral acceleration gain $G^{a_y^{-1}}_{\delta_{sw}}$ (deg/g) versus lateral acceleration response time T_{ay} (ms) for the former production Volvo 264 GLE for lateral accelerations between a_y = 0 (m/s²) and a_y = 7 (m/s²) and steering frequencies between f_{sw} = 0.3 (Hz) and f_{sw} = 0.7 (Hz) on high friction surface.

carpet type of characteristic indicates how much the vehicle is changing in gain and response time when operated within the above-mentioned frequency and lateral acceleration limits.

Good controllability can be reached by keeping the inverse gain and response time generally low. Good stability can be reached by keeping the response time low especially at high lateral accelerations. Good manoeuvreability however will be reached if the lateral accelerations are high at low response times.

The new Volvo 760 GLE contains a number of different subsystem changes. Their influence on steering gain and response time will be shown in the following diagrams separately for each subsystem.

In order to get a better fuel and performance efficiency, the weight of the 760 GLE has been decreased by 5% while the number of features in the vehicle has been increased.

The influence of a 5(%) or 50 (kg) weight reduction on steering gain and response time is shown in Figure 12. The diagram indicates a very little change towards lower inverse gain and lower response time, but practically not noticeable. It might be important to mention here that the weight distribution between front and rear has not been changed in this calculation.

To get more room and comfort for the rear seat passengers, the rear axle has been moved backwards which gives about 13 (cm) longer wheel base and about 4(%) more weight on the front axle compared to the Volvo 264 GLE.

Figure 13 shows the influence of increased wheelbase and increased percentage of load on the front axle. The

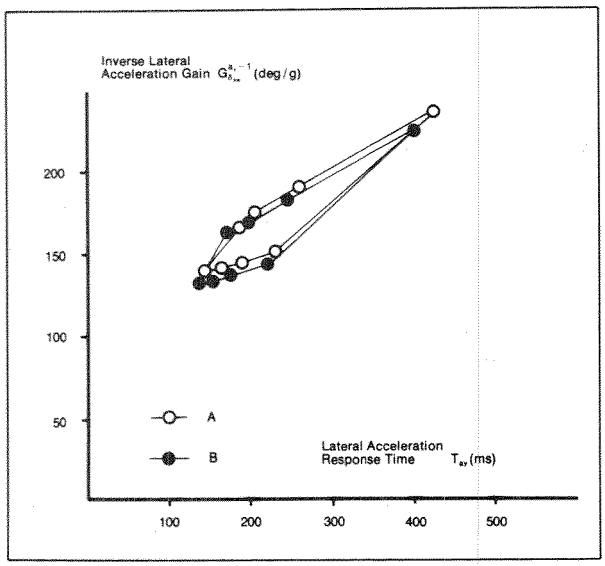


Figure 12. Calculated influence of weight reduction on inverse gain/response time characteristic.
A. Former production Volvo 264 GLE (data according to Appendix) with m = 1450 (kg)
B. As vehicle A, except m = 1400 (kg)

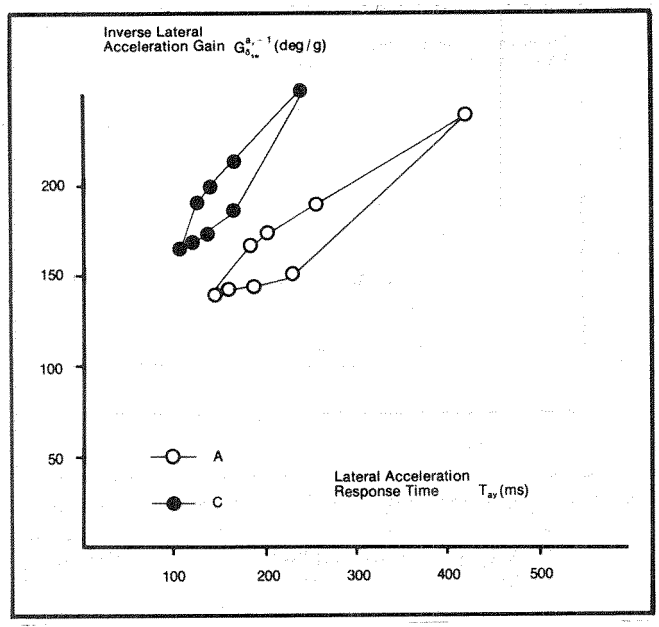


Figure 13. Calculated influence of increased wheelbase and increased percentage of weight on front axle on inverse gain/response time characteristic.
A. Former production Volvo 264 GLE (data according to Appendix) with (a + b) = 2.64 (m) and b/(a + b) = 0.52
C. As vehicle A, except (a + b) = 2.77 (m) and b/(a + b) = 0.56

weight of the vehicle here has not been changed. The diagram shows a clear reduction in response time but also an increase in inverse gain.

Vehicles with very high percentage of front axle load suffer from high inverse gains which means less steering precision. The design of a new steering and front wheel suspension system made it possible to increase the stiffness between the steering wheel and the front wheels.

How an increase of the stiffness between steering wheel and front wheels is influencing the steering characteristics can be seen in Figure 14. Inverse gain is decreasing but response time is increasing. The reason for this is that increased stiffness between steering wheel and front wheels leads to less cornering compliance on the front axle. This again leads to lower natural frequency and higher damping in the whole vehicle system.

On the new 760 GLE, the tyres used are generally wider and lower. The tyre size is 195/60HR15. This leads basically to higher cornering stiffness in the entire range of side forces.

Figure 15 shows how inverse gain and response time are influenced when cornering stiffness is increased by 10(%) in the whole range of lateral accelerations. A clear reduction in response time can be seen. At higher steering frequencies also a reduction in inverse gain is noticed. Figure 16, however, shows what happens if the cornering stiffness is increased mainly in the range between a_y =

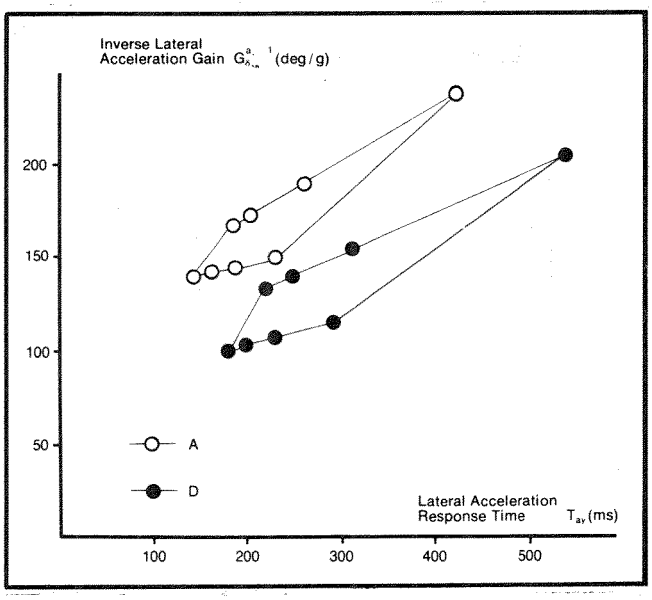


Figure 14. Calculated influence of stiffness between steering wheel and front wheels on inverse gain/response time characteristic.

A. Former production Volvo 264 GLE (data according to Appendix) with CS_L = 6500 (Nm/rad) measured on front wheels
D. As vehicle A, except CS_L = 15000 (Nm/rad)

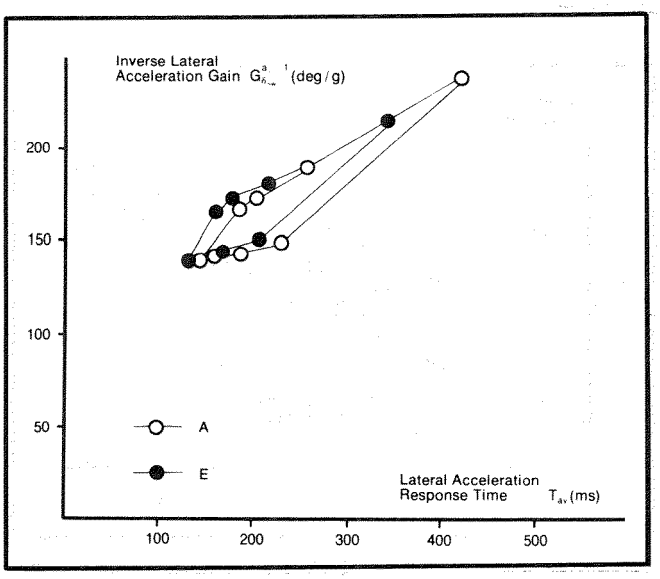


Figure 15. Calculated influence of cornering stiffness on front and rear axle at lateral acceleration a_y = 0 (m/s²) on inverse gain versus response time characteristic.

A. Former production Volvo 264 GLE (data according to Appendix) with $C1_F$ = 100000 (N/rad) and $C1_R$ = 100000 (N/rad)
E. As vehicle A except $C1_F$ = 110000 (N/rad) and $C1_R$ = 110000 (N/rad)

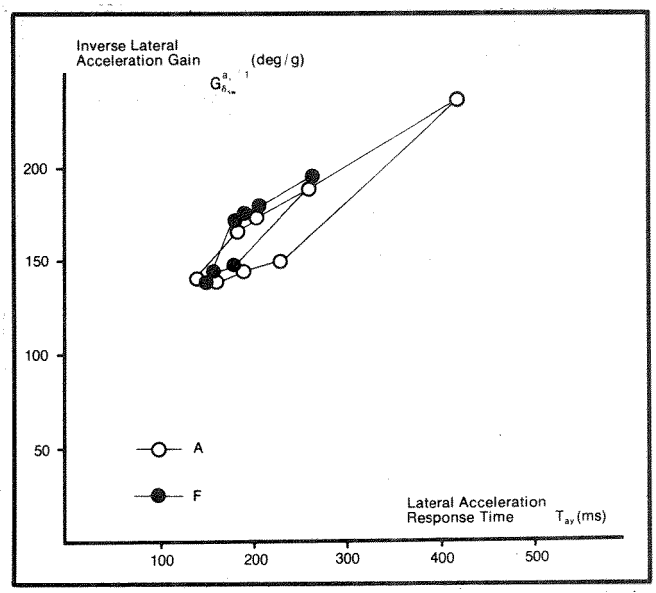


Figure 16. Calculated influence of cornering stiffness on front and rear axle in the range of lateral accelerations $a_y \simeq 2$ (m/s²) to $a_y \simeq 7$ (m/s²) on inverse gain/response time characteristic.

A. Former production Volvo 264 GLE (data according to Appendix) with m_F = 1.9 (−) and m_R = 1.9 (−)
F. As vehicle A except m_F = 3.0 (−) and m_R = 3.0 (−)

2 (m/s²) and a_y = 7 (m/s²). A considerable reduction of inverse gain and response time can be noticed particularly at high lateral accelerations. As can be seen from the equations in the Appendix, increased cornering stiffness both on front $(\partial S/\partial\alpha)_F$ and rear $(\partial S/\partial\alpha)_R$ axles leads to increased damping ratio ζ (−) but, above all, to increased natural frequency υ_f (Hz) of the vehicle system which, of course, also means a reduction in response time.

If now all the new system characteristics are put in to the mathematical model including the characteristics for the new front and rear wheel suspensions, the inverse gain/response time diagram will change as shown in Figure 17. Here, both inverse gain and response time have been reduced considerably which is increasing predictability and steering precision.

The Measured Steering Control Characteristics of the Volvo 760 GLE

The measured results of inverse gain and response time for the new Volvo 760 GLE and the Volvo 264 GLE are shown in Figure 18. As already indicated in Figure 17, inverse gain and response time have been reduced in the 760 GLE due to the different subsystem changes which have been mentioned before.

Lowest and highest inverse gain has been reduced from 140-230 (deg/g) to 120-175 (deg/g) at the same lateral

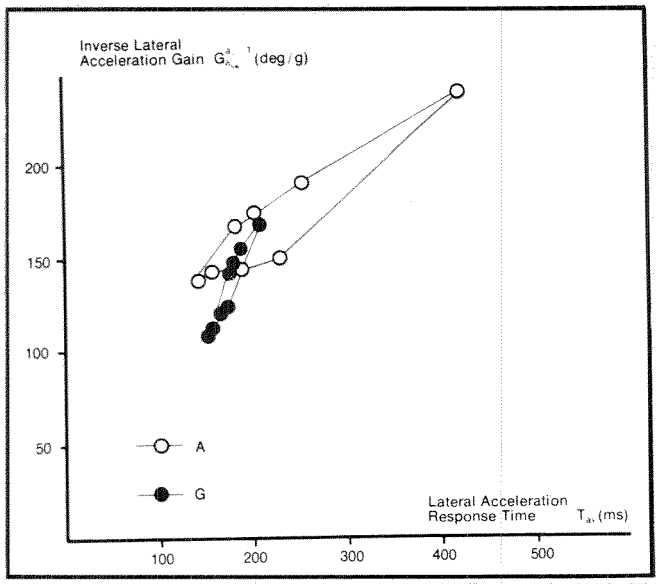


Figure 17. Calculated influence of all the new system characteristics on inverse gain/response time characteristic.

A. Former production system (see Appendix)
B. New production system (see Appendix)

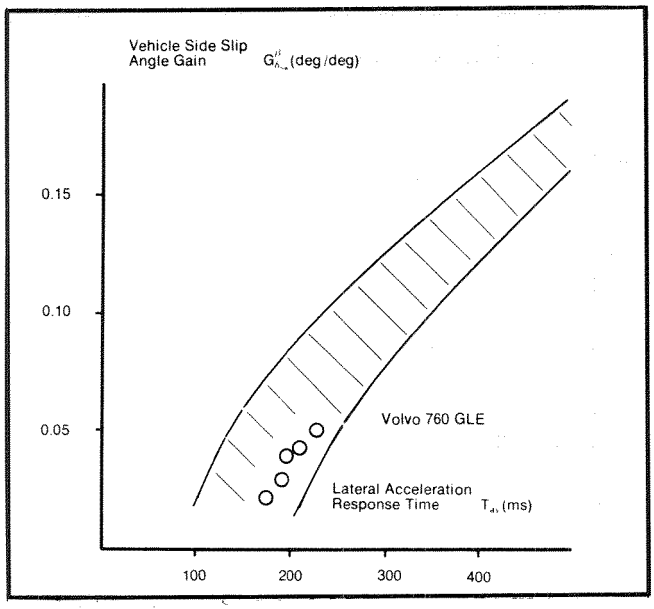


Figure 19. The range of vehicle side slip angle gain $G^{\beta}_{\delta_{sw}}$ (deg/deg) versus lateral acceleration response time T_{ay} (ms) for 6 different cars and the Volvo 760 GLE measured on high friction surface with sinusoidal steering wheel angle input at a steering frequency of $f_{sw} = 0.3$ (Hz). The measurements on the Volvo 760 GLE are performed with lateral accelerations between $a_y = 5$ (m/s^2) and $a_y = 9$ (m/s^2).

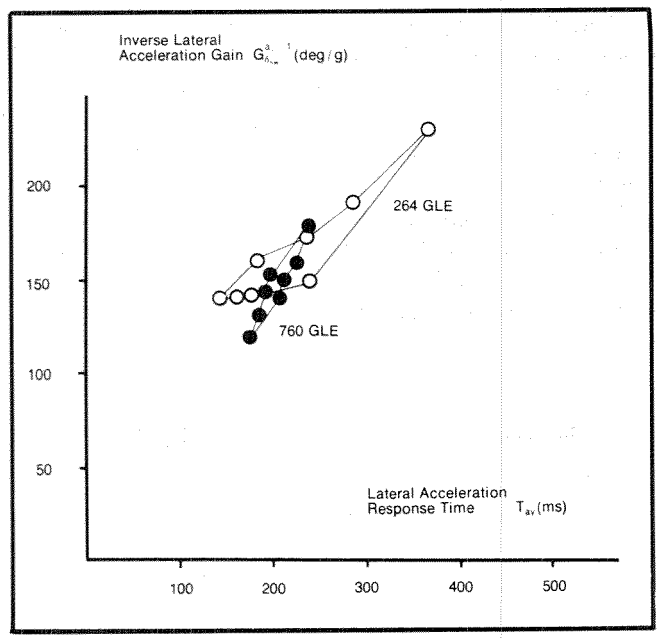


Figure 18. Measured results of inverse lateral acceleration gain versus lateral acceleration response time characteristic for the former production Volvo 264 GLE and the new 760 GLE.

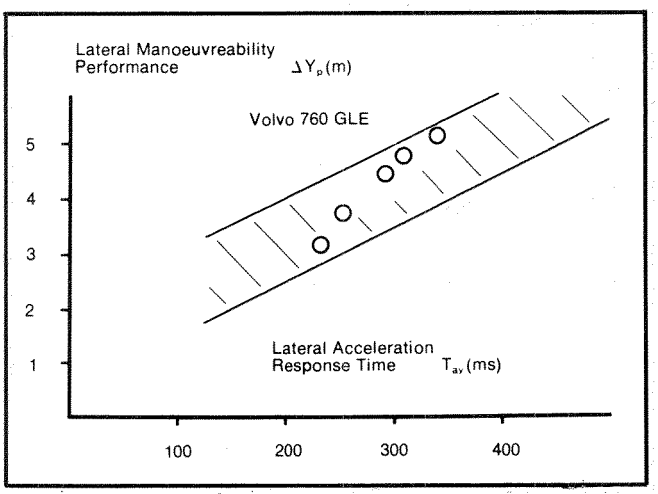


Figure 20. Typical range of lateral manoeuvreability performance ΔY_p (m) versus lateral accelertion response time T_{ay} (ms) at different lateral accelerations a_{ymax} (m/s^2), a steering frequency of $f_{sw} = 0.7$ (Hz) and a vehicle speed of $u_o = 80$ (km/h) for 25 different passenger cars and the Volvo 760 GLE measured on high friction surface. The measurements on the 760 GLE are performed with lateral accelerations between $a_y = 5$ (m/s^2) and $a_y = 8.5$ (m/s^2).

acceleration level. This leads to better steering precision and more highway driving comfort.

The highest lateral acceleration response time has been reduced from about 370 (ms) down to 240 (ms) measured at the same lateral acceleration level. It must be mentioned here that the 760 GLE was able to perform higher lateral accelerations than the 264 GLE, which is expected with respect to the tyres used on the 760 GLE.

It is certainly of interest to discuss how the lateral acceleration response time could be kept low even when cornering stiffness is decreasing at increased lateral acceleration.

In a simple oscillation system, the response time is a function of the natural frequency and the damping factor, and therefore also a function of spring stiffness and damping. If the spring stiffness is decreasing, the response time is increasing.

The two degree of freedom vehicle system, as described in the Appendix, is somewhat more complex. Here, the response time can be held relatively low even if the stiffness is decreasing. In this system, the lateral acceleration response time T_{ay} at the steering frequency $f_{sw} = 0$ (Hz) can be defined as follows:

$$T_{ay} = \left(\frac{b}{u_o} - \frac{2\zeta_f}{\upsilon_f}\right) \cdot 1000 \qquad \text{(ms)}$$

b = Distance, centre of gravity to rear axle

u_o = Vehicle speed

ζ_f = Damping factor

υ_f = Undamped natural frequency

In the previous equation, the undamped natural frequency can be written as follows:

$$\upsilon_f = \sqrt{\frac{\left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot \left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot (a + b)^2 + m \cdot u_o^2 \left(\left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot b - \left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot a\right)}{m^2 \cdot k_z^2 \cdot u_o^2}} \qquad \text{(rad/s)}$$

where

$\left(\frac{\partial S}{\partial \alpha}\right)_{FT}$ = Total cornering stiffness on front axle

$\left(\frac{\partial S}{\partial \alpha}\right)_{RT}$ = Total cornering stiffness on rear axle

a = Distance, centre of gravity to front axle

b = Distance, centre of gravity to rear axle

m = Total vehicle weight

k_z = Radius of gyration around vertical axis

u_o = Vehicle speed

As can be seen in the equations above, the undamped natural frequency and therefore the response time can be influenced by the:

—product of the total cornering stiffness on the front and rear axle and the;
—difference of the total cornering stiffness on the front and rear axle.

The total cornering stiffness on front and rear axle, on the other hand, is influenced by:

—tyre cornering stiffness
—side force steering in the wheel suspension
—roll steering in the wheel suspension; and
—camber steering in the wheel suspension.

It is quite obvious from the equations above that if the tyre cornering stiffness is decreasing, the difference of total cornering stiffness has to be increased if the natural frequency should be held low. This again keeps the response time in the system low. That is what has been done in the Volvo 760 GLE in order to keep the area of the carpet type characteristic shown in Figure 18 as little as possible.

The Stability Characteristic of the Volvo 760 GLE

The vehicle side slip angle and the vehicle side slip angle gain are important stability characteristics. Figure 19 shows the vehicle side slip angle gain versus lateral acceleration response time for the Volve 760 GLE and the range of 6 different cars both with front and rear wheel drive measured on a high friction surface.

The measured results for the 760 GLE in the diagram cover lateral accelerations between $a_y = 5$ (m/s^2) and $a_y = 9$ (m/s^2). The diagram shows that the side slip angle gain at 9 (m/s^2) lateral acceleration is relatively low, which means high stability at the side force limit.

The diagram does not show any measurements below the lateral acceleration of $a_y = 5$ (m/s^2), because side slip gain and response time are practically not changing.

The highest side slip angle gain among the 6 cars measured is $G_{\delta}{}^{\beta}{}_{sw} \simeq 0.20$ (deg/deg) at a lateral acceleration

response time of $T_{ay} \simeq 500$ (ms) and a lateral acceleration of $a_y \simeq 8.0$ (m/s^2).

Manoeuvreability versus Stability of the Volvo 760 GLE

Very high stability or very short response time at the side force limit can reduce lateral manoeuvreability, which means the vehicle has difficulties to move laterally at high lateral accelerations. Those vehicles would normally be called heavy understeering vehicles.

Figure 20 shows a typical range of lateral manoeuvreability performance versus the lateral acceleration response time for 25 different cars measured on a high friction surface.

The diagram in Figure 20 indicates that the 760 GLE has good manoeuvreability performance at relatively low lateral acceleration response time. This also means good manoeuvreability at a high stability level.

SUMMARY AND CONCLUSIONS

The development of steering control, stability and manoeuvreability performance characteristics for the new Volvo 760 GLE has been described. The characteristics have been measured and compared with other passenger cars. Furthermore, requirements on steering characteristics related to the driver's performance ability obtained during the research in the Volvo Car Corporation have been described.

The Volvo 760 GLE shows a combination of high steering precision, high lateral manoeuvreability performance and high yaw stability. Normally, high steering precision or high lateral acceleration gain tend to give a lower level of yaw stability.

The combination of high steering precision and high yaw stability has been reached by optimization of a number of different vehicle subsystems. The systems and vehicle parameters which are contributing the most to the new steering characteristics in the 760 GLE are:

- —the new wheel suspension characteristics especially in the rear axle
- —the increased percentage of weight on the front axle
- —the increased torsional stiffness between steering wheel and front wheels
- —the tyres with higher side force capability
- —the reduced aerodynamic yaw coefficient of the body due to the unusual body shape.

The very limited variation of the steering characteristics for the 760 GLE in the entire range of lateral accelerations will increase the level of safety in the driver/vehicle system on all surface friction levels. This is especially important on low friction surfaces, because the variation of steering characteristics is always increasing when the surface friction level is decreasing.

5. LIST OF SYMBOLS

A_2	Numerator time constant
A_3	Numerator time constant
A_4	Numerator time constant
Aa_y	Amplitude of lateral acceleration
$a_{\delta sw}$	Amplitude of steering wheel angle
a	Distance, centre of gravity to front axle
a_y	Lateral acceleration
a_{ymax_F}	Lateral acceleration at which $\left(\frac{\partial S}{\partial \alpha}\right)_F = 0$
a_{ymax_R}	Lateral acceleration at which $\left(\frac{\partial S}{\partial \alpha}\right)_R = 0$
ay_p	Peak value of lateral acceleration
b	Distance, centre of gravity to rear axle
C	Total vehicle roll stiffness (excluding tyres)
$C1_F$	Cornering stiffness at $a_y = 0$, front axle
$C1_R$	Cornering stiffness at $a_y = 0$, rear axle
CS_L	Torsional stiffness between steering wheel and front wheels
CS_F	Torsional stiffness front wheel suspension around vertical axis
CS_R	Torsional stiffness rear wheel suspension around vertical axis
f_{sw}	Steering wheel angle frequency
$G\frac{a_y}{\delta_{sw}}(j\omega)$	Lateral acceleration gain
$G\frac{\beta}{\delta_{sw}}(j\omega)$	Vehicle side slip angle gain
h	Height, centre of gravity, total weight
i_s	Total steering gear ratio
j	$\sqrt{-1}$
k_z	Radius of gyration for total vehicle mass around vertical axis
m	Total vehicle weight
m_F	Tyre constant, front axle
m_R	Tyre constant, rear axle
M_{sw}	Steering wheel torque
$\left(\frac{\partial Mw}{\partial S}\right)$	Tyre castor ground offset
$\left(\frac{M_{sw}}{a_y}\right)$	Steering wheel torque gradient
nc_F	Geometrical castor, front wheel suspension
n_F	Distance, turning centre to wheel centre around vertical axis, front wheel suspension
n_R	Distance, turning centre to wheel centre around vertical axis, rear wheel suspension
r_F	Roll centre height front axle
r_R	Roll centre height rear axle
$\left(\frac{\partial S}{\partial \alpha}\right)_{FT}$	Total cornering stiffness, front axle
$\left(\frac{\partial S}{\partial \alpha}\right)_{RT}$	Total cornering stiffness, rear axle

$\left(\frac{\partial S}{\partial \alpha}\right)_F$	Tyre cornering stiffness, front axle
$\left(\frac{\partial S}{\partial \alpha}\right)_R$	Tyre cornering stiffness, rear axle
$\left(\frac{\partial S}{\partial \gamma}\right)_F$	Tyre side force due to camber angle, front axle
$\left(\frac{\partial S}{\partial \gamma}\right)_R$	Tyre side force due to camber angle, rear axle
T	Time
t	Time, general
T_{ay}	Lateral acceleration response time
u_o	Vehicle forward velocity, constant value
ΔY_p	Peak value of lateral vehicle deviation
α	Axle side slip angle
β	Vehicle side slip angle
$\dot{\beta}$	Vehicle side slip angle velocity
$\left(\frac{\partial \gamma}{\partial \phi}\right)_F$	Camber steer coefficient, front axle
$\left(\frac{\partial \gamma}{\partial \phi}\right)_R$	Camber steer coefficient, rear axle
δ_{sw}	Steering wheel angle
$\left(\frac{\partial \epsilon}{\partial \phi}\right)_F$	Roll steer coefficient, front wheels
$\left(\frac{\partial \epsilon}{\partial \phi}\right)_R$	Roll steer coefficient, rear wheels
ζ_f	Damping ratio
ν_f	Undamped natural frequency
ϕ	Roll angle
$\dot{\psi}$	Yaw velocity
$\ddot{\psi}$	Yaw acceleration
ω	Disturbance frequency

6. LIST OF REFERENCES

1. Jaksch F. O. "The Steering Characteristics of the Volvo Concept Car" VIIIth ESV Conference, Wolfsburg, October, 1980
2. Jaksch F. O. "Vehicle Characteristics Describing the Steering Control Characteristics of Cars" VIIth ESV Conference, Paris, June, 1979
3. McRuer D. et al. "Automobile Controllability—Driver/Vehicle Response for Steering Control" US Department of Transportation, Report No. DOT-HS-801-407
4. Lincke W., Richter B., Schmidt R. "Simulation and Measurement of Driver-Vehicle Handling Performance" SAE Paper 730489 May, 1973
5. Jaksch F. O. "Driver—Vehicle Interaction with Respect to Steering Controllability" SAE Paper 790740 June, 1979
6. Rönitz R., Braess H. H., Zomotor A. "Verfahren und Kriterien zur Bewertung des Fahrverhaltens von Personenkraftwagen" Automobil Industrie Volume 1 and 3 1977.
7. Richter B. "Driving Simulator Studies: The Influence of Vehicle Parameters on Safety in Critical Situations" SAE Paper 741105 October, 1974
8. Mitschke M. "Dynamik der Kraftfahrzeuge" Handbook in Automobile Engineering Springer Verlag Berlin, Heidelberg, New York 1972
9. Mitschke M. "Comparison of the Stability of Front Wheel and Rear Wheel Steering Motor Vehicles" International Association of Vehicle System Dynamics (IAVSD), Berlin 1979
10. Mitschke M. "Wichtige Daten fur die Kurshaltung von Kraftfahrzeugen" Automobiltechnische Zeitschrift ATZ 80, No. 6, 1978

7. APPENDIX

Mathematical Model

The equations of motion for the linear, two degree of freedom vehicle system used for the calculations are the following

$$m \cdot u_o \cdot \dot{\beta} - \left(-m \cdot u_o^2 + \left(\left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot b - \left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot a\right)\right) \cdot \frac{\psi}{u_o} + \left(\left(\frac{\partial S}{\partial \alpha}\right)_{FT} + \left(\frac{\partial S}{\partial \alpha}\right)_{RT}\right) \cdot \beta = \left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot \delta_{sw} \cdot \frac{1}{i_s}$$

$$I \cdot \ddot{\psi} + \left(\left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot a^2 + \left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot b^2\right) \frac{\dot{\psi}}{u_o} - \left(\left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot b - \left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot a\right) \cdot \beta = \left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot \delta_{sw} \cdot \frac{1}{i_s} \cdot a$$

The lateral acceleration gain $G^{a_y}_{\delta_{sw}}$ due to steering wheel angle input derived from the differential equation above is

$$G^{a_y}_{\delta_{sw}}(j\omega) = G^{a_y}_{\delta_{sw}}(0)\,\frac{(1 - A_3 \cdot \eta^2) + (j \cdot A_4 \cdot \eta)}{(1 - \eta^2) + (j \cdot 2 \cdot \zeta_f \cdot \eta)}$$

where

$$G^{a_y}_{\delta_{sw}}(0) = \frac{\left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot \left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot (a + b)}{m^2 \cdot k_z^2 \cdot v_f^2 \cdot i_s}$$

$$A_3 = \frac{m \cdot k_z^2 \cdot v_f^2}{\left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot (a + b)}$$

$$A_4 = \frac{b \cdot v_f}{u_o}$$

$$\eta = \frac{\omega}{v_f} = 2\pi \cdot \frac{f_{sw}}{v_f}$$

The vehicle side slip angle gain $G^{\beta}_{\delta_{sw}}$ due to steering wheel angle input is

$$G^{\beta}_{\delta_{sw}}(j\omega) = G^{\beta}_{\delta_{sw}}(0)\,\frac{1 + (j \cdot A_2 \cdot \eta)}{(1 - \eta^2) + (j \cdot 2 \cdot \zeta_f \cdot \eta)}$$

where

$$G^{\beta}_{\delta_{sw}}(0) = \frac{\left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot \left(m \cdot u_o^2 \cdot a - \left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot b \cdot (a + b)\right)}{m^2 \cdot k_z^2 \cdot u_o^2 \cdot v_f^2 \cdot i_s}$$

$$A_2 = \frac{m \cdot k_z^2 \cdot u_o \cdot v_f}{m \cdot u_o^2 \cdot a - \left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot b \cdot (a + b)}$$

The undamped natural frequency v_f and the damping factor ζ_f are

$$\zeta_f = \frac{\frac{1}{k_z^2}\left(\left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot a^2 + \left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot b^2\right) + \left(\frac{\partial S}{\partial \alpha}\right)_{FT} + \left(\frac{\partial S}{\partial \alpha}\right)_{RT}}{2 \cdot m \cdot u_o \cdot v_f}$$

$$v_f = \frac{\left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot \left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot (a + b)^2 + m \cdot u_o^2 \left(\left(\frac{\partial S}{\partial \alpha}\right)_{RT} \cdot b - \left(\frac{\partial S}{\partial \alpha}\right)_{FT} \cdot a\right)}{m^2 \cdot k_z^2 \cdot u_o^2}$$

The equations for the total cornering stiffness front and rear $(\partial S/\partial\alpha)_{FT}$, $(\partial S/\partial\alpha)_{RT}$ or total cornering compliance $(\partial\alpha/\partial S)_{FT}$, $(\partial\alpha/\partial S)_{RT}$ can be written as follows

$$\left(\frac{\partial \alpha}{\partial S}\right)_{FT} = \left(\frac{\partial \alpha}{\partial S}\right)_{F} + \left(\left(\frac{\partial \epsilon}{\partial \phi}\right)_{F} + \left(\frac{\partial \gamma}{\partial \phi}\right)_{F} \cdot \left(\frac{\partial S}{\partial \gamma}\right)_{F} \cdot \left(\frac{\partial \alpha}{\partial S}\right)_{F}\right) \frac{1}{C}\left(h - \frac{a \cdot r_R + b \cdot r_F}{(a + b)}\right) + \left(\frac{\partial Mw}{\partial S}\right)_{F} \cdot \left(\frac{1}{CS_L} + \frac{1}{CS_F}\right) + \left(\frac{\partial n_{cF}}{\partial_{CSL}}\right) + \left(\frac{\partial n_F}{\partial_{CSF}}\right)$$

$$\left(\frac{\partial \alpha}{\partial S}\right)_{RT} = \left(\frac{\partial \alpha}{\partial S}\right)_{R} + \left(\left(\frac{\partial \epsilon}{\partial \phi}\right)_{R} + \left(\frac{\partial \gamma}{\partial \phi}\right)_{R} \cdot \left(\frac{\partial S}{\partial \gamma}\right)_{R} \cdot \left(\frac{\partial \alpha}{\partial S}\right)_{R}\right) \frac{1}{C}\left(h - \frac{a \cdot r_R + b \cdot r_F}{(a + b)}\right) + \left(\frac{\partial_{Mw}}{\partial S}\right)_{R} \cdot \frac{1}{CS_R} + \left(\frac{\partial n_R}{\partial CS_R}\right)$$

The lateral acceleration response time T_{ay} is defined as follows

$$T_{ay} = \frac{\phi(\omega)}{\omega} = \frac{1}{2\pi}\,\frac{\phi(\omega)}{f_{sw}}$$

where

$$\phi(\omega) = \frac{((A_4 \cdot \eta) \cdot (1 - \eta^2) - (1 - A_3 \cdot \eta^2) \cdot (2 \cdot \zeta_f \cdot \eta))}{((1 - A_3 \cdot \eta^2) \cdot (1 - \eta^2) + (A_4 \cdot \eta) \cdot (2 \cdot \zeta_f \cdot \nu))}$$

The simplified model which has been used to simulate the total cornering stiffness on front and rear axle $(\partial S/\partial\alpha)_F$, $(\partial S/\partial\alpha)_R$ due to tyre slip has been defined as follows

$$\left(\frac{\partial S}{\partial \alpha}\right)_{F,R} = C_{1_{F,R}} \left(1 - \left(\frac{a_y}{ay_{max_{F,R}}}\right)^{m_{F,R}}\right)$$

Vehicle Data Used during the Calculation

	Former Production Volvo 264 GLE	New Production Volvo 760 GLE	
m	= 1450	1400	(kg)
k_z	= 1.32	1.37	(m)
a	= 1.27	1.20	(m)
b	= 1.37	1.57	(m)
u_o	= 22.22	22.22	(m/s)
i_s	= 17	17	(−)
CS_L	= 6500	15000	(Nm/rad)
[1] $\left(\frac{\partial \epsilon}{\partial \phi}\right)_F$	= 0.08	0.05	(deg/deg)
[2] $\left(\frac{\partial \epsilon}{\partial \phi}\right)_R$	= −0.02	0.02	(deg/deg)
$\left(\frac{\partial \gamma}{\partial \phi}\right)_F$	= 0.8	0.9	(deg/deg)
$\left(\frac{\partial \gamma}{\partial \phi}\right)_R$	= 0	0	(deg/deg)
$\left(\frac{\partial S}{\partial \gamma}\right)_F$	= 2000	2000	(N/rad)
$\left(\frac{\partial S}{\partial \gamma}\right)_R$	= 2000	2000	(N/rad)
C	= 50000	45000	(Nm/rad)
h	= 0.55	0.55	(m)
r_F	= 0.03	0.01	(m)
r_R	= 0.30	0.30	(m)
$\left(\frac{\partial_{Mw}}{\partial S}\right)_F$	= 0.05	0.05	(m)
$\left(\frac{\partial_{Mw}}{\partial S}\right)_R$	= 0.05	0.05	(m)
CS_F	= 80000	80000	(Nm/rad)
CS_R	= 100000	40000	(Nm/rad)
[1] nc_F	= 0.018	0.018	(m)
[2] n_F	= 0.05	0.05	(m)
n_R	= 0.05	0.05	(m)
S	= [3]1.38	1.45	(m)
f_{sw}	= 0.3-0.7	0.3-0.7	(Hz)
a_y	= 0-7	0-7	(m/s²)
ay_{max_F}	= 11	11	(m/s²)
m_F	= 1.9	3.0	(−)
C_{1_F}	= 100000	110000	(N/rad)
ay_{max_R}	= 11.5	12.5	(m/s²)
m_R	= 1.9	3.0	(−)
C_{1_R}	= 100000	110000	(N/rad)

[1] + Understeering
− Oversteering
[2] + Oversteering
− Understeering
[3] Average of front and rear track

Mathematical Tyre Model Used During the Calculation

The mathematical tyre model used during the calculation describes the cornering stiffness $(\partial S/\partial\alpha)_{F,R}$ on the front and rear axle as a function of the lateral acceleration a_y. This cornering stiffness characteristic includes the tyre cornering stiffness itself and the influence of the wheel load transfer on the front and rear axle caused by wheel suspension springs and roll stabilizers.

The tyre model equation is defined as follows:

$$\left(\frac{\partial S}{\partial \alpha}\right)_{F,R} = C_{1_{F,R}} \left(1 - \frac{a_y}{ay_{max_{F,R}}}\right)^{m_{F,R}} \quad (N/rad)$$

where

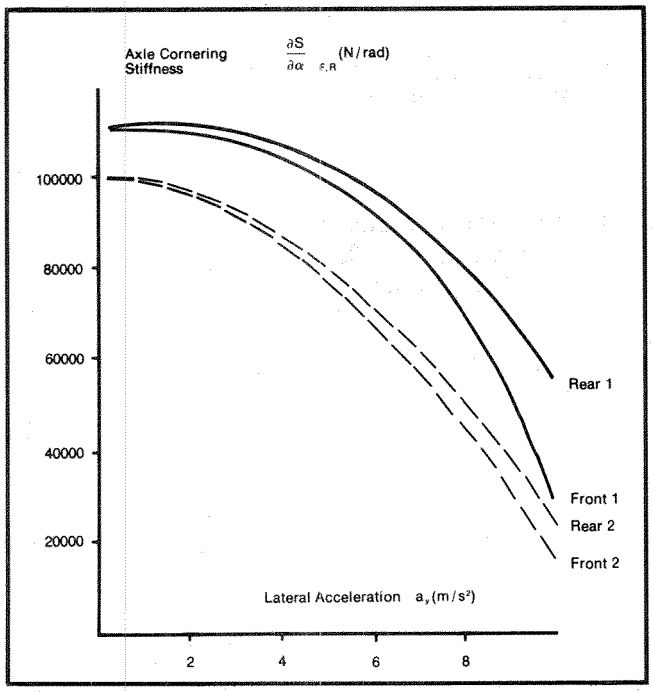
$C_{1_{F,R}}$ = Cornering stiffness on front and rear axle at lateral acceleration $a_y = 0$ (m/s²).

a_y = Lateral acceleration of the vehicle.

$ay_{max_{F,R}}$ = Lateral acceleration on front and rear axle at which the cornering stiffness $(\partial S/\partial\alpha)_{F,R} = 0$ (N/rad).

$m_{F,R}$ = Factor influencing the cornering stiffness in the range $a_y = 0$ (m/s²) and $a_y = ay_{max}$.

The cornering stiffness characteristics used during the calculations are shown in the diagram following.



Tyre cornering stiffness on front and rear axle $(\partial S/\partial \alpha)_{F,R}$ versus lateral acceleration a_y (m/s²) for two different tyre/wheel suspension combinations.

Combination 1

ay_{max_F}	= 11.0	(m/s²)
m_F	= 3.0	(–)
C_{1_F}	= 110000	(N/rad)
ay_{max_R}	= 12.5	(m/s²)
m_R	= 3.0	(–)
C_{1_R}	= 110000	(N/rad)

Combination 2

ay_{max_F}	= 11.0	(m/s²)
m_F	= 1.9	(–)
C_{1_F}	= 100000	(N/rad)
ay_{max_R}	= 11.5	(m/s²)
m_R	= 1.9	(–)
C_{1_R}	= 100000	(N/rad)

Aerodynamics of Trailer Towing

JOHN ZELLNER
Systems Technology, Inc.
LLOYD H. EMERY
National Highway Traffic Safety Administration

ABSTRACT

An experimental investigation of combination vehicle aerodynamics, pertinent to crosswind and truck-induced disturbances, was performed. This was accomplished via 1/10 scale model wind tunnel measurements performed on 6 trailers and 4 tow vehicles, and various combinations thereof. For some tests, a non-metric tractor trailer model was placed in the flow field near the combination vehicle model. A large data base of aerodynamic characteristics was generated comprising 6 force and moment coefficients as a function of crosswind angle. The effects of airspeed, articulation angle, trailer and tow vehicle shape, surface roughness, and truck proximity were quantified. Preliminary results suggested some design and development guidelines for manufacturers, and ranges of crosswind sensitivity for various vehicle shape features.

ACKNOWLEDGEMENTS

The author is indebted to Systems Technology, Inc. (STI) for their excellent work (Ref. 2) in exploring the aerodynamic characteristics of passenger vehicle/trailer combinations. This paper is essentially a report of the work performed during the referenced study.

INTRODUCTION

Current industry research has a strong emphasis on fuel economy considerations. Aerodynamic changes are being made to vehicles and trailers to improve vehicle fuel economy. The effects of crosswinds on vehicle crash avoidance capabilities cannot be neglected, especially since the solutions to fuel economy problems may aggravate vehicle stability problems. A review of accident investigation reports related to wind conditions has shown that wind-related accidents occur more frequently for vehicles towing trailers and other recreational vehicles than for any other vehicle type.

These data were supported by recent results of full scale crosswind tests (Ref. 1) on a sample of vehicles. Although some vehicles had little or no problems, some trailers were found to have directional control instabilities induced by the driver attempting to maintain lane position after being hit by a gust. Other vehicles were found to have basic rollover problems due to their high side area to mass ratio. In some cases high crosswind velocities changed a directional control problem into a potential rollover problem.

In summary, prior research has shown the need for further development, analysis, and recommendations for the RV public and industry regarding trailer towing in crosswinds. For example, it would be desirable to provide a more definitive basis for advising certain vehicles not to travel during high wind conditions. Currently a blanket "campers and trailers prohibited" statement is issued in some states in the U.S., which may ban some vehicles that do not have significant wind problems. On the other hand, vehicles with more serious problems may be allowed to proceed. Subsequent research may make it possible to placard certain vehicles with a maximum safe crosswind speed, for the benefit of drivers. Using another approach it would also be desirable to develop design guidelines for trailers, hitches, and hookup practices that would minimize combination vehicle crosswind sensitivity.

OBJECTIVES

The overall objectives of the study (Ref. 2) were to:

- Analyze and quantify the instability of tow vehicle-trailer combinations under crosswind disturbances.
- Measure the basic aerodynamic properties of selected tow vehicle-trailer combinations.
- Investigate via computer simulation the dynamic stability of various combinations under simulated crosswind disturbances.
- Perform a series of full scale tests of combination vehicles to verify selected simulation results.
- Develop recommended design criteria for improved stability in crosswinds and consumer guidelines for proper tow vehicle-trailer crosswind operation.

This paper will describe the results of the "aerodynamic measurements" and parts of the "simulation" tasks. The performance of a series of full scale tests of combination vehicles to verify selected simulation results is planned for a future research activity. Preliminary recommended design criteria for improved stability in crosswinds and consumer guidelines for proper tow vehicle-trailer crosswind operation will also be made.

BACKGROUND

The current research described in this paper is part of a logical sequence of investigations by the U.S. Department of Transportation, National Highway Traffic Safety

Administration (NHTSA) into the dynamics of trailer towing, and as such was motivated by existing experimental data.

It has long been known that articulated road vehicles can exhibit various stability problems, such as tail wagging or "swing" oscillations, and jackknifing. Early attempts were made in the academic and automotive fields to examine these problems analytically.

Analytical models of tow-vehicle/trailer combinations have been around since the 1930s, and a wide variety of models and simulations currently exist at various stages of development. The real impetus for articulated vehicle modeling occurred in the late 1950s when tire slip models were developed for studies of automobile dynamics. By the mid-1960s, Jindra in the U.S. (Ref. 3), Ellis in the United Kingdom (Ref. 4), and Kullberg in Sweden (Ref. 5) were considering the linear stability of car/trailer systems via mathematical models. The Swedish work included some experimental studies comparing full scale and linear model results.

Subsequent modeling work involved development of digital and hybrid simulations of tow-vehicle/trailer systems. Ellis' (Ref. 6) braking-while-turning nonlinear simulation was probably one of the earliest examples of these.

The next wave of models was directed toward tractor-semitrailer dynamics. By 1971, Mikulcik (Ref. 7) had developed a digital computer model having 6 degrees of freedom for both tractor and trailer. Krauter, Susemihl, Tobler, and Vincent (Refs. 8-13) extended Mikulcik's model to include wheel dynamics, multiple axles, and various tire models, resulting in a 22 degree of freedom model. Other work by Highway Safety Research Institute, IIT Research Institute, Systems Technology, Inc., and others has carried the truck dynamics area to levels of greater completeness and complexity.

Up to this point, most of the analytical models:

- Focused on tractor/semitrailer dynamics.
- Did not include the effects of crosswinds and aerodynamic disturbances.
- Lacked validation with respect to car/trailer response.

Some work by the automotive industry in the late 1960s began to emphasize car/trailer dynamic simulations (e.g., Ref. 14) and aerodynamics. Still, perhaps the high water mark in car/trailer aerodynamic disturbance simulation occurred in the early 1970s. This was associated with a Federal Highway Administration study (Ref. 15) of truck and bus induced aerodynamic disturbances. A digital simulation was developed including car/trailer dynamics, closed-loop driver model, and the disturbing aerodynamic forces and moments due to a large adjacent vehicle. Numerous analyses were conducted to assess the effects of, for example, increased bus and truck width, driver control techniques, wind conditions and relative speed, lane width, etc.

In the mid-1970s, an initial landmark NHTSA study was accomplished at STI involving the development of car/trailer handling test procedures (Ref. 16). This examined 20 or so maneuvers and ended up with four most critical ones useful in assessing handling and stability. This was supported by linear and nonlinear modeling efforts. A spinoff from the Ref. 16 trailer study involved a simulation development and validation performed by a Canadian researcher (Ref. 17). Anderson's objective was to develop the simplest simulation that would adequately match actual full scale data. Several levels of simulation were developed. The simplest of these, a 4 degree of freedom nonlinear model, gave close agreement with the NHTSA full scale data.

Other NHTSA efforts, also conducted at STI, were aimed at defining:

- Recommended trailering practices.
- Consumer guidelines for trailering.
- Possible trailer handling and braking standards.

These included the Ref. 18 investigation of load equalizing type hitch; development of handling standards in Ref. 15; and design and testing workshops for trailer industry representatives.

In an investigation of aerodynamic crosswind sensitivity of various vehicle classes reported in Ref. 1, STI verified that passenger vehicle/trailer combinations—along with 2 wheeled vehicles—exhibit relatively high sensitivity and possible loss of control behavior when subjected to realistically heavy gusts. Moreover, the problem was related to driver/vehicle interaction and driving technique, as well as vehicle configuration. The results provided the main strong incentive for the current study.

Accident Data

Among U.S. road vehicles involved in accidents, passenger vehicle/trailer combinations account for less than 1 percent of the total fatality and injury producing accidents, over the past decade. This good record is generally ascribed to low exposure and high personal investment—and, therefore, conservative driving patterns—of the trailering public (Ref. 20). At the same time, it has been observed that such accidents can have relatively high costs in terms of personal and property loss.

Accident data on trailer towing is sparse at best, especially in terms related to vehicle selection factors. The two main extant sources of such data are the studies by the University of California at Los Angeles (UCLA) (Ref. 20) and the University of Kentucky (Ref. 21).

Not surprisingly, among trailer accident, potential loss of control and vehicle dynamic factors appear quite prevalent. Reference 20 data show that in all trailer towing accidents studied, from 50-60 percent were *single vehicle.* Of these single vehicle accidents about one-third were attributed to crosswinds or aerodynamic disturbance from

Table 1. Probable cause of single vehicle trailering accidents (Ref. 20).

Probable Causes	California (n = 44)	New Mexico (n = 100)
Wind	20.4%	27.0%
Passing truck or bus	11.4	6.0
Total Possible Aerodynamic Causes	31.8%	33.0%

a passing bus or truck, as shown in Table 1. So, possible aerodynamic problems were the most common causes of single vehicle trailering accidents. Also, 80 to 90 percent of the single vehicle accidents resulted in an overturned trailer, underlining the relatively large values of c.g. height to track ratios occurring in trailers. This may also suggest that trailer roll motions can be important in some aerodynamic disturbance situations, and this has been observed in the previous experimental work (e.g., Ref. 1).

A second study concentrating on recreational vehicles (Ref. 21) provided multidisciplinary accident reports on 226 cases of which 173 (77 percent) involved trailers. For the total sample, wind was a relevant accident causal factor in 26 cases, or between 10 and 15 percent of the trailer accidents. The type, direction, and magnitude of wind in these 26 cases, or between 10 and 15 percent of the trailer accidents. The type, direction, and magnitude of wind in these 26 accident cases are listed in Table 2. These results indicate that the most likely accident scenario occurs when the recreational vehicle is in the vicinity of another vehicle, and with the wind blowing from the left at moderate (10-20 mph) speed. This condition is likely to occur when the vehicle is passed by a larger vehicle.

Though the categories of tow vehicle types involved in the Ref. 21 trailer accidents are different from those of Ref. 20, the results showed that:

Table 2. Wind conditions for 26 RV accidents from Kentucky MDAI study (Ref. 21).

Condition	Percent	Description
Type of wind	35	Sudden wind gust
	12	Sudden variation due to roadside break
	53	Vortex from other vehicle
Wind direction	50	From left
	31	From right
	25	Variable
	4	Other
Wind magnitude	27	Light (0-10 mph)
	38	Moderate (10-20 mph)
	53	Strong (20 mph)

- Pickups and pickups with camper tops accounted for 34 percent of the tow vehicles, and
- passenger cars (including sedans and station wagons) accounted for 50 percent of the tow vehicles.

These results are in good agreement with the UCLA results.

An example of an aerodynamically induced trailer accident is given in Table 3 and Figure 1, which is a random excerpt from the Kentucky case studies. Here a gust from a passing truck apparently excited a trailer swing oscillation, which rapidly developed into a loss of control situation. Based on this and similar accident scenarios, the recommendations of the University of Kentucky team were:

- Motor Vehicle Safety Standard specifying maximum height of center of gravity and minimum weight to wind pressure area ratios for travel trailers.
- Driver examination/education for licensing specifically for towing of travel trailers.
- Mandatory effective anti-sway devices, with appropriate Motor Vehicle Safety Standard for travel trailers.

These recommendations again emphasize the interplay of driver and vehicle design factors in this type of accident.

Table 3. Example aerodynamically induced trailer accident scenario (Ref. 21).

Excerpt from Fatal Accident
Case No. UK-766-04

Pre-Crash:

V1-combination [sedan-travel trailer] traveling south on Interstate 65 in lane 1 at 45-50 mph (72-80 km); passed by VY (car) and VX (semi-trailer truck) traveling in lane 2; VY traveling 60-65 mph (96-104 km), VX traveling 70 mph (112 km); V1/D steered into lane 1 to pass VY which remained in lane 2 after passing V1-combination; in passing V1-combination the wind vortex created by VX initiated a weaving motion of V1-trailer; the rear of VX narrowly missed the front of V1-car; V1/D steered slightly to right and braked to avoid hitting the rear of VX; this action increased the weaving of V1-trailer; V1/D then steered back to left — attempting to regain control of the trailer; V1-trailer left pavement edge to the right, deposited 42′ (12.8 m) of right tire cornering and braking scrub marks on right shoulder before re-entering lane 1; V1-combination completely out of control; V1-trailer swung back across lane 1 and into lane 2 forcing V1-car crossways in lane 1; V1-trailer tilted about roll axis onto left wheels; left side V1-trailer tires deposited 33′ (10 m) of cornering scrub marks in lane 2 before passing V1-car on the left and re-entering lane 1; trailer still hitched to car.

Crash;

V1-tailer re-entered lane 1 tipped over about the left wheels, left side struck pavement 5′ (1.5 m) beyond end....

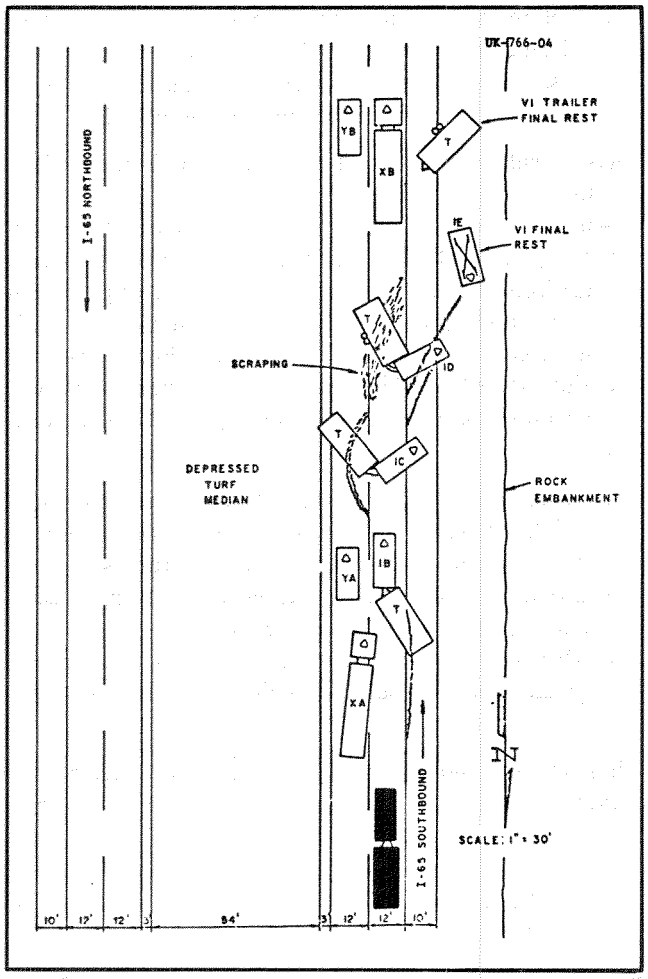


Figure 1. University of Kentucky case no. UK-766-04 (Ref. 21).

On a more detailed level, there appears to be some data relating to vehicle type in the UCLA data base. Figure 2 is based on the Ref. 20 data for 118 trailering accidents in California and New Mexico, and 1,331 responses to a trailer owner use survey. The data are plotted according to tow vehicle type. There seems to be reasonable consensus on the rank ordering of tow vehicle type, i.e.: pickups (including those with cover and camper shells), sedans, and station wagons; followed by carryalls, vans, and motorhomes. Beyond this, there is less agreement among the three data bases. If the California use and accident data were emphasized, pickups would appear to be overrepresented in accident rate relative to their usage, and compared to other vehicle types.

Figure 3 is a similar plot for trailer accident involvement. From this it appears that trailers up to 18 feet in length are under- or proportionately represented in accidents. Above this length, however, involvement rises disproportionately to usage rate. At the extreme trailer lengths, only 3 percent of all trailer accidents are accounted for. The greatest numbers of overinvolved trailers seem to occur at the medium size, 19- to 29-feet range.

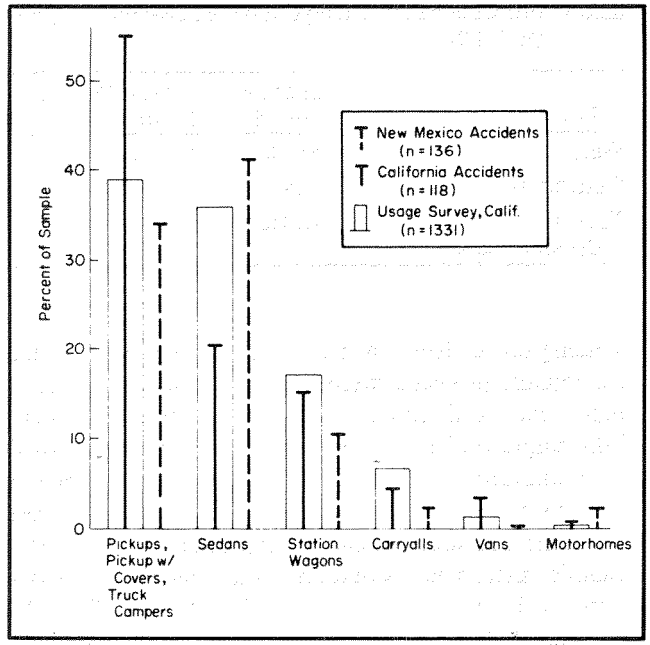


Figure 2. Trailering accident data by tow vehicle type, various samples (Ref. 20).

In summary, trailering accidents account for a small fraction of highway fatalities and injuries (less than 1 percent of the total). Yet, among these, a large portion (10-20 percent) appear to be aerodynamically induced, and one-third of single vehicle trailer accidents seem to be aerodynamically related. Pickup trucks—especially those with campers or covers—sedans, and station wagons are the most common tow vehicles; and medium length trailers seem to be overrepresented in accidents.

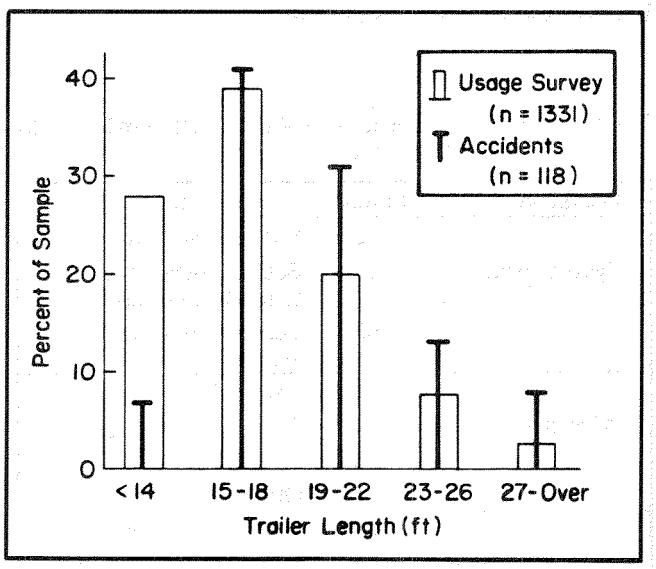


Figure 3. California trailering accident data by trailer length (Ref. 20).

VEHICLE SELECTION

Three passenger type tow vehicles, three recreational trailers, and three utility trailer shapes were selected, which were representative of the range of tow vehicle/trailer combinations existing in the population. The following factors were considered in selection of vehicles:

- Vehicle size and weight.
- Vehicle type, i.e., truck, van, car, etc.
- Vehicle design, i.e., front wheel drive, rear wheel drive, etc.
- Trailer size and weight.
- Trailer geometrical shape.
- Trailer design, i.e., number of axles, c.g. location, etc.
- Existing sales and accident involvement data and trends.
- Requirement for load-leveling trailer hitch.

Other factors also considered were availability of vehicles and previous data (tires, handling dynamics, inertias, etc.), and tow vehicle/trailer compatibility.

Selection Considerations

Tow Vehicle. Of course *tow vehicle size* and *weight* are highly variable in the real world population. Size and weight variables are ordinarily dependent on another variable, i.e., vehicle type. In other words, most domestic pickups and wagons are either large (3600–4600 lb) or compact (e.g., downsized intermediate, 2900–3800 lb), while most American vans are nearly the same length and weight as the large class vehicles. Among the size and weight parameters, side-area-to-weight ratio is a main determinant of aerodynamic sensitivity. Such tow vehicles as lightweight vans and pickup-campers and larger, lightweight travel trailers would tend to show greater lateral accelerations per unit wind gust. For example, other key size-related parameters include tow vehicle wheelbase and yaw moment of inertia.

Example candidate tow vehicles and their characteristics are listed in Table 4.

Tow vehicle types are fairly well defined as: sedan; wagon; carryall; van; and pickup, with or without camper shell. Each of these types is clearly distinguishable in its most relevant factors: profile shape, and the ratio of side area to wheelbase.

A main factor here is the so-called center of pressure location, which in a profile view tends to be near the side area centroid. Imprecisely stated, vehicles with forward or elevated c.p.'s tend to show larger adverse yaw and roll sensitivities to wind gusts, respectively. Again, vans and pickup-campers are the interesting cases in this regard.

Tow vehicle design factors other than size, weight, and shape are also of potential importance. In particular, front/rear weight distribution and tire side force centroid are key factors, as identified in the Ref. 1 study. For the tow vehicle alone case, rearward c.g.'s and tire side force centers tend to yield more sensitivity, all other factors being equal. The extent to which this is true for combination vehicles remains to be determined. A heavy front weight distribution is likely with front wheel drive, and this is increasingly common in sedans. Many other design factors are also involved, such as suspension and steering system design, and these tend to affect the response to gusts and driver control inputs to greater or lesser degrees.

Trailer. Trailer size and weight tends to be proportional for full size travel trailers. That is, most travel trailers average about eight feet in height, and the gross weight runs about 300 lb per body foot (and a little less than this for new and future models). Again, among size parameters the more sensitive aerodynamic cases would be the greatest side-area-to-weight ratios, so the interesting cases are probably the longest trailers at their lightest (empty) weights. Newer, medium length, lightweight trailers are also interesting since they probably represent the wave of the 1980s.

Trailer geometrical shape may have a fairly important effect on aerodynamic sensitivity, though little data are currently available here (Ref. 22 is a first cut). For a given side area, trailers with less resistance to crossflow (i.e., more streamlined in cross section) might be expected to show somewhat reduced sensitivity compared to flatsided models. The main example of the former is trailers such as the Airstream. "Center of pressure" location (i.e., aerodynamic yaw moment) is again a potentially important factor, in both yaw and roll sensitivities to crosswind gusts. In general, as is well known, streamlining tends to increase adverse yaw moment.

Trailer design factors, other than aerodynamic shape, primarily involve number of axles, axle-to-axle distance, longitudinal and vertical center of gravity location, and suspension design. It has been determined that tandum axles provide better swing damping, so this was an attractive candidate. Center of gravity location relative to the hitch-to-axle length is easily varied on any given trailer, so this was not a selection criterion. Currently, trailer suspensions do not vary significantly (almost all are leaf), although a continuing interest of manufacturers has been the amount and direction of leaf spring roll steer that should be provided.

Tow Vehicle-Trailer Compatibility. Compatibility of the tow vehicle-trailer is another area which deserved attention. The first consideration is hitch type and recommended hookup practices. SAE and trailer manufacturers' recommendations generally are that trailers in excess of 3500 lb require Class III hitches; sway dampers are additionally recommended for those in excess of 5000 lb. The latter fact tended to shift attention away from the over 5000 lb class in the current study, because well

Table 4. Example vehicle characteristics.
a) Tow Vehicle

Type	Size	Weight Class (lb)	Drive Axle	Examples
Sedan	Subcompact	2200	F	Accord, Fiesta, Horizon[a]
		2200	R	Chevette, Datsun, Toyota
		2700	F	Citation[a]
	Compact	2900	R	Malibu, Fairmont
	Large	3700	R	Impala, LTD
Station wagon	Subcompact	2600	R	Datsun, Toyota
	Compact	3200	R	Malibu, Fairmont
	Large	4000	R	LTD[a], Impala
Van	Compact	3000	R	VW
	Large	4100	R	Ford, Dodge
Pickup	Compact	3000	R	Toyota, Datsun, Luv
	Large	3600	R	Ford F100/F250, Chevrolet C10

[a]Denotes vehicle previously used in Refs. 1-3 trailer studies.

b) Trailer

Size Class	Length (ft)	Gross Weight Class (lb)	Approx. Side Area (ft^2)	Shape[b]	No. Axles	Examples
Small	13-18	1300-3000	80-100	SQ	1	Komfort 15L/16L 16 ft Cal Samp Mustang[a] 18 ft Shasta[a] 18 ft Starcraft Galaxy
				STR	1	19 ft Jayco Songbird
Medium	18-26	3000-5000	100-150	SQ	2	21 ft Kit Deluxe Companion 22 ft Prowler[a] 23 ft Komfort Bunkhouse
				STR	1,2	21 ft Airstream Caravelle 19 ft Silver Streak 25 ft Jayco Songbird
Large	26-40	5000-7000	150-250	SQ	2	27 ft Holiday Rambler[a]
				STR	2	29 ft Airstream[a]

[a]Denotes vehicle previously tested in Refs. 1-3 trailer studies.
[b]SQ = Square; STR = Streamlined.

damped cases are less of a problem. Also, the current trend toward downsized vehicles would *make small and medium trailers more relevant*, and this in fact would follow the historical trend in Europe, for example. With nearly all but the lightest trailers, some form of load leveling may be desirable, among which might be load equalizing devices, air shocks, coil or leaf spring boosters, spacers, etc.

In terms of two vehicles, most manufacturers specify maximum allowable hitch loads; and domestic vehicles offer trailer towing suspension and tire options as well. In selected cases it may be desirable to exceed recommended practices to assess what is likely to occur over the next decade. European experience, for example, has led to widespread use of trailers that weigh up to twice as much as tow vehicles.

Test Vehicles

Based on the above factors, the vehicles described in Table 5 were selected for measurement and testing. Note the abbreviations for each to be used throughout the remainder of the text.

EXPERIMENTAL APPROACH

The measurement of the aerodynamic characteristics of the 10 vehicles described above was accomplished via wind tunnel tests. This section describes the following topics concerning these tests:

- Test method and rationale
- Vehicle models
- Test conditions
- Aerodynamic measures

TEST METHOD AND RATIONALE

The measurement method comprised wind tunnel measurements using 1/10 scale vehicle models. Tow vehicle and trailer characteristics (alone and in combination) were quantified for straight ahead and crosswind flow. Combination Vehicle forces and moments were also determined in the presence of an adjacent, flow disturbing tractor-trailer.

Data Requirements

The desired aerodynamic data consisted of the six force and moment coefficients for each vehicle (i.e., 12 coefficients for each combination vehicle) under a range of crosswind angles. These describe the lateral properties:

- Side force coefficient
- Yaw moment coefficient
- Roll moment coefficient

and the longitudinal properties:

- Lift coefficient
- Drag coefficient
- Pitch moment coefficient

Basically, the characteristics in the first group form the main directional disturbance inputs to the vehicle and, by analogy, are part of the main inputs to appropriate vehicle dynamic simulations. They are the more crucial set. The second group of properties is often neglected in handling studies. In some cases they can affect the vertical loads and, therefore, side forces produced by the tires. This might be especially the case for a vehicle such as a car/trailer, where aerodynamic forces on the vehicles can have relatively large effects on tire vertical loads and tire side force requirements (Ref. 19).

The required aerodynamic sideslip angles of the tow vehicle cover a relatively wide range. The previous Ref. 1 work speculated that sideslip angles up to 40 or even 60 degrees may be encountered under certain unusual circumstances. This could correspond to worst case peak gusts encountered while driving in the desert, plains, or other open areas (e.g., "traveler's advisory" conditions). What may be more pertinent is that aerodynamic coefficients tend to become nonlinear above 15 or 20 degrees sideslip, so that extrapolation of small angle data is not

Table 5. Vehicles used in aerodynamic tests.

Tow Vehicle	Symbol	Wheelbase (ft)	GVWR (lb)	Maximum Hitch Load* (lb)
Chevrolet Citation Hatchback	C	8.7	3500	200.
Ford Fairmont Sedan	F1	8.8	4100	400.
Ford Fairmont Station Wagon	F2	8.8	4100	400.
Ford F250 Pickup Truck	P	11.1	8100	800.

*Manufacturer's recommendation.

Trailer	Symbol	Box Length (ft)	Dry Weight (lb)	Nominal Dry Hitch Load (lb)
Utility Trailer with Flat Face	AV1	8	860	38.
Utility Trailer with Rounded Corners	AV3	8	700	52.
Utility Trailer with Nosecone and Rounded Corners	AV4	8	720	57.
Komfort 15L Travel Trailer	K	15	1580	170.
Silver Streak SS-190 Travel Trailer	S	19	2780	350.
Fleetwood Taurus TG Travel Trailer	T	24	3305	389.

always appropriate. Moreover, it is reasonable that gust-induced trailer upsets and other wind-related incidents occur primarily under large gust conditions since smaller disturbances tend to be fairly benign.

In addition to crosswind angle, the articulation angle of the trailer relative to the car is another aerodynamic variable of interest. Obviously, the flow over the aft of the car and the entire trailer will change as the trailer swings upwind and downwind of the car. These differences in aerodynamic forces can affect the swing oscillation phenomenon. However, past results indicate that this tends to be a second-order effect for typical vehicles. That is, the articulation angle adds or subtracts small amounts from the aerodynamic yaw moment. Yet the effects with off-nominal tow vehicles, such as pickup campers, and the behavior at larger sideslip angles appear to be unknown. In terms of magnitude, wind angles up to 15 degrees would completely cover the full range encountered in the real world (short of jackknifing).

Available Measurement Techniques

The available methods of determining road vehicle aerodynamic characteristics are shown in Table 6. As shown, the measurement vehicle can be either full scale or reduced scale. The measurement means can be either an air pressure survey or force transducers incorporated in an internal strain gauge array or external balance. After weighing the large number of factors involved, the scale model, force transducer method (i.e., scale wind tunnel model) was selected as the most advantageous approach in the current effort.

As is well known, in any wind tunnel measurement there can be differences between forces that occur in the real world and those occurring under tunnel (albeit controlled) conditions. These include the effects of the following.

Blockage. This refers to the obstruction of flow due to presence of a model in the wind tunnel test section. When blockage is large, airstream velocity over portions of the model increases, which can affect pressures and the resultant measured forces. Blockage ratios of less than 15 percent generally cause few problems in open test section tunnels (e.g., Ref. 23) and closed test section tunnels can tolerate about half this. Moreover, in most wind tunnels, dynamic pressure can be calibrated so as to include modest blockage effects; or a blockage correction factor is applied to the data if the blockage is small and variable. In the current effort the latter approach was used.

Table 6. Method of aerodynamic measurement.

Measurement Vehicle	Measurement method	
	Pressure survey	Force transducer
Full scale, over the road	✓	✓
Full scale, wind tunnel	✓	✓
Scale model, wind tunnel	✓	ⓥ

In the current study note that, for the larger combination vehicles (e.g., 50 ft lengths), blockage at large yaw angles in even the largest full scale tunnels would be excessive. Primarily for this reason scale model wind tunnel testing was selected as the most favorable approach.

The remaining question is which scale size to use. Here again trade-offs among technical and cost factors were made. Larger models can be more costly, and blockage or tunnel compatibility issues are important. Excessively small models can involve more intricate detailing work (which also can be costly), higher tunnel speed requirements and, therefore, potential compressibility problems, difficulties with potential boundary layer effects, and balance signal to noise ratios. After weighing these and other technical factors, a model scale of 1/10 was selected as the best compromise.

Reynolds Number. Defined as the product of airspeed and vehicle length, divided by the kinematic viscosity, this index shows the relative importance of fluid inertia versus viscous forces. The important factor is not that the real world Reynolds number be maintained, but that the flow is above the critical Reynolds number. That is, at sufficiently high Reynolds numbers (i.e., 3×10^5), flow separates behind bluff bodies, giving a turbulent wake. Since the total aerodynamic forces in crosswinds acting on vehicles such as cars and trailers are characterized by large areas of separated flow, sufficiently high Reynolds numbers must be retained. A rule of thumb is to use at least 4 or 5 times the critical value, which yields minimum values for R_e of about 1.5×10^6. For a 1/10 model of a tow vehicle, for example, this would yield a *minimum* tunnel speed of about 200 mph.

Boundary Layer. In both real world and wind tunnel flows, ground plane boundary layer effects can be present that may cause differences in the flow and resultant forces. The usual example given is that of a real vehicle traveling in still air, which sees no boundary layer; versus a tunnel model resting on a finite ground plane, which does see some vertical gradient in flow velocity. The critical factor is the relative size of the boundary layer versus some characteristic model dimension, such as underbody clearance. Past results have shown that with full scale wind tunnels the effect can be negligible (e.g., Ref. 23). With scale models it can be more important; yet past work reported in Ref. 25 and 26 has shown that the tunnel boundary layer mainly affects longitudinal forces, and not the crucial lateral properties.

In the crosswind case, on the other hand, the real world road vehicle sees a crosswind boundary layer due to the local terrain. This means that the flow at the roof height can be different in magnitude and direction than that at

bumper height. This rotational shear effect is not generally reproducible in conventional wind tunnels. It might be of some importance for taller vehicles such as trailers, at high sideslip angles. Yet, based on the physics of the situation and on fairly good matches between past full scale and simulation responses, this is probably not a first-order effect.

Another related factor is the presence of turbulence in the full scale case, as recently reported in Ref. 6. This tends to be another relatively minor source of potential real world/wind tunnel differences.

Transient Effects. This refers to the situation where various parts of the vehicle are experiencing the same flow field at different times, i.e., gust penetration. Though it is feasible to measure such effects via dynamic wind tunnel tests (i.e., rotary or translational models), the main point is that such effects are not important for the problem at hand. For example, Buning and Beauvais have shown in Ref. 28 that transient aerodynamic forces: 1) only come to the fore at very large sideslip angles (e.g., 75 deg); 2) are over within three vehicle lengths (e.g., half a second at 60 mph); and 3) affect mainly the yaw moment, in the expected manner. In all other cases that Ref. 28 examined, the "transient" data duplicated the steady data to within 5 percent. The real point is that such effects are at higher frequency (i.e., more rapid) than the crucial driver/vehicle directional motions and control activity occurring below ½ to 1 Hz.

Nonrotating Wheels. Though of some importance in high speed, open wheel race cars with wide tires, past studies have repeatedly shown this to be a very minor effect with typical passenger vehicles (e.g., Ref. 23).

Other Wind Tunnel Effects. These include flow angularity and streamline curvature, due to presence of tunnel walls; buoyancy effects, due to axial static pressure gradients; and flow nonstationarity due to separation and reattachment phenomena. These were relatively small in the current experiments, and various calibration, correction, and measurement techniques were applied.

Note that in the current experiments—since vehicle *differential* effects were emphasized—minor discrepancies in the absolute values of aerodynamic characteristics, due to the above factors, were of little consequence and would not affect the ordering of differences.

Test Method

The experiments were conducted at the Northrop Aircraft Low Speed Wind Tunnel in Hawthorne, California. This facility was selected for its large yaw table needed for the adjacent truck studies. The Northrop tunnel is a continuous flow type driven by a single six-bladed propeller with a power capacity at 3600 hp. The test section is 7 ft high by 10 ft wide (rectangular cross section) and is approximately 20 ft long. A full width yaw table, 10 ft in diameter, is mounted in the tunnel floor.

The test setup involved mounting a six component strain gauge balance internal to each of the car and trailer models (as described in the next article). Each balance was mounted to a support strut, then the vehicle body shell was fitted over the balance and attached to it. The model assembly was attached via the support strut to special floor plates placed in the tunnel yaw table.

Most test runs were made at a nominal tunnel dynamic pressure (q) of 140 psf which gave a Reynolds number of approximately 2.2×10^6 per foot. Based on a typical vehicle model wheelbase of 1 ft, this provides an effective Reynolds number of 2.2×10^6. This is about 40 percent of full scale (at 55 mph), and is about a factor of 4 above the critical value.

All models were designed to fit on the same balances. Articulation angles were accomplished by changing predrilled floor plates. The models were placed on the balance blocks, tightened down with hold-down screws, and all holes taped over. The tunnel was then manually brought up to specified dynamic pressure, relative wind angle was set, and data were taken. The relative wind angle ($_w$) was varied according to the following yaw schedule:

0, −5, −2, 0, +2, +5, +10, +15,
+20, +25, +30, +35, +40, +45, 0 degrees

VEHICLE MODELS

Ten vehicle metric models were used in the wind tunnel tests. These were 1/10 scale models constructed from hardwood and urethane foam, with aluminum internal mounting pieces. Photos of the ten vehicles are presented in Figures 4 through 13.

As discussed, the purpose of the tests was primarily to determine the influence of overall body shape on lateral aerodynamic properties of the combination vehicles. Specific makes and models were not being assessed as much as generic shapes and forms. Therefore, minor body de-

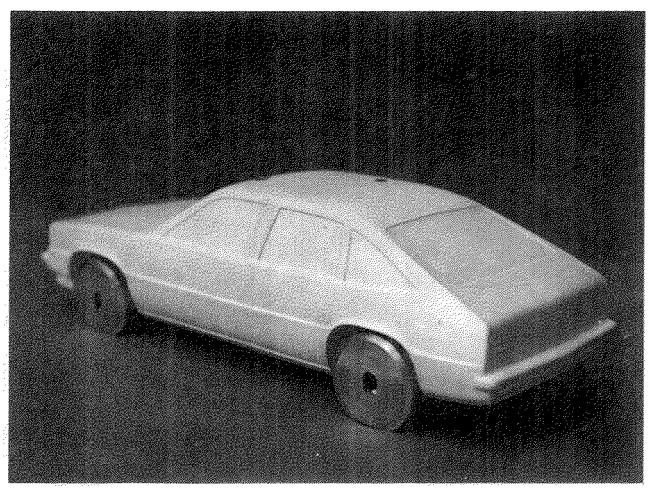


Figure 4. Compact hatchback model (C).

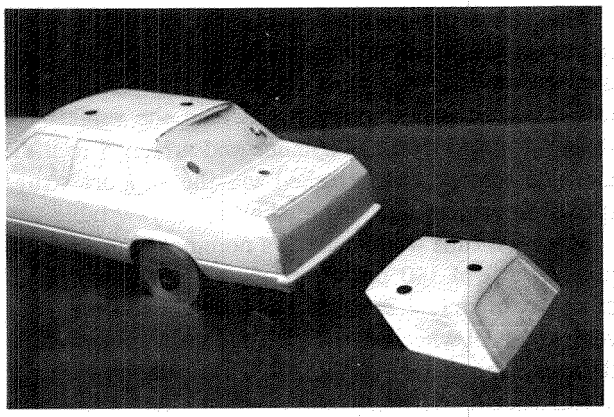


Figure 5. Sedan model (F1).

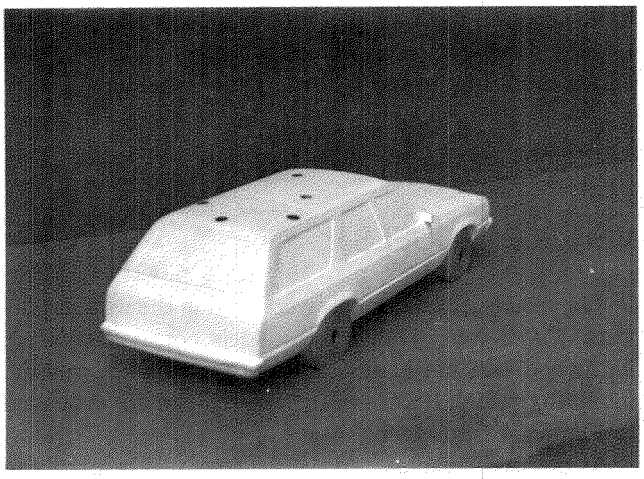


Figure 6. Station wagon model (F2).

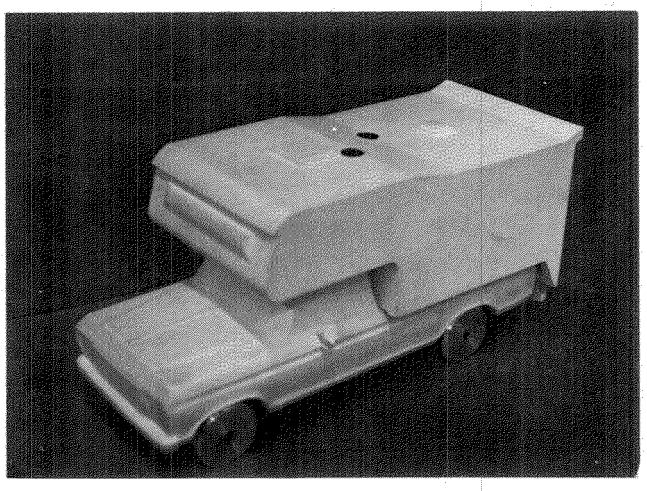


Figure 7. Pickup/camper model (P).

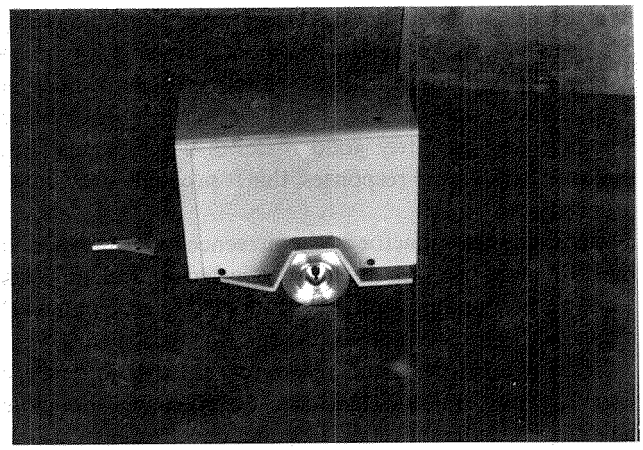


Figure 8. Bosy 5 x 8 utility trailer model (AV1).

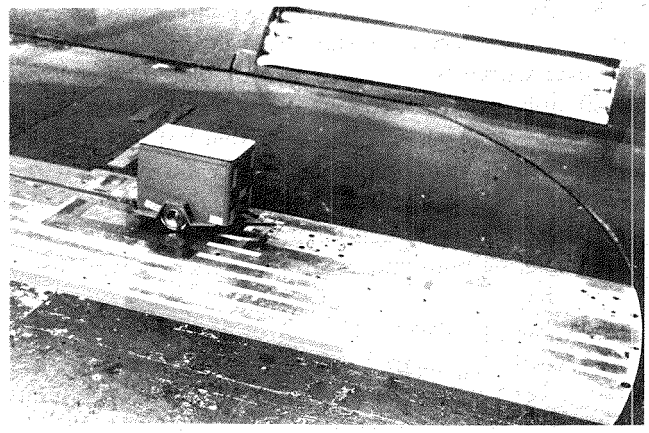


Figure 9. 5 x 8 utility trailer model with rounded vertical corners (AV3).

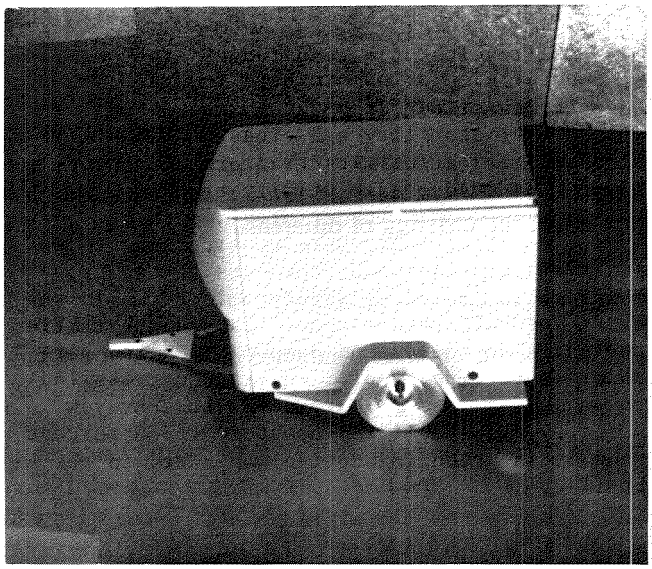


Figure 10. 5 x 8 utility trailer model with rounded corners and nose cone (AV4).

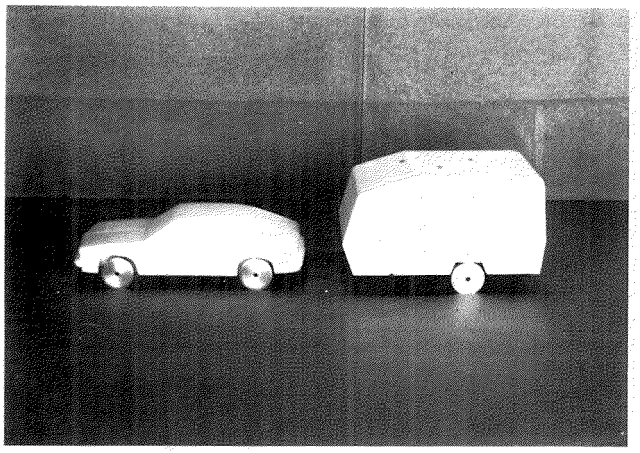


Figure 11. Small travel trailer model (K), with tow vehicle C.

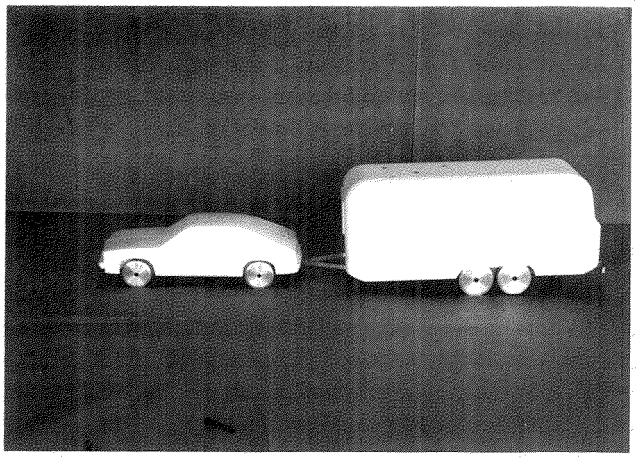


Figure 12. Streamlined travel trailer model (S), with tow vehicle C.

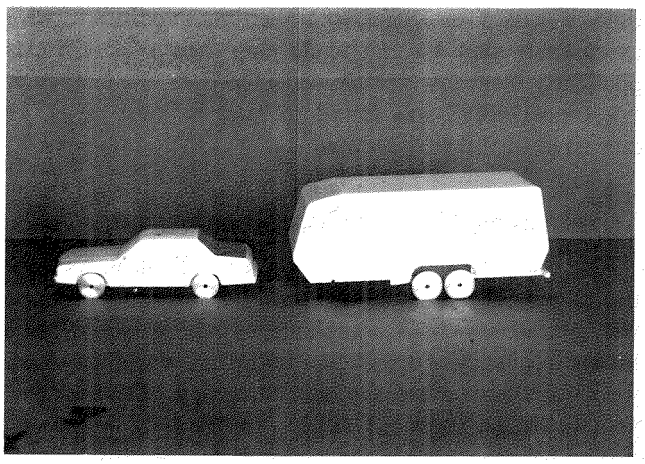


Figure 13. Large travel trailer model with tow vehicle F1.

tails—such as chrome trim strips, exposed windshield wipers, radiators and internal flow which could have a minor effect on drag—were not modeled. Somewhat larger features such as mirrors, bumpers, window insets, and underbody elements were modeled, as these could have small influences on the planform flow.

Several of the vehicles were of variable configuration and this aided in test efficiency and comparison between configurations. The station wagon was simulated by adding a shaped "wagon back" block to the aft of the sedan. Similarly the various 5 × 8 utility trailer configurations were obtained by changing top and front surfaces, etc., via interchangeable "blocks." The three utility trailer models obtained were:

AV1: Basic 5 × 8 trailer with
- — square corners and
- — rounded top

AV3: Basic 5 × 8 trailer with
- — 6 in. radius vertical leading edges
- — flat top, gutter around edge, *no* nose cone

AV4: Same as AV3, plus nose cone

The wheels, fenders, and tongue were unchanged as the configuration varied.

The underbody detail of the utility trailer model is pictured in Figure 14. It consists of crossmembers and aluminum shapes to represent the springs. The hole at the back of the model was provided for the balance struts on this short model only.

The tires for all models had short "flats" on their bottoms; and they were adjusted for $\frac{1}{8}$ in. clearance between the tire and ground plane in each test run to ensure that all forces and moments were carried through the instrumented mounting strut.

Tow vehicle/trailer articulation angle was varied by using different trailer/ground plane mounting or "position" plates. These were constructed so that the trailer would rotate about a center of rotation located at the imaginary hitch point.

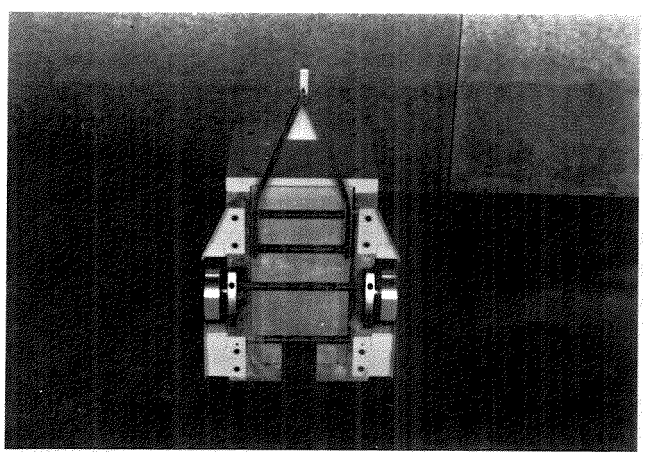


Figure 14. View of underbody detail on utility trailer model.

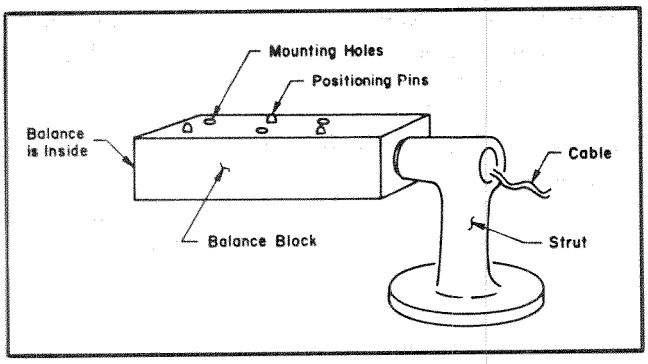


Figure 15. Balance, balance block, and strut.

Each metric model was mounted to the strain gauge balance via a balance block, as shown in Figure 15. In turn, the balance itself was supported by a strut which fit into a recess in the ground plane. The balance sensed 6 component forces and moments, and cables transmitted the resulting signals to the data acquisition and reduction system for processing and plotted output.

A series of tests were also run with an adjacent, non-metric truck model in the tunnel, as shown in Figure 16. This was a COE dual tandem tractor with 40 ft closed van semitrailer, used in previous studies of truck aerodynamics (e.g., Ref. 29). The objective was to measure the forces and moments on the combination vehicle as affected by the flow around the truck. The two vehicles were placed as though they were in adjacent lanes (corresponding to a 12 ft centerline spacing) and their relative fore/aft positions were varied on successive runs (as in a passing maneuver). This was accomplished by varying both truck and combination vehicle longitudinal mounting stations on the ground plane.

TEST CONDITIONS

A range of nominal and off-nominal test conditions was used to study the effects of interest. These included the effects of:

- Crosswind angle (all runs)
- Operating conditions (e.g., vehicle and wind speed)
- Tow vehicle or trailer alone
- Tow vehicle/trailer combinations
- Adjacent truck

The values of crosswind angles used were mentioned above. The largest angle (45 deg) corresponds to a 50 mph crosswind gust being encountered at a vehicle speed of 50 mph.

The other test conditions are described below.

Sensitivity to Operating Conditions

A series of tests examining various operating conditions looked at:

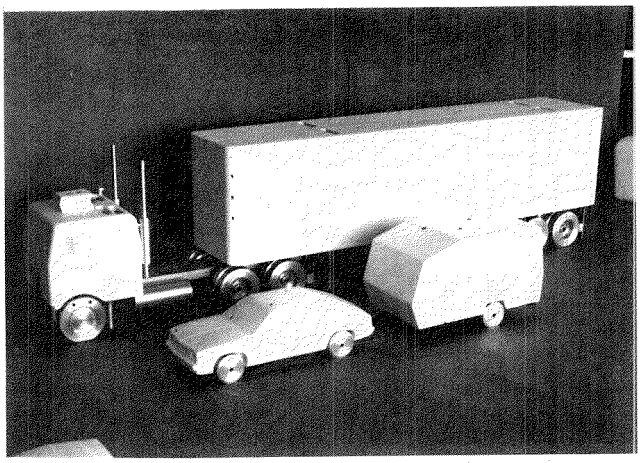


Figure 16. Model of COE 6 x 4 tractor with 40 ft van used as adjacent truck, with combination vehicle C/K.

- Test repeatability, including flow hysteresis, and the effects of:
  - — Airspeed (i.e., Reynolds number),
  - — Vehicle surface roughness, and
  - — Combination vehicle articulation angle.

Table 7 summarizes the operating conditions tested.

Vehicle Alone Tests

Tow vehicle alone tests were run so that, later on, the effects of trailer presence—and various trailer configurations—could be assessed. For example, the extent to which tow vehicle yaw moments are affected by presence of a trailer could be examined.

A similar series was run for trailers alone, for a different reason. Though the trailer alone case may at first sound unrealistic and immaterial—particularly because flow superposition is not theoretically valid—it was desirable to see whether there were any coarse "rules of thumb" that might apply to trailer aerodynamic characteristics, *independent* of tow vehicle. If this were found to be the case, it would be useful to trailer manufacturers, who presumably would prefer to develop their vehicles independently from tow vehicle considerations. In fact, such "superposability" was found to exist in most cases, as discussed in the next section.

Tow Vehicle/Trailer Combinations

The tested combinations are shown in Table 8. As seen, not all possible combinations were run; instead, emphasis was placed on those combinations which would have higher frequency of occurrence in the real world, or which were otherwise technically interesting (e.g., a "sleek" tow vehicle/trailer, such as C/S).

The baseline vehicle for many of the sensitivity runs was the midsize tow vehicle/trailer combination, F2/S.

Table 7. Summary of operating conditions examined in experiments.

Operating variable	Values or Conditions Used
Crosswind angle	0, ±2, ±5, +10, +15, +20, +25, +30, +40, +45, 0 degrees (nominal)
Articulation angle	0, ±8 degrees (±2, ±4, −16 degrees also used)
Repeatability/hysteresis	Same configuration tested twice, 5 hours apart Hysteresis check: 0, +5, 0, −5, −10, −15, −20, −25, −30, −35, −40, −35, −30, −25, −20, −15, −10, −5, 0 degrees crosswind angle
Reynolds number	q = 20, 60, 100, 140 psf (for cleanest configuration, C/S)
Vehicle surface roughness (detail)	Tufts on tow vehicle rear window and trunk lid, trailer front face. 1/16 x 1/16 in. transverse balsa strips placed full width of vehicle, at base of windshield and rear window.

Table 8. Matrix of combination vehicles tested.

Tow vehicle \ Trailer	None	AV1	AV3	AV4	K	S	T
None	—	72	75	74	81	130	132
C	152*	163	162	161	106	160	—
F1	34	43, 55	44	40	105	83	112
F2	35	42	—	41	104	82 Baseline	111
P	153	—	—	—	—	129	110

*Run number.

Adjacent Truck

Previous FHWA research in Refs. 29-31 examined in detail the disturbances caused by adjacent trucks and buses, mostly on single passenger vehicles. This included the effects of truck geometry, size, vehicle lateral separation, truck gap size, crosswind angle, fore/aft relative positions, etc. The current tests sought to expand this data base in one other direction, namely by focusing on combination vehicles and the relative sensitivities of various vehicle and trailer shapes and sizes to truck-induced disturbances.

As a gross generality, the previous FHWA and other research showed that the main effect of the disturbing truck is to create a "bow wave" of lateral moving air near the cab face, and a secondary gap flow coming through the space between the cab and van. Of course, the worst case is when the passing vehicle is "downwind" of the truck in a crosswind situation. As the passing vehicle encounters these two crossflow jets, the vehicle undergoes yaw disturbances which may lead to driver/vehicle control oscillations and degraded control. In the combination vehicle case, the parameters of interest are the relative sizes and spacings of tow vehicle and trailer relative to the truck cab and gap. In general, the presence of the trailer leads to additional yaw disturbances on the tow vehicle as the trailer also encounters the truck jets.

Figure 17 shows the relative fore/aft position used for metric vehicles and non-metric truck model. These were chosen to emphasize bow and gap flow effects, and also wake flow interaction.

On certain runs, the combination vehicle articulation angle was also varied in truck proximity to determine whether "aerodynamic camber" created additional suction or repulsion relative to the side of the truck van, for example.

AERODYNAMIC MEASURES

The experimental data obtained comprised the 6 aerodynamic forces and moments for each vehicle, as a func-

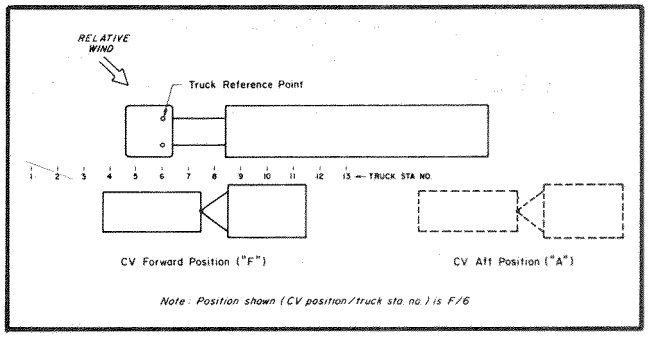


Figure 17. Model relative positions for adjacent truck experiments.

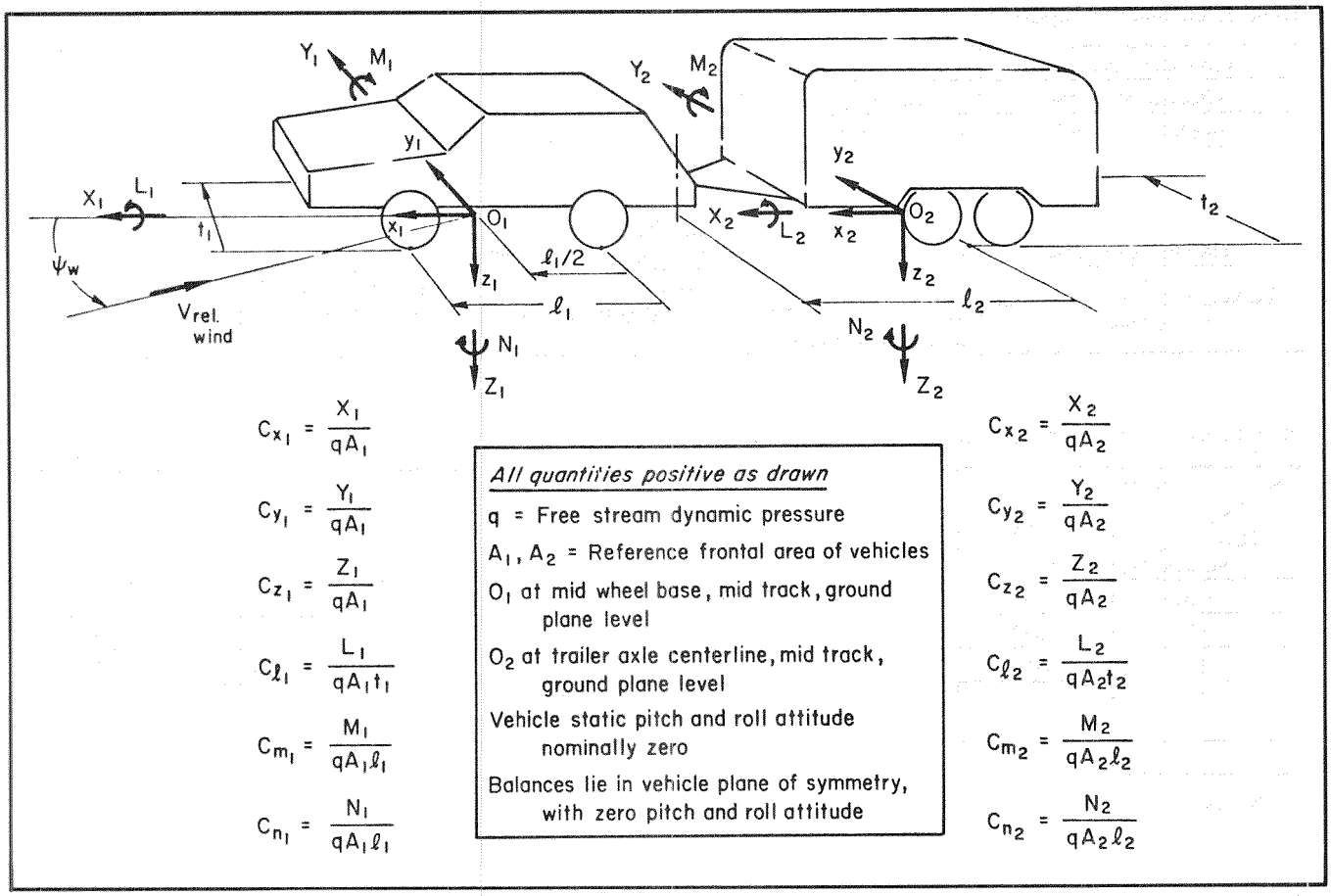


Figure 18. Definition of aerodynamic reference centers, axis systems, reference dimensions, and sign conventions.

tion of crosswind angle. These were reduced to corresponding aerodynamic coefficients for purposes of plotting, analysis and comparison between vehicles; and for direct comparisons between the model and full scale situations.

Figure 18 defines the vehicle geometry, axis systems, nomenclature and aerodynamic coefficient definitions. All data were tabulated and plotted in these axis systems, which are fixed relative to the metric vehicles. All quantities have positive signs as drawn.

With regard to the relative wind angle (i.e., the angle between the vehicle centerline and the wind) and the articulation angle (angle between trailer and tow car), Figure 19 shows positive values for these quantities.

Table 9 defines the reference dimensions for each of the metric models. Note that 2 is measured from the trailer axle centerline, or the midpoint between the two axles for tandem axle trailers.

RESULTS OF EXPERIMENTS

This section presents results of the wind tunnel measurement of combination vehicle aerodynamic properties, pertinent to studies of:

- Effects of Operating Conditions
- Effects of Vehicle Design and Hookup Practice

The interpreted results presented herein are necessarily brief and, owing to premature termination of this work, the crucial parameters with regard to trailer stability have yet to be determined. Nevertheless, a recent exploratory study in this area was accomplished and is reported in Ref. 32. Some of the results of the Ref. 32 study of small utility trailer aerodynamic sensitivity are mentioned here, as a point of departure.

It has been shown in Ref. 32 and elsewhere that streamlining of towed trailers can substantially reduce aerodynamic drag. At the same time, this is also accompanied by substantial increases in aerodynamic side force and yaw moment acting on the box in crosswinds. Using a vehicle dynamic simulation, Ref. 32 showed that, for small trailers, the net effect of this was mainly

- To increase the critical, mid frequency, yawing motion of the tow vehicle,

which tends to degrade driver control. Previous results (e.g., Ref. 1) have suggested that such disturbance motions can be large enough to cause the driver to make substantial steering corrections, which in turn can lead to

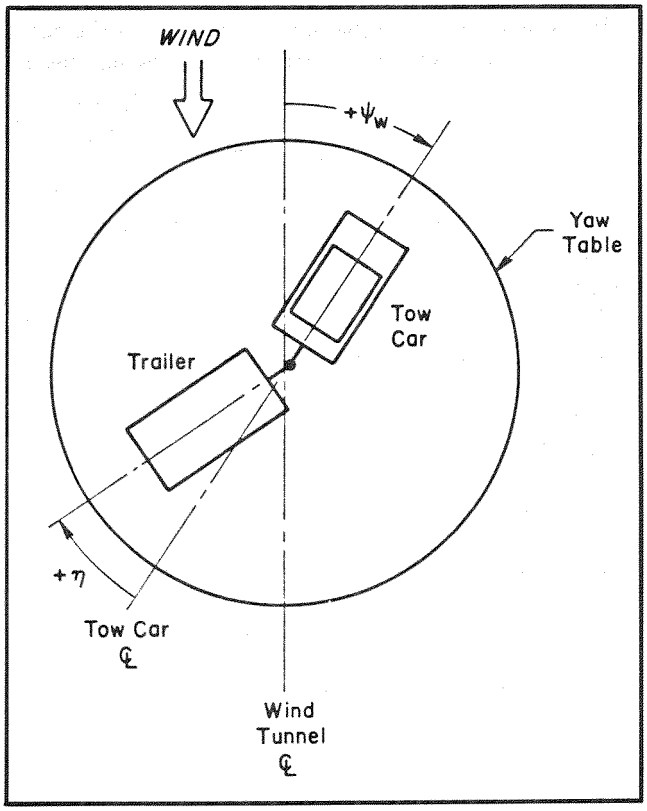


Figure 19. Positive values for relative wind and articulation angle.

loss of control in the closed loop driver/vehicle/trailer system. The key point is that the stability of the car/trailer system itself is not substantially changed by trailer (still air) aerodynamics, but rather the trailer—and in particular some streamlined trailers—can increase the disturbance forces acting on the tow vehicle in a crosswind.

This leads to a grossly simplified way of looking at the current wind tunnel test data, as a starting point. From the standpoint of the tow vehicle, the disturbance forces caused by the trailer are limited to those acting on the hitch ball. In reality, these comprise a whole list of forces, such as longitudinal, lateral, and vertical forces due to trailer accelerations and direct crosswind force transfer. Under steady state, straight ahead conditions, the dominant yaw-inducing force on the hitch can be said to be due to the trailer aerodynamic yaw moment with respect to the trailer axle. Since this is the reference point used in the current data (see Fig. 18), the steady state side force on the hitch ball due to the crosswind is merely

$$Y_{hitch} = C_{n_2} qS_2$$

In other words, some appreciation for the trailer-induced yaw disturbance acting on the tow vehicle can be obtained by looking at the trailer yaw moment data (C_{n_2}).

Also, the instantaneous side-to-side acceleration of the trailer due to a crosswind gust is directly proportional to the trailer side force data (C_{y_2}), i.e.,

$$\left(y_{\substack{\text{trailer} \\ \text{instantaneous}}} = C_{y2} \frac{qS2}{m2}\right)$$

On the other hand, the rollover potential of a given trailer is related to both the aerodynamic rolling moment and the trailer lift force measured in the current data.

Note that the above observations only consider the steady state and instantaneous extremes of the crosswind input (very low and very high frequencies), and do not consider the mid-frequency effects important for driver control. The mid-frequency response is determined by the complicated interaction between aerodynamic, inertial, tire and suspension effects; and a study of these interactions—using a suitable dynamic model, such as was begun under this study—is beyond the scope of this report.

In summary, the following points are made with regard to the measured aerodynamic data:

- The trailer-induced yaw disturbance acting on the tow vehicle is proportional to the trailer yaw moment coefficient, C_{n_2}.
- The instantaneous lateral acceleration of the trailer when encountering a crosswind is proportional to the trailer side force coefficient, C_{y2}.
- The overturning tendency of the trailer in a steady crosswind is proportional to a weighted sum of trailer rolling moment and vertical force coefficients, C_2 and C_{z2}.

Table 9. Wind tunnel model reference data.

Tow vehicle model	ℓ_1 (ft)	t_1 (ft)	A_1 (ft²)	Balance center x-Coordinate* (ft)	(in.)
C	0.874	0.491	0.208	−0.004	−0.05
F1	0.880	0.492	0.200	−0.118	−1.41
F2	0.880	0.492	0.200	−0.118	−1.41
P	1.108	0.544	0.625	−0.178	−2.13

* For tow vehicle balance center, y-coordinate is 0.0 ft; z-coordinate is −0.198 ft.

Trailer model	ℓ_2 (ft)	t_2 (ft)	A_2 (ft²)	Balance center x-Coordinate** (ft)	(in)
AV1	0.782	0.597	0.325	0.053	0.63
AV3	0.782	0.597	0.328	0.053	0.63
AV4	0.782	0.597	0.328	0.053	0.63
K	1.000	0.607	0.475	0.123	1.47
S	1.370	0.622	0.575	0.487	5.84
T	1.458	0.675	0.674	0.582	6.98

**For trailer balance center, y-coordinate is 0.0 ft; z-coordinate is −0.298 ft.

Effects of Operating Conditions

As described previously, several areas were examined which are more or less independent of vehicle configuration. These included:

- Repeatability and hysteresis
- Total airspeed
- Vehicle surface roughness (level of detail)

These are described below, referring to the plots in the Appendix (for lateral data) and (for longitudinal data).

Repeatability and Hysteresis. Plot 1 in Appendix shows aerodynamic data for the sedan with body utility trailer (F1/AV1) taken on two separate runs. The lateral data show excellent—nearly identical—agreement for both tow car and trailer data between the two runs.

The longitudinal data are less repeatable—particularly in car vertical force—though still quite good. Checking the vertical force and pitching moment sensor resolution and noise levels shows that the basic resolution band ($\pm$1o) is about one plotting symbol wide. This is about the same as the variation in the C_{z_1} data between the two runs. Other differences around zero yaw angle, associated with the large drag peak, may be related to nonstationary flow.

Hysteresis is examined in Plot 2 for the station wagon with streamlined travel trailer (F2/S). Almost no hysteresis is detectable in any of the data at nominal yaw angles. The only hint of hysteresis is at 30 degrees yaw angle in the trailer drag data, and reflected also in the side force and roll moment data. From the shape of the curves this is probably related to stall of the planform flow, and associated shifts in the backside separation point with ascending and descending yaw angle. Though of small magnitude, it is remotely conceivable this could excite limit cycle trailer swing behavior at large crosswind angles, and could be studied via simulation.

Total Airspeed. It is well known that the aerodynamic forces acting on a body are directly proportional to the square of the relative airspeed or, in other words, proportional to the dynamic pressure

$$q = \frac{1}{2}\rho V^2$$

where

q = Dynamic pressure
ρ = Air density
V = Relative or total airspeed = $\sqrt{U_o^2 + U_g^2 + V_g^2}$
U_o = Vehicle speed
U_g = Headwind speed
V_g = Crosswind speed

This speed-squared proportionality holds true to a very high degree, except when large parts of the flow are initially laminar, but separate and become turbulent as speed increases. This transition is Reynolds number dependent [occurring at about $R_e = 0.5(10)^6$]. However, with typical real ground vehicles at real highway speeds, the Reynolds number is about ten times this value, and so the flow always involves turbulent, separated flow with large wakes. The only time Reynolds number (or, in other words, V^2 proportionality) becomes an issue is when the real flow is being simulated in a wind tunnel.

To test whether any non-speed-squared effects were present, a range of dynamic pressures were examined, using the most sensitive vehicle combination (i.e., the smooth hatchback/streamline trailer, C/S). The following range of speeds was used:

e (psf)	R_e (10^6 ft^{-1})	V (ft/sec)
20.	0.8	132.
62.	1.4	233.
102.	1.8	300.
141.	2.1	351.

The results are shown in Plot 3. The lateral data show virtually no sensitivity to Reynolds number across this wide range. So the lateral results reported in the bulk of the data apply directly to full scale. Furthermore, in full scale all speed effects can be modeled as q-dependent, via Eqs. 2 and 3.

The longitutinal data—particularly those of the trailer—show some very modest differences between the lowest and highest Reynolds number runs. These are small enough so that useful inter-vehicle comparisons can still be made.

Most of the remainder of the test runs were performed at the highest dynamic pressure of 140 psf, which is closest to the full scale Reynolds number of about $5(10)^6$.

Vehicle Surface Roughness. As shown in Fig. 20, some tufts and disturbance strips were added to surfaces of the sedan and boxy trailer. This was done for a threefold purpose, namely:

- For flow visualization.
- To confirm that omission of minor modeling details (such as windshield wipers) and generally low flow turbulence did not affect the measurements.
- To attempt to uncover the mechanism causing the large drag cusp near zero yaw, as seen in the longitudinal data.

The results are shown in Plots 4 and 5. Once again the lateral data show no sensitivity to either tufting or roughness elements. The longitudinal data show little sensitivity to tufting, and a moderate reduction of the sharp lift and drag cusps in the car data. This suggests that the latter may partly be artifices of model smoothness and vortex flow. The overall drag and lift curves are unaffected.

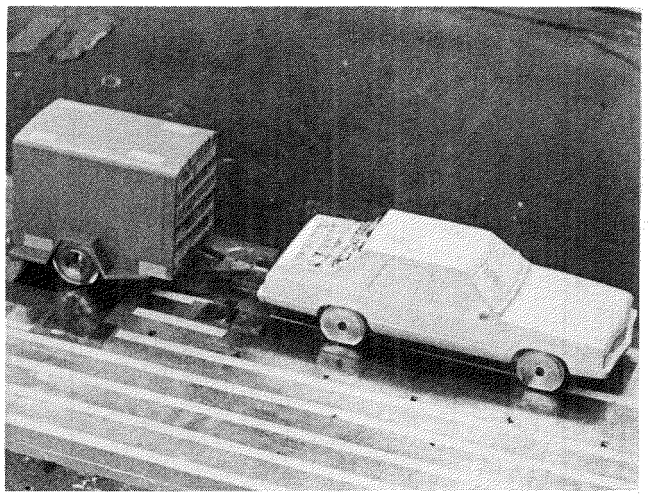


Figure 20. View of tufts and roughness strips added to combination vehicle F1/AV1.

Effects of Vehicle Shape, Configuration, and Combination

This article discusses the influence of configuration on the aerodynamic characteristics of combination vehicles. In particular, this describes the effects of:

- Trailer shape
- Tow car shape
- Articulation angle
- Truck proximity

Trailer Shape. A key area of interest at the outset of this study was the influence of trailer box shape and layout on crosswind sensitivity. Figure 21a and b (Plot 6) shows trailer aerodynamic characteristics for four different trailers being towed by the hatchback car. Note that among the trailers the only systematic shape change is between AV1 and AV4, these being very similar except for fairing details. Trailers K and S are of different size as well as shape. The lateral data show several interesting trends. The side forces on the trailers (normalized by frontal area) are strikingly similar, except for the boxy utility trailer, which has *lower* side force at larger yaw angles. This could be due to larger backside separation regions, whereas the smoother or finer (longer) trailers may have more back corner "vacuum" because of less separation. A similar trend is evident in the roll moment data. However, here there is some evidence that the rounded longitudinal edges on the streamlined trailer S give some advantage, in that it has slightly *less* overturning moment—though it is higher and larger—than the more angular K trailer. (This is clearer in some subsequent data.) The yaw moment data show a wide spread in characteristics, and, as discussed, this seems to be one of the more crucial characteristics for handling. Generally speaking, the rounded nose trailers show substantially

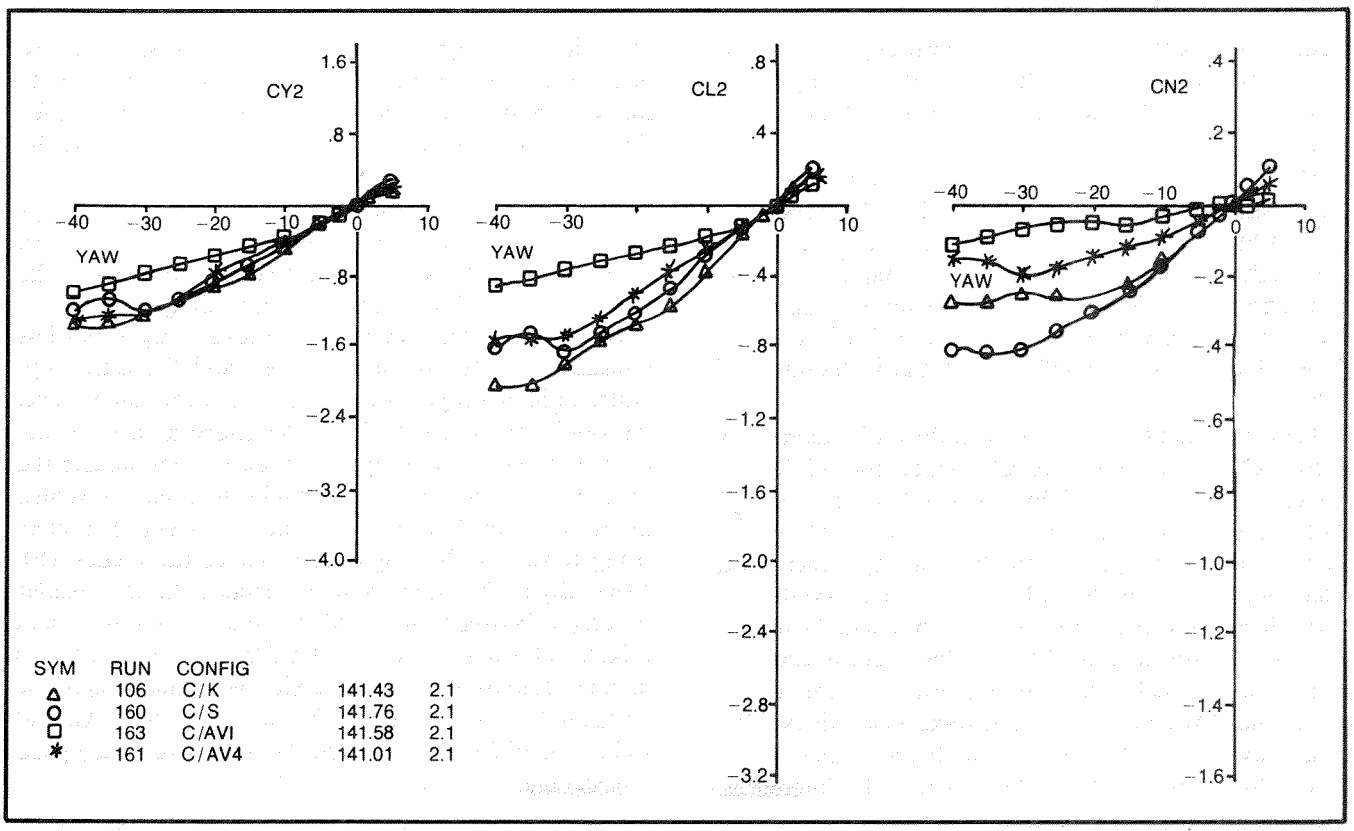


Figure 21a. Effects of various hatchback/trailer combinations on trailer lateral characteristics.

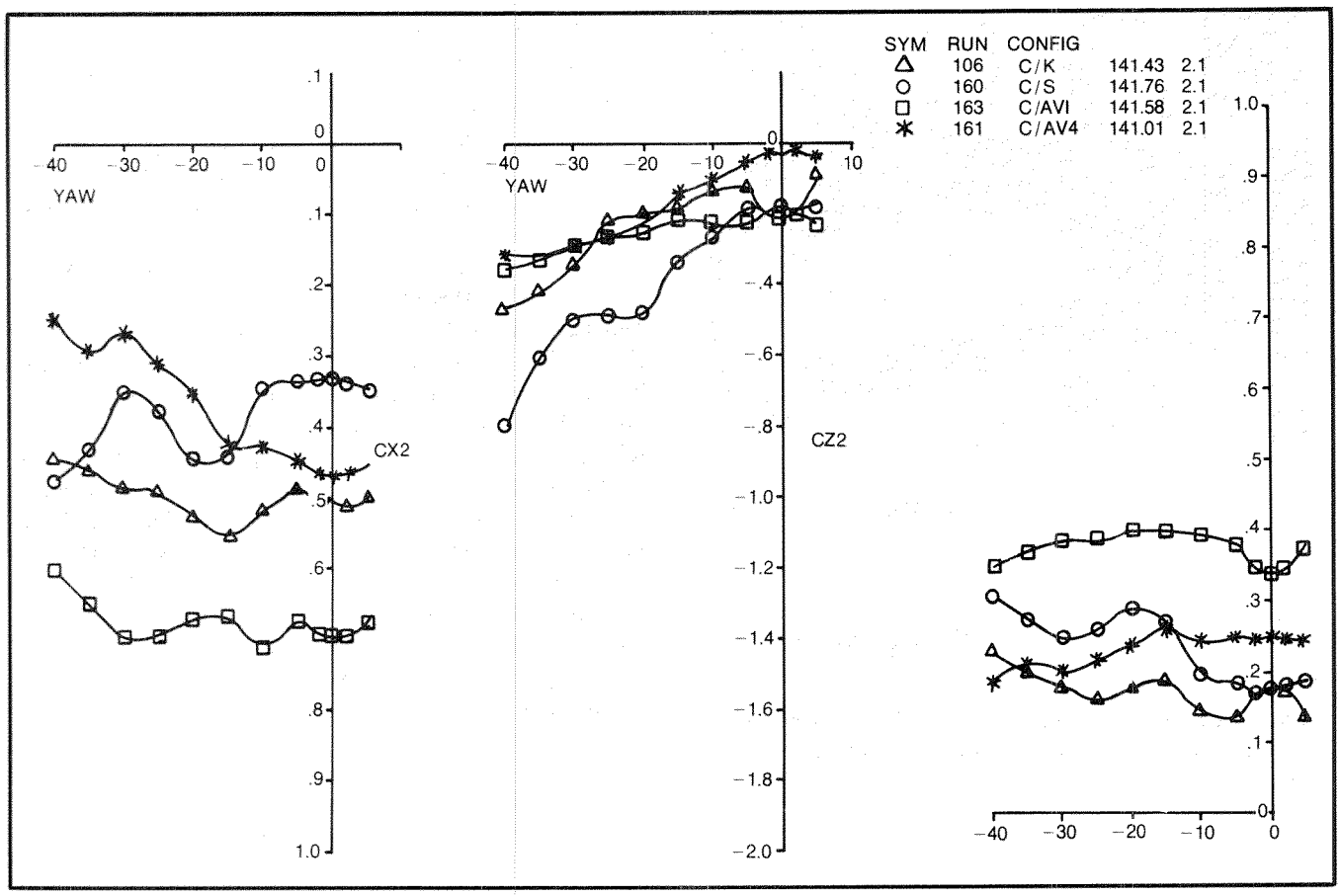


Figure 21b. Effect of various hatchback/trailer combinations on trailer longitudinal characteristics.

higher yaw moments than similar sized angular trailers. This is partly due to their higher stall angle (30 deg versus 10 to 20 deg) and is probably again related to greater suction at the front downwind corner.

The trailer longitudinal data are not surprising. The drag coefficient varies by a factor of 2 to 1 between the boxy utility trailer AV1 and the streamlined travel trailer (although these must be multiplied by frontal area to get actual drag force). The drag stays relatively constant with crosswind angle, except for the noseconed utility trailer AV4, which has substantially less drag at high crosswind angles.

These data can be compared with the trailer alone data of Plot 27. As seen in the lateral data, absence of the tow vehicle results in only slightly higher (e.g., 10 percent) coefficients in most cases, and very similar curve shapes. The prominent exception is the boxy utility trailer AV1, which for crosswind angles less than 30 deg—without a tow vehicle—shows a reversal of yaw moment coefficient (giving a weathercock tendency). This is not unexpected and is the classical result reported elsewhere for rectangular solids (Adding a tow vehicle wake makes this vehicle behave like the other, typical "blunt body" trailers.). The longitudinal data similarly show very little differences, with and without tow vehicle, for the straight-ahead condition. The main difference is that *without* a tow vehicle, the trailer drag increases substantially at crosswind angles of 20 or 30 deg, typical of single, blunt bodies whereas for combinations, drag stays about constant. Overall, for this relatively "sleek" contemporary hatchback car, the presence of the tow vehicle has surprisingly little effect on the trailer aerodynamic forces and moments. The dynamic pressure prevailing at the trailer could be said to be 90 percent or more of its freestream value (with the exception of the high crosswind angle drag case).

Of course, as the tow vehicle becomes larger and less streamlined, this situation changes, and the trailer operates in increasingly "dead" air behind the tow vehicle. As would be expected, the trailer shape differences become less and less important in such a situation, and the magnitude of the forces also diminishes. This is shown in Plots 7 and 8, which compare the S and T trailers being towed by the wagon (F2) versus the pickup (P). Especially in the case of drag, the pickup shows a smaller difference between the rounded and angular trailers and a factor of 3 reduction in trailer drag. (Of course, this is compensated by a large increase in tow vehicle drag.) The prevailing dynamic pressure for the trailer could be said to be around 25 percent of freestream. So, to a very good approximation, with some exceptions,

- Wind tunnel measurements performed on single trailers alone can provide useful quantitative infor-

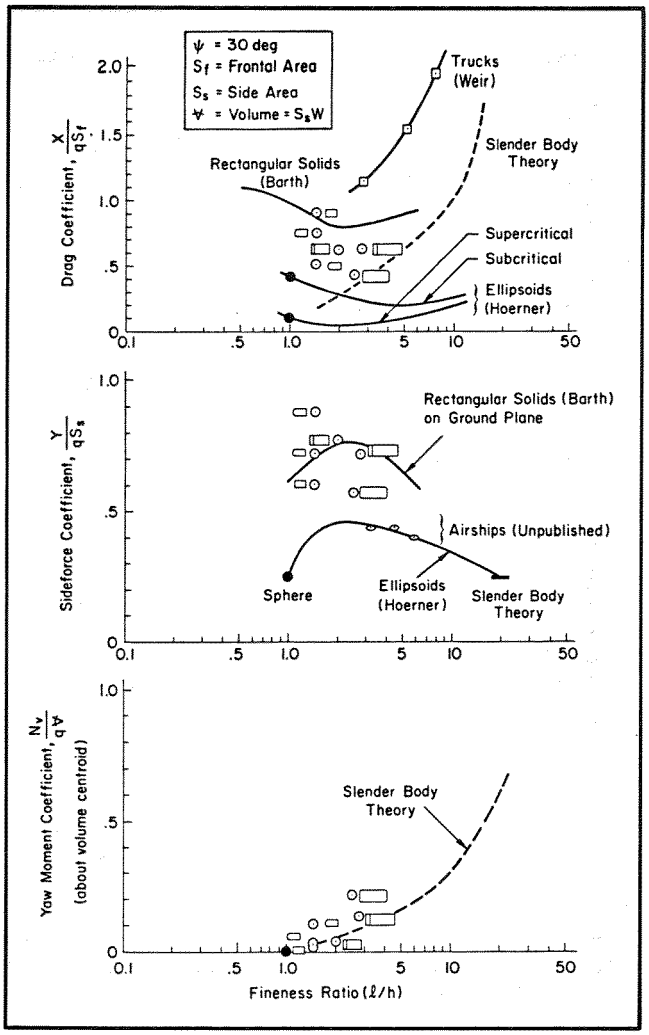


Figure 22. Comparison of aerodynamic drag, side force, and yaw moment of various bodies at 30 degrees crosswind angle.

mation applicable to their characteristics when being towed behind contemporary passenger cars.

Other trailer shape effects are shown in Plots 9, 10, and 11 for the utility trailer variations. These support the observation that adding rounded vertical corners and nosecone can result in increases as large as 50 percent in side force and 100 percent in yaw and roll moment at large crosswind angles. The change in trailer yaw moment seems partly due to rounded corners, while the changes in side force and roll moment seem to mainly be due to the nosecone addition.

All the above data show very small effect of trailer shape on tow vehicles forces and moments, with the possible exception of tow vehicle drag.

A final comparison of trailer shape effects is presented in Figure 22. As noted, the previous lateral data have been normalized by frontal area, hitch-to-axle distance, and wheel track. A more pertinent normalization from a designer's standpoint would be by side area and box dimensions. This would help answer the question:

- Given a certain side area, what shape characteristics can help improve lateral aerodynamics?

This normalization has been performed in Figure 22, which shows drag coefficient (relative to frontal area), side force coefficient (relative to side area), and yaw moment coefficient (relative to box volume and volume centroid) for trailers alone. These are plotted for a 30 deg yaw angle as a function of body fineness ratio, defined as the ratio of length to height. Besides the six trailers shown, other reference bodies are shown for comparison.

The data show that trailer type bodies bear a close relationship to other ground and airborne body shapes, when properly normalized. In terms of drag, they lie a little below the rectangular solids reported by Barth (Ref. 33) and the tractor-trailer trucks measured by Weir, et al. (Ref. 29); and at somewhat higher drag than predicted by slender body theory and ellipsoidal shapes (e.g., Ref. 35). The trailer drag coefficients range from a high of about 0.9 for the boxy utility trailer (AV1), followed by: the slightly rounded utility trailer (AV3); the two "chisel-nosed" travelers (K, T); the noseconed utility (AV4); and the most streamlined travel trailer (S), having a drag coefficient under 0.45. This suggests the range of drag coefficients that can be practically obtained via body shape.

The sideforce data show the trailers to be generally closer to the rectangular solid shapes, as expected. The one exception is the streamlined trailer S, which is closer to the ellipsoids and airship shapes (e.g., Ref. 36). An interesting point is the vast difference between the noseconed vehicle (AV4) and the streamliner. The much lower side force for the latter is probably due to the rounded longitudinal corners (cross-section streamlining). On the other side, the extreme nose rounding and sharp longitudinal corners of AV4 magnify its side force sensitivity.

The yaw moment data, taken about the center of volume, show the trailers to be in good agreement with slender body theory; that is, the longer the vehicle, the greater the antiweathercock yaw moment about the box center. As expected, the trailers with rounded noses give higher yaw moments, while the boxy and chisel shapes are lower. The verified relation to the volume centroid in the last plot suggests that:

- The location of the volume centroid of the box is an important parameter for yaw sensitivity of the trailer and therefore the car/trailer combination.

Obviously, if the box center could be moved aft relative to the axle, more of the lateral aerodynamic forces would be reacted by the trailer tires, and less by the tow vehicle, which is the desirable trend. Of course, this may be in conflict with the trailer weight distribution requirements.

Also, it needs to be borne in mind that a substantial part of the yaw moment on these vehicles can be caused by fore/aft pressure differentials (i.e., drag) acting out of the plane of symmetry, as opposed to slender body effects.

Tow Vehicle Shape. Tow vehicle shape has already been mentioned in regard to its effects on trailer aerodynamic forces. The tow vehicle itself, of course, represents another disturbance input source, expressed in terms of its lateral aerodynamic characteristics. These are shown for the four tested tow vehicles alone in Plot 12.

The lateral data show the expected trends with body shape, with the streamlined hatchback having the lowest side force and greatest adverse yaw moment sensitivity. For the more flatsided and weathercock shapes, the expected trend away from this shows up, and the pickup/camper gives into the wind yaw moments. The extremely large roll moment of the pickup/camper is also noted. In general, the tow vehicles show yaw moment stall around 25 deg and no side force stall up to 40 deg, in some contrast to the trailer shapes.

The longitudinal data are remarkable, with typical drag "buckets" being shown by all vehicles. The drag varies over a range of 2 to 1, like the trailers, though the tow vehicles are at generally lower values because of higher fineness. The pickup/camper shows a large nose up pitch moment (due to drag), which conceivably could affect its high speed handling, expecially when coupled to a large trailer.

Other effects of different tow car shapes are shown in Plots 13, 14, 15, 16, 17, 18, 19, and 20. These again confirm that:

- Lateral tow car and trailer characteristics are relatively unaffected by the presence of the other vehicle, except for the case of large high drag tow car, which can reduce the lateral aerodynamic forces acting on the trailer.
- There can be a relatively strong interaction between tow car and trailer drag, each one being reduced somewhat by the presence of the other; and the drag on the total vehicle being greater than the drag on either one, and less than the sum of the two.

The lateral aerodynamic characteristics of the six trailers, as affected by the four tow vehicles, at 30 deg crosswind angle, are summarized in Figure 23. These have been plotted in terms of the "side force effective area" (defined as the side force divided by dynamic pressure or, in other words, the side force coefficient times the side area); and the "hitch force effective area" (defined as the yaw moment divided by dynamic pressure and hitch-to-axle distance). The former is an indication of the side-to-side accelerating force acting on a trailer due to gusting; the latter indicates the hitch side force acting on the car, due to gusts hitting the trailer.

As clearly shown, the *presence or shape of the tow car has little effect on these trailer characteristics,* until one

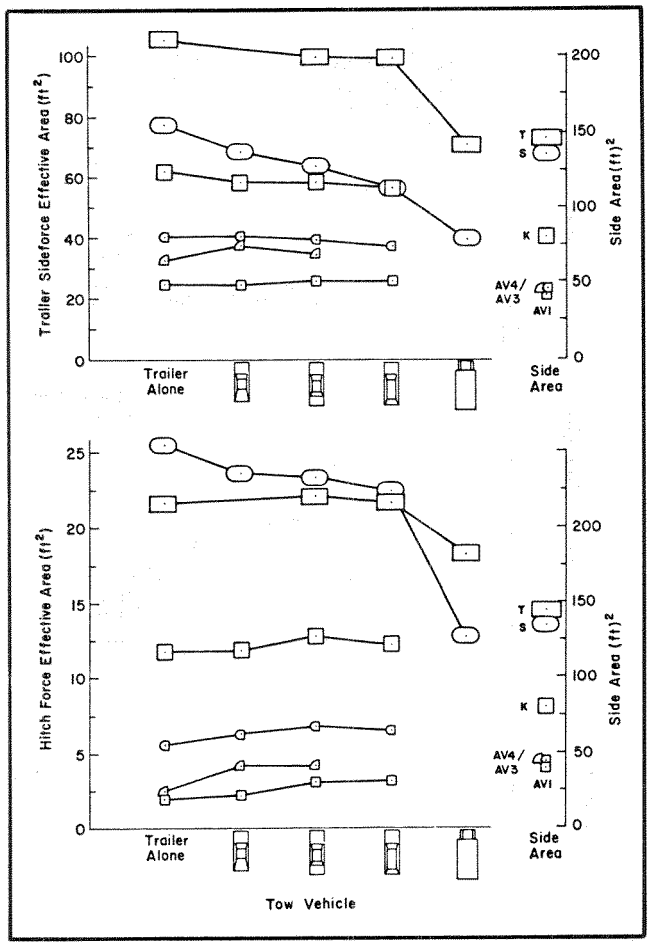


Figure 23. Comparison of trailer yaw and side force crosswind sensitives.

considers the large pickup/camper. (Also, the most streamlined trailer, S, seems to show some sensitivity to tow car shape.) Otherwise, the rank ordering of the trailers shows interesting trends. In terms of side force area, the nosecone utility trailer is substantially more sensitive than the boxy utility trailer, with the rounded trailer lying between these. On the other hand, the most streamlined travel trailer is fairly close to the smaller chisel shaped travel trailer, though its side area is substantially larger. This underlines the effectiveness of rounded cross sections, and the adverse effects of rounded planforms. The latter is brought out even more dramatically in the hitch force area data, where the rounded planforms result in larger hitch forces than squarer bodies of similar or even larger side area.

Articulation Angle. The effects of articulation angle on combination vehicle aerodynamics are shown in Plots 21, 22, 23, 24, and 25. For the trailer lateral data these generally show that:

- Articulation angle changes are similar in effect to crosswind angle changes.

- When the sum of articulation and crosswind angles is large enough to produce stall (around 30 deg), articulation angle changes have little effect.

The effect of articulation angle on tow vehicle lateral aerodynamics is relatively small, though perhaps noticeable with the large "tail area" vehicles such as the pickup camper.

A further analysis showed that, for at least one combination vehicle (F1/AV1), the trailer side force coefficient was 40 percent "stiffer" due to articulation angle changes than due to crosswind angle changes. This may be due to aerodynamic camber effects.

The longitudinal data showed only modest (and not highly organized) changes in tow vehicle and trailer drag with articulation angle changes.

The full implications of these effects on combination vehicle stability are yet to be uncovered.

Truck Proximity. The subject of truck/combination vehicle aerodynamic interaction is a complex one, and one which should be treated via appropriate dynamic simulation. The data presented in this report are voluminous and have not been examined in detail with regard to the effects of vehicle shape and size. Casual examination confirms the presence of truck bow wave and gap flows resulting in large forces and moments on both tow vehicle and trailer, which are also dependent on relative longitudinal position. Of course, for straight-ahead (no crosswind) conditions there is a repulsion force between truck and trailer when the trailer is alongside the gap; and there is a small suction force between the van and trailer toward the aft of the rig.

Regarding articulation angle effects in truck proximity, Plot 26 and other similar data show that articulation angle has little effect toward the rear of the truck, and somewhat more effect near the gap and bow waves, as compared to the freestream (no truck) condition.

CONCLUSIONS AND RECOMMENDATIONS

Recapitulation

An experimental investigation of combination vehicle aerodynamics, pertinent to crosswind and truck-induced disturbances, was performed. The need for this work was indicated by previous full scale tests which showed potential loss of control situations. Also, past accident data indicate a relatively high involvement of wind, truck blast, and aerodynamic disturbances in passenger vehicle/trailer accidents.

The study was accomplished via 1/10 scale model wind tunnel measurements performed on 6 trailers and 4 tow vehicles, and various combinations thereof. For some tests, a non-metric tractor trailer model was placed in the flow field near the combination vehicle model.

A large data base of aerodynamic characteristics was generated for these contemporary vehicles, comprising 6 force and moment coefficients as a function of crosswind angle. The effects of airspeed, articulation angle, trailer and tow vehicle shape, surface roughness, and truck proximity were quantified.

The program, which was to be followed up with computer simulation and full scale tests phases to uncover basic problem areas, was curtailed after the wind tunnel experiments, because of Governmentwide fiscal cuts at that time.

General Findings. The following are preliminary observations and trends substantiated by these data:

- To a very good approximation, the aerodynamic characteristics of a typical utility or travel trailer in tow are accurately represented by the characteristics of the trailer by itself. With some exceptions (extremely sharp edged or streamlined vehicles), it seems reasonable and useful for trailer manufacturers to perform trailer alone wind tunnel measurements during vehicle development.
- Contemporary passenger vehicles are aerodynamically clean enough that their presence does not greatly alter the flow and forces on the trailer, with the occasional exception of drag. Of course larger, body RV type tow vehicles reduce all the aerodynamic forces and moments on the trailer and tend to reduce inter-trailer differences.
- A good appreciation for the effects of shape on trailer aerodynamics can be gained by referring to the classical aeronautical shapes and extent data. The latter accurately bound the forces and moments acting on real trailers at large crosswind angles, when the proper normalizing dimensions are used. The best set of the latter was found to be: frontal area (for drag), box side area (for side force), box volume (for yaw moment).
- Rounded front faces (in trailer planform) tend to give somewhat higher side force sensitivity and substantially higher (up to 100 percent) yaw moment sensitivity, as has been shown in past aeronautical studies.
- Rounded longitudinal edges (i.e., rounded cross sections) can result in greatly reduced side force sensitivity, as is also known from past data.
- The yaw moment sensitivity of trailers can be improved by moving the center of volume of the box aft relative to the axle centerline. All other factors remaining equal, this can result in reduced tow car yaw dispersions and control difficulty in crosswinds.
- The drag interaction between tow car and trailer seems to result in the total drag being less than the sum of the tow and greater than either one, with large variations within this range dependent on vehicle shape details and interaction.

Recommendations

Since only a cursory examination of this large data base could be performed, and in the absence of simulation, analysis and full scale work on this problem area, it is recommended that at some future date the original contract objectives be again pursued. It is realized that this should take place as a result of established and contemporary accident trends, and need for problem identification, and also recognizing that the trailer and RV industry could probably make constructive use of such results.

The extent and depth of the current experimental data are large enough that other investigators could make more fruitful use of them than what has been possible here.

REFERENCES

1. Klein, Richard H., and Jeffrey R. Hogue, *Development of Aerodynamic Disturbance Test Procedures. Vol. II: Technical Report,* DOT HS-805 079, August 1979.
2. Zellner, John W., *Aerodynamic Characteristics of Passenger Vehicle/Trailer Combinations. Vol. II: Technical Report,* Unpublished, April 1982.
3. Jindra, F., "Tractor and Semi-Trailer Handling," *Automobile Engineering,* October 1963, pp. 439-446.
4. Ellis, J. R., *Vehicle Dynamics,* London, Business Books, Ltd., 1969.
5. Kullberg, G., et al., *Studies of Dynamic Driving Characteristics of Passenger Cars with Caravan Trailers,* Statens Vaginstitute Reports (Sweden), No. 93, 1967, pp. 8-45.
6. Ellis, J. R., "The Dynamics of Vehicles During Braking," in *Symposium on Control of Vehicles During Braking and Cornering,* London, Inst. of Mech. Engrs., 1963.
7. Mikulcik, E. C., "The Dynamics of Tractor-Semitrailer Vehicles: The Jackknifing Problem," *SAE Trans.,* Vol. 80, 1971, p. 154.
8. Krauter, A. I., and R. K. Wilsen, "Simulation of Tractor-Semitrailer Handling," *SAE Trans.,* Vol. 81, 1972, p. 2621.
9. Susemihl, E. A., and A. I. Krauter, "Automatic Stabilization of Tractor Jackknifing in Tractor-Semitrailer Trucks," *SAE Trans.,* Vol. 83, 1974, p. 2071.
10. Susemihl, E. A., and A. I. Krauter, "Jackknifing of Tractor-Semitrailer Trucks—Detection and Corrective Action." *ASME J. Dynamic Systems, Mass. and Cont.,* Vol. 96, Series G., No. 2, June 1974, p. 244.
11. Tobler, W. E., and A. I. Krauter, "Tractor-Semitrailer Dynamics: Design of the Fifth Wheel," VDS 1, 1972.
12. Vincent, R. J., and A. I. Krauter, "Tractor-Semitrailer Handling: A Dynamic Tractor Suspension Model," SAE Paper 730653, 1973.
13. Bundorf, R. T., "Directional Control Dynamics of Automobile-Travel Trailer Combinations," SAE Paper 670099, presented at SAE Automotive Engineering Congress, Detroit, January 1967.
14. Klein, Richard H. and Henry T. Szostak, *Development of Car/Trailer Handling and Braking Standards. Vol. I: Executive Summary. Vol II: Technical Report for Phase I—Rear Wheel Drive Tow Cars. Vol. III: Appendices for Phase I. Vol. IV: Technical Report for Phase II—Front Wheel Drive Tow Cars,* Systems Technology, Inc., DOT HS-805 326, 327, 328, and 329, November 1979.
15. Johnston, Donald E., John W. Zellner, and Irving L. Ashkenas, *Handling Test Procedures for Passenger Cars Pulling Trailers. Vol. I: Summary Report. Vol. II: Technical Report. Vol. III: Appendices,* DOT HS-801 935, 936, and 937, June 1976.
16. Anderson, Ronald James, *Dynamic Handling Characteristics of Car-Trailer Systems: Development and Validation of Mathematical Models,* Queen's University, Kingston, Ontario, Ph.D. Thesis, 1977.
17. Klein, Richard H., and Henry T. Szostak, *Effects of Weight Distributing Hitch Torque on Car-Trailer Directional Control and Braking,* Systems Technology, Inc., TR-1098-1, October 1977.
18. Beauvais, F. N., "Aerodynamic Characteristics of a Car-Trailer Combination," SAE Paper 670100, presented at Automotive Engineering Congress, Detroit, January 1967.
19. Wojcik, C. K., and R. L. Mellinger, *Pilot Study of Housetrailer and Truck Camper Safety, Phase No. 2,* UCLA-ENG-7208, December 1971.
20. Hutchinson, J. W., et al., *Recreational Vehicle Accident Investigation Study,* Univ. of Kentucky, Multidisciplinary Accident Study Team, DOT HS-801 523, April 1975.
21. Bellino, Joseph Paul, *A Study of the Effects of Exterior Profiles of Travel-Trailers on Aerodynamic Forces.* Worcester Polytechnic Institute, Worcester, MA, M. S. Thesis, August 1971.
22. Cogotti, A., R. Buchheim, A. Garrone, and A. Kuhn, "Comparison Tests Between Some Full-Scale European Automotive Wind Tunnels—Pininfarina Reference Car," SAE Paper 800139, presented at SAE Congress and Exposition, Detroit, February 1980.
23. Maskell, E. C., *Flow Separation in Three Dimensions,* Royal Aircraft Establishment, Rept. Aero 2656, November 1955.
24. Heffley, Robert K., "Aerodynamics of Passenger Vehicles in Close Proximity to Trucks and Buses," SAE Paper 730235, presented at International Automotive Engineering Congress, Detroit, January 1973.
25. Heffley, Robert K., *The Effects of Boundary Layer Properties on Wind Tunnel Forces and Moments,* Systems Technology, Inc., WP-1016-4, March 1972.
26. Cooper, K. R., "An Examination of the Effects of

Wind Turbulence on the Aerodynamic Drag of Vehicles," in Clark Kramer and Hans-J. Gerhardt, eds., *Proceedings of the 4th Colloquium on Industrial Aerodynamics,* Aachen, FRG, June 1980, pp. 283-294.
27. Buning, H., and F. N. Beauvais, "Wind Tunnel Can Measure Actual Forces and Yaw on Car in Gust," *SAE J.,* Vol. 75, No. 6, June 1967, pp. 66-70.
28. Weir, David H., Jay F. Strange, and Robert K. Heffley, *Reduction of Adverse Aerodynamic Effects of Large Trucks. Vol. I: Technical Report,* FHWA-RD-79-84, September 1978.
29. Weir, David H., Robert F. Ringland, Robert K. Heffley, and Irving L. Ashkenas, *An Experimental and Analytical Investigation of the Effect of Truck-Induced Aerodynamic Disturbances on Passenger Car Control and Performance,* FHWA-RD-71-3, October 1971.
30. Weir, David H., Roger H. Hoh, et al., *An Experimental and Analytical Investigation of the Effect of Bus-Induced Aerodynamic Disturbances on Adjacent Vehicle Control and Performance,* Systems Technology, Inc., Tr-1016-1, November 1972.
31. Weir, David H., Richard H. Klein, and John W. Zellner, "Crosswind Response and Stability of Car Plus Utility Trailer Combinations," SAE Paper 820137, presented at International Congress and Exposition, Detroit, February 1982.
32. Barth, R., "Effect of Unsymmetrical Wind Incidence on Aerodynamic Forces Acting on Vehicle Models and Similar Bodies," SAE Paper 650136, presented at International Automotive Engineering Congress, Detroit, January 1965.
33. Weir, D. H., C. P. Shortwell, and W. A. Johnson, "Dynamics of the Automobile Related to Driver Control," SAE Paper 680194, February 1967.
34. Hoerner, S. F., *Fluid-Dynamic Drag; Practical Information on Aerodynamic Drag and Hydrodynamic Resistance,* published by author, 1958.
35. Hoerner, S. F., and H. V. Borst, *Fluid-Dynamic Lift,* Hoerner Fluid Dynamics, Bricktown, NJ, 1975.

Consideration About the Relation of Headlamp Glare and Driving Visibility

HIROAKI SHINKAI, YOSHIMASA OSUMI
Toyota Motor Corporation

ABSTRACT

As we often drive a car at night under the driving situation that only the use of low beam in headlamps is permitted, despite driver's desire to use high beam, photometric improvement in the low beam is considered to be necessary in order to improve driving visibility. Most drivers wish to have improved low beam which is capable to see a far distance, while they demand not to have dazzling light distribution on opposing cars. A means to see a far distance is to increase the lamp intensity or an upward looking lighting line. In the latter case road surface near the vehicle becomes dark. For that reason an increase of lamp intensity is selected in order to see a far distance. But, as we know, it is the glare that affects driver's visibility which causes an increased serious problem.

Hence the threshold level of the glare is examined based on field tests finding a tolerable level of discomfort due to the dazzling and target visibility. Further, increase of visibility distance is examined when the headlamp intensity is increased to threshold level of the glare.

INTRODUCTION

Driving visibility at night is obtained with roadway lighting and vehicle headlamp. Roadway lighting brightly illuminate the road surface and surrounding, and contribute to accident prevention. Figure 1 shows effect of roadway lighting in Japan (1). Furthermore this effect has been reported in several countries (2) (3) (4). But, installing roadway lighting to all roadways would give adverse effect to energy and cost saving. For that reason it will not be enforced. Hence headlamp performance becomes important to secure driving visibility at night. Headlamps are equipped with low and high beam. Presently, high beam is used few times. According to our investigation, the rate of used low beam is over ninety percent on ordinary roads in Japan. According to a study in the U.S.A., seventy-five percent of drivers use low beam even in very light traffic (5). Considering that situation, a single beam headlamp, with removed high beam, has been made for a study (6).

On the other hand, at traffic conditions which require more than low beam, thoughtless drivers who use high beam for unsatisfactory low beam visibility annoy other drivers. If the low beam gives a proper visibility, unsatisfactory visibility and annoyance to the other drivers are solved. A three-beam headlamp system, for supply be-

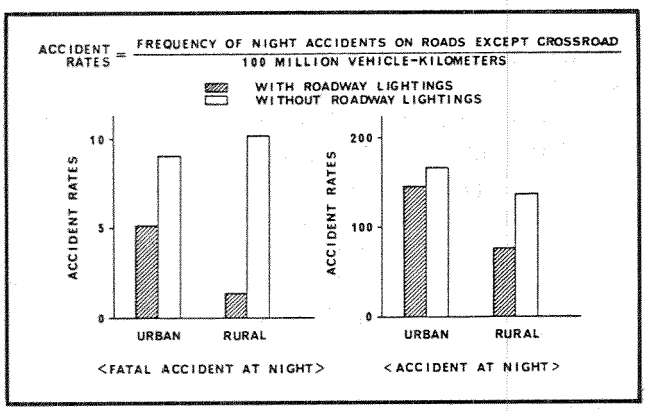


Figure 1. Accident rate at night with and without roadway lightings.

tween low and high beam visibility, has been studied (7) (8) (9).

From the cases discussed so far, we consider that improvement of driving visibility at night means to improve the low beam, and to increase the visibility distance. Therefore the low beam needs an intensity increase. But, increasing low beam intensity, opposing drivers suffer discomfort due to dazzling and visual obstacle in forward field of view. A polarized headlamp system has been reported to be successful to reduce glare and see a far distance (10). But it is not yet used in practice.

Hence, when the low beam intensity in the current headlamp system is increased, we considered the following:

1) What is the permitted glare level?
2) How much is the increase of visibility distance when the lamp intensity is increased to the permitted glare level?

ESTABLISHMENT OF THRESHOLD LEVEL OF GLARE

Concept

Glare is a temporary visual disturbance, which occurs when the eye receives more than the adaptation light. Glare has been distinguished between discomfort glare, which is subjective glare, and disability glare, which becomes a visual obstacle in the forward field of view. In this study, we experimented discomfort glare test, which answered the glare feeling, and disability glare test, which recognizes the target shape. We considered the threshold level of the glare from both test results.

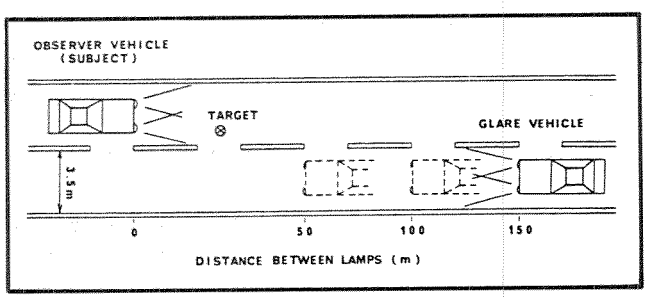


Figure 2. Location of test vehicles.

Method

Procedure. Location of observer and glare vehicle are shown in Figure 2. Test was done at static condition.

The following explains the test procedure.

1) Observer and glare vehicle is set at a normal aiming which is provided by the security and inspection standard in Japan.
2) Subject watches the target which moves farther away, and gives a signal when the target shape becomes the threshold level of recognition.
3) Glare vehicle headlamp is changed by certain degrees to a look upward position. (Glare increasing method is increase of intensity and look upward position. In this test, look upward was chosen.)
4) Subject gives a signal when the target shape becomes unrecognizable.
5) At that time, illuminance of eye position (cornea illuminance) is measured.
6) Subject answers discomfortability feeling a five point scale:
   5 unbearable
   4 very dazzling
   3 dazzling
   2 a little dazzling
   1 same as normal aiming condition
7) Glare vehicle is moved to the next distance point.

Procedures from number one to six are repeated. From the above procedures, cornea illuminance of threshold level of target shape recognition and evaluation value of discomfortability feeling are obtained.

Condition. The distances between observer vehicle lamp and glare vehicle lamp are selected in the range of 50 m, 100 m and 150 m, that they may affect glare. The lamps with the U.S. and the European beam pattern adapted for Japanese Industrial Standards are used as the glare lamps. As the target, a gray cylinder of 300 mm height, 110 mm radius and 13 percent reflectivity is used. 10 male

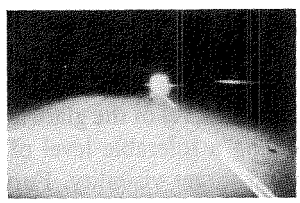


Figure 3. Forward field of view during the test. (Target is seen in the center of the photograph.)

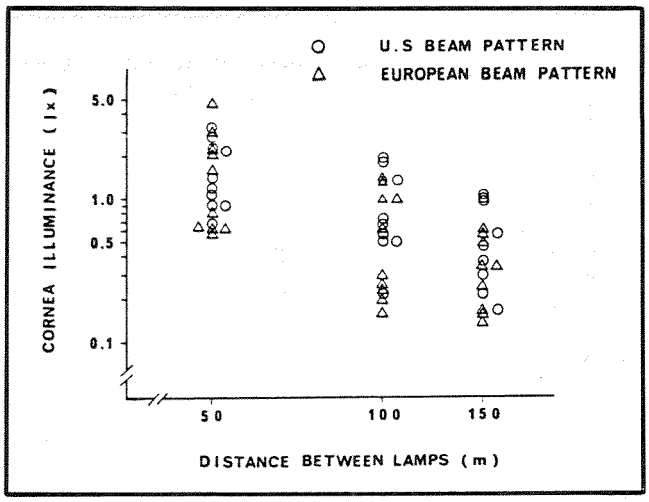


Figure 4. Comparison of beam patterns.

subjects, whose visual acuity are from 0.7 to 1.5 measured by Landolt Ring, participated in this experiment.

Result and Consideration

Comparison of Beam Pattern. The relation of the distance between lamps and the maximum cornea illuminance for the shape recognition of the target, is shown in Figure 4 by the U.S. and the European beam patterns. The significant difference could not be observed between the U.S. and the European beam pattern.

A comparison of these beams has been made many times (11), but a superiority of either one has not been concluded.

The Threshold Level of the Glare. Since there are no difference of beam patterns, these data are pooled and the mean value is calculated. Figure 5 shows the maximum cornea illuminance level for the shape recognition of the target and the isodiscomfort level.

Since the mean of the maximum cornea illuminance level is equivalent to the 'dazzling' level, its illuminance level is not allowable as the threshold level of the glare.

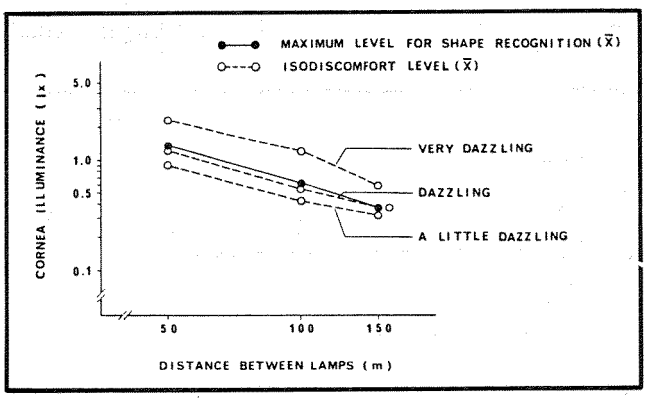


Figure 5. The maximum cornea illuminance level for the shape recognition and the isodiscomfort level.

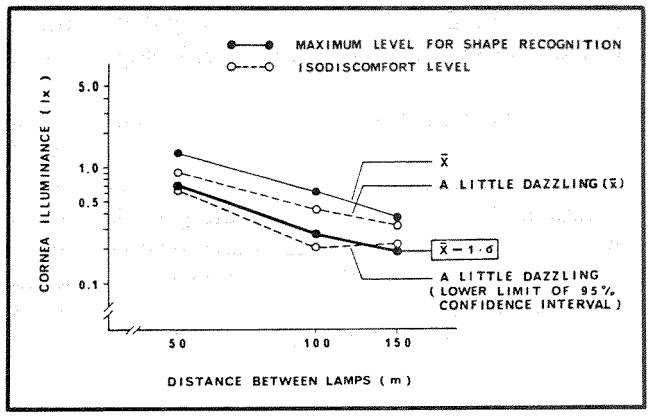


Figure 6. Threshold level of the glare ($\bar{x} - 1 \cdot \sigma$).

The threshold level of the glare must be selected in the range that almost all drivers can see targets with little discomfortability. A lower limit of 95 percent confidence interval of 'a little dazzling' level is selected as little discomfortability level and shown in Figure 6. It is nearly equal to the '$\bar{x} - 1 \cdot \sigma$' of the maximum cornea illuminance level.

Statistically about 85 percent of drivers can recognise the target at '$\bar{x} - 1 \cdot \sigma$'.

Therefore the '$\bar{x} - 1 \cdot \sigma$' of maximum cornea illuminance level is adopted as the threshold level of the glare.

The Relation among Opposing Vehicle Position, Cornea Illuminance and Target Visibility. It is said that the veil produced by the lamp of the opposing vehicle increases the background brightness of the target and produces a negative effect on the visibility (12). The formula based on this fact is expressed as follows.

$$Bv' = 10 \cdot E' \,/\, (\theta\,(\theta + 1.5))$$

Where Bv' is veiling brightness, E' is cornea illuminance and θ is angle between opposing vehicle lamps and target from driver's view point. The relations among Bv', E' and θ are shown in Figure 7 by applying this formula with

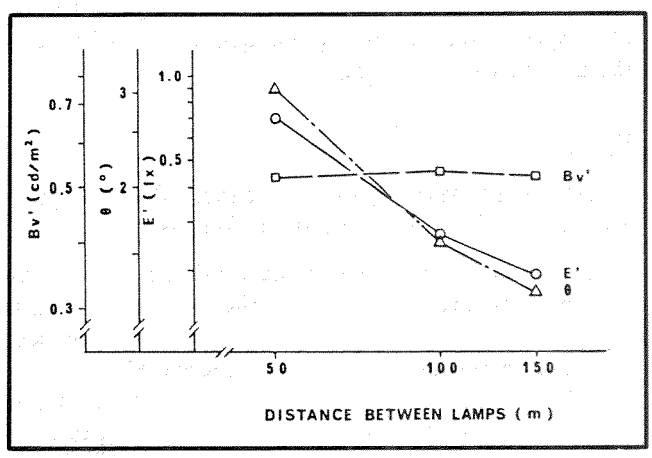


Figure 7. Relation of distance between lamps and veiling brightness.

E′ as the threshold level of the glare and θ as the calculated value from the distance between lamps and target position.

When the glare vehicle is far and θ is small, in terms, the glare lamps reaches central vision, and the allowable cornea illuminance E′ decreases. When the glare vehicle is near and θ is large, in terms, the glare lamps is far from central vision, and the allowable cornea illuminance E′ increases. Whether the glare vehicle is far or near, accordingly, the veil brightness Bv′ almost remains at a constant level. Since Bv′ affects the target visibility, it is almost the same regardless of the glare vehicle's position.

CERTIFICATION OF INCREASED VISIBILITY DISTANCE BY INCREASING LAMP INTENSITY

The effect that increasing lamp intensity up to the threshold level of the glare increased visibility distance is introduced in the case of shape recognition and presence recognition.

Shape Recognition

Method. The distance between lamps is set at 50 m or 100 m, and the test procedures are as follows.

1) The lamps of the observer and glare vehicle are set at normal aiming.
2) The Subject watches the target and answers the farthest position in which he can recognize its shape. The visibility distance is defined as the distance between the observer vehicle and the target.
3) The lamp intensity of the vehicles is increased up to the threshold level of the glare.
4) The subject answers the farthest position in which he can recognize its shape.

Result. Figure 8 shows that increasing the lamp intensity makes the visibility distance 6 to 10 percent longer with glare vehicle and 19 percent without glare vehicle. It is expected that increasing the lamp intensity improves the driving visibility at night.

Presence Recognition

Method. The visibility distance is derived without glare vehicle, and the procedures are as follows.

1) The subject in the stationary vehicle watches the moving target and answers the farthest position in which he can recognize its presence. At that position, a vertical illuminance is measured.
2) The lamp intensity measured in darkroom is converted into the vertical illuminance on the road, whose isolux line is drawn.
3) The visibility distance is defined as the distance between the observer vehicle and the point where the isolux line at the vertical illuminance, observed in the field test, intersects the extention line of the vehicle center line.
4) The visibility distance is derived at normal aiming level and at the threshold glare level.

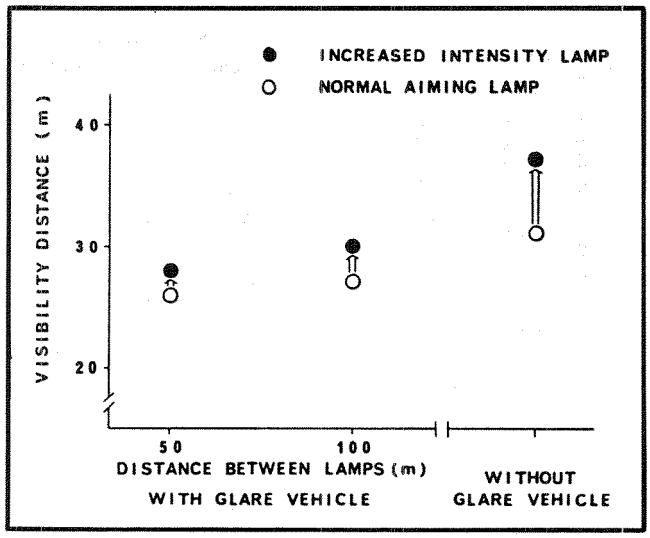


Figure 8. Visibility distance for shape recognition.

Result. The result of the field test shows that the subject can see the target when the vertical illuminance is more than 3.8 lx.

The isolux line at 3.8 lx vertical illuminance calculated is shown in Figure 9. It shows that the visibility distance is 45 m in normal aiming level and 60 m in the threshold glare level. Therefore, the rate of increased distance is 33 percent without glare vehicle. Accordingly, increasing lamp intensity makes visibility distance longer to give drivers the time for judgment and reaction.

CONCLUSION

Improvement of night time visibility can be expected by the increase of low beam intensity. If so, increased intensity has maximum value. Threshold level of the glare is considered from relation of glare and target visibility.

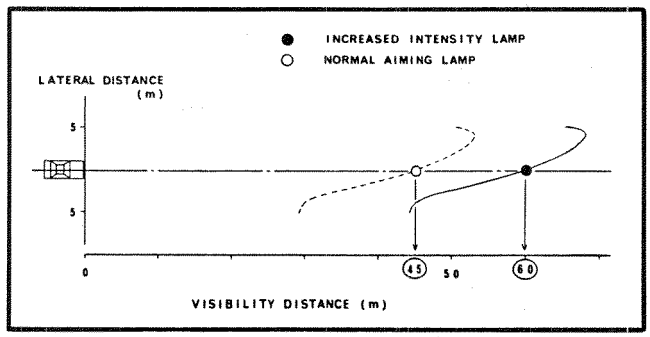


Figure 9. Visibility distance for presence recognition.

1) Headlamps intensity which do not exceed the threshold level of the glare, can be increased up to the said glare level. Then visibility distance will be increased. Visibility distance, in our case, was about 40 m to the shape, and about 60 to the presence recognition.
2) Headlamps intensity which exceed the threshold level of the glare, should be decreased down to the said glare level to reduce the glare of driver.

These results were obtained under the static condition, and supposed target was used. However, these results may change with road and traffic environment. Therefore further studies are needed.

REFERENCES

1. K. Kinoshita, "Road Traffic and Accident Rate." The Traffic Monthly, 1981.
2. B. R. Austin, Traffic Engineering & Control, June 1976.
3. Paul C. Box, Traffic Engineering, Oct. 1976.
4. I. Scholz, International Lighting Review, 1974. 4.
5. R. N. Schwab, et al., "Improvement of Visibility for Night Driving." Highway Research Record No. 377, 1973.
6. R. Halstead-Nossloch, et al., "Evaluation of the Feasibility of a Single-Beam Headlighting System." DOT-HS-805-219, Oct. 1979.
7. R. G. Mortimer and P. L. Olson, "Evaluation of meeting beams of Two- and Three-Beam Headlighting Systems." SAE paper 770237, 1977.
8. P. W. Maurer, "New Headlighting Systems Provide Increased Visibility." Environmental Activities Week, June 1973.
9. J. Tsukahara and N. Kuno, "New Headlight for Motor Vehicle." Toshiba Review, 1973.
10. R. H. Hemion and Roy W. Hull, "Headlight Requirement in 1990-Cost-Benefits and Mini-Field Trial of Polarized Headlights." PB-258 145, 1976.
11. P. L. Olson, "The Relative Merits of Different Low Beam Headlighting Systems A Review of the Literature." PB-278 062, 1977.
12. V. D. Bhise, et al., "Modeling Vision with Headlights in a Systems Context." SAE paper 770238, 1977.
13. K. Yokoi, "Visibility of Automotive Headlamp." Journal of the Illuminating Engineering Institute of Japan, 1980.

Vehicle Handling and Active Safety Alfa Romeo's Researches on Driver Vehicle System

LUCIANO CHIDINI
ALFA ROMEO s.P.a.

ALFA ROMEO FOR SAFER DRIVING

The aim of research on Active Safety is to reduce accident risk to a minimum by improving stability, handling and braking characteristics.

The directions followed by such research are threefold: to analyze these characteristics with precision, to establish the type of improvement called for, and to find the way to obtain it.

The problem is made all the more complex by the wide range of factors that affect the dynamic behaviour of a vehicle; moreover, safety depends above all on the interaction between DRIVER, ENVIRONMENT and VEHICLE.

Up to now the main approach to this question has taken the form of simulation by expert test-drivers of the various kinds of manoeuvre that may be made by various kinds of driver. The acceptability of a vehicle's safety is based on a subjective evaluation of the results given by the vehicle.

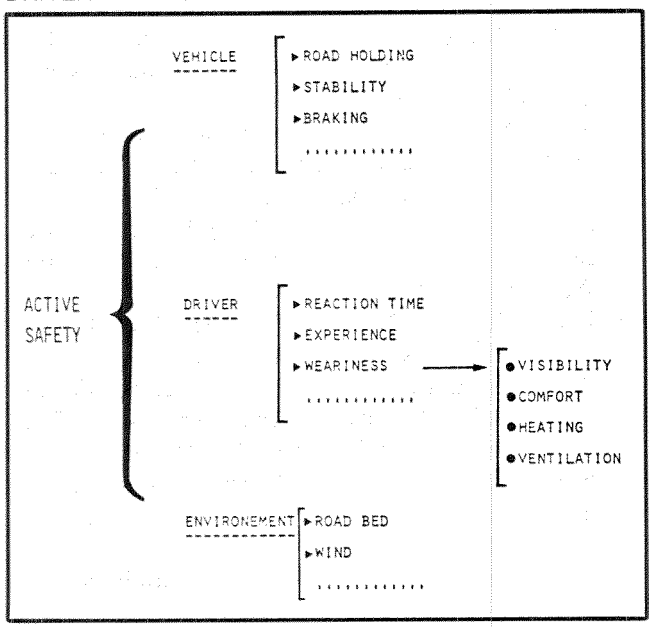
Obviously, this experimental approach cannot be applied in the design phase but only afterwards when the prototypes are built. It is therefore essential to realize to what extent the design parameters contribute to achieving the ideal characteristics of progressiveness, predictability and uniformity of vehicle behaviour.

With this aim in mind the real behaviour of the DRIVER/VEHICLE System is subjected to intensive study at Alfa Romeo. This research activity has two interrelated facets: the experimental approach and the theoretical approach. The purpose of the theoretical approach is to obtain mathematical simulation models.

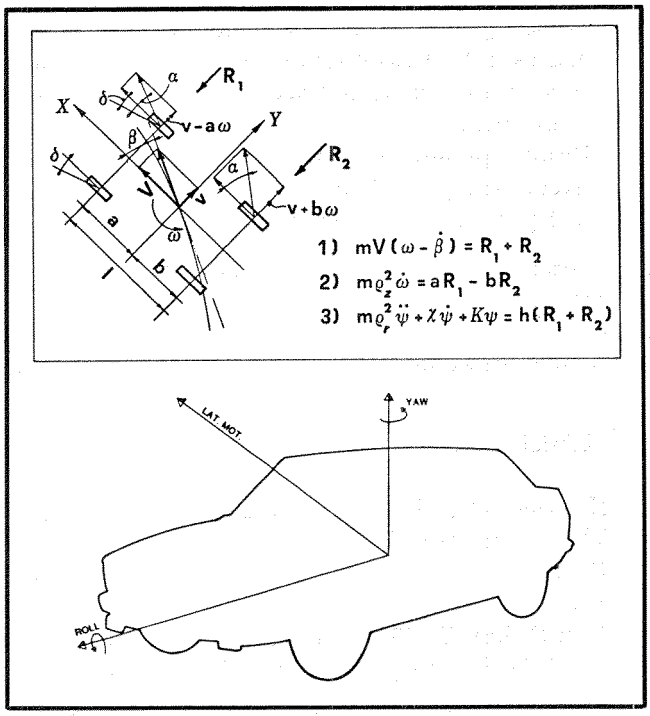
The experimental approach uses track tests to learn about the vehicle's dynamic behaviour in a series of manoeuvres, thanks to instruments able to establish all the parameters regarding motion, course angle, and sideslip angle.

Alfa Romeo's experimental research is carried out on the Balocco track, which covers an area of 500 acres with driving surfaces totalling more than 20 kilometres in

DRIVER – VEHICLE – ENVIRONMENT LOOP



VEHICLE'S MATHEMATICAL MODEL



length. The roads include bends with radii ranging from 20 to 300 metres and reproduce the most frequently encountered types of surface and irregularities.

The vehicles used are in effect mobile laboratories, incorporating the latest and most sophisticated instruments available, which are capable of measuring all the parameters of movement.

Some of these instruments are actually designed by Alfa Romeo: for example, sensors for measuring the slip angles of tyres, the device for maintaining predetermined angles and others.

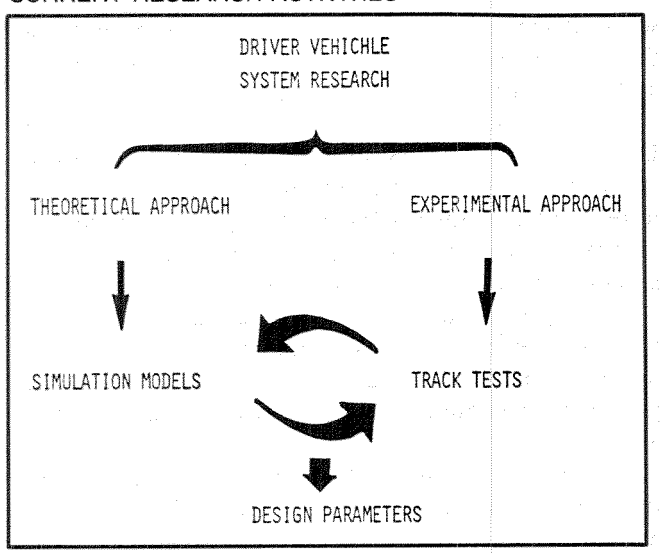
In the course of theoretical research a model with N degrees of freedom is studied, bearing in mind the non-linearity of the real behaviour of tyres, suspensions, shock absorbers, etc. The most important movements are those of roll, yaw and lateral traverse of the sprung masses.

The validity and refinement of the mathematical model are determined by an experimental/theoretical comparison of the main parameters of the vehicle's steady state and transient state responses.

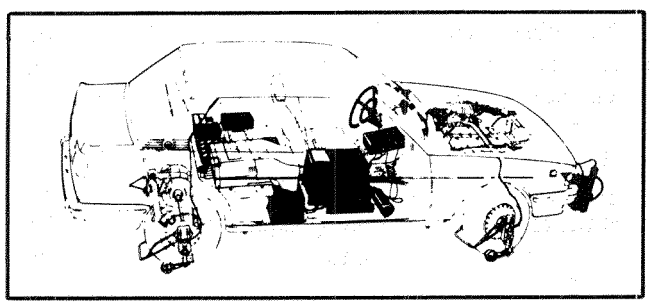
The various aspects of the vehicle's motion are noted by the on-board instruments, recorded on tape and decoded with a processing computer.

A comparison of the motion parameters measured experimentally and those obtained by calculation from the mathematical model of the vehicle assures the validity of the latter.

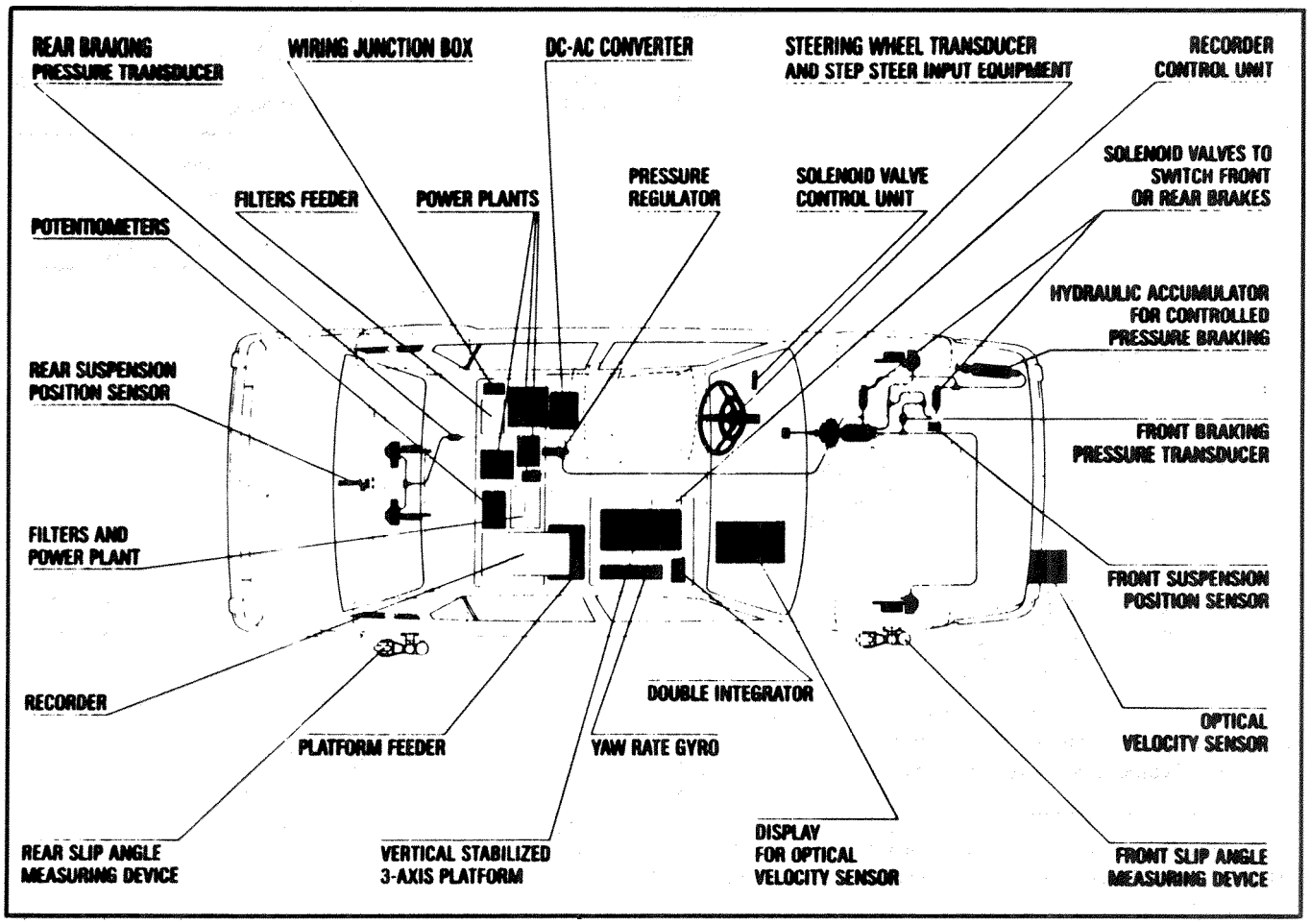
CURRENT RESEARCH ACTIVITIES



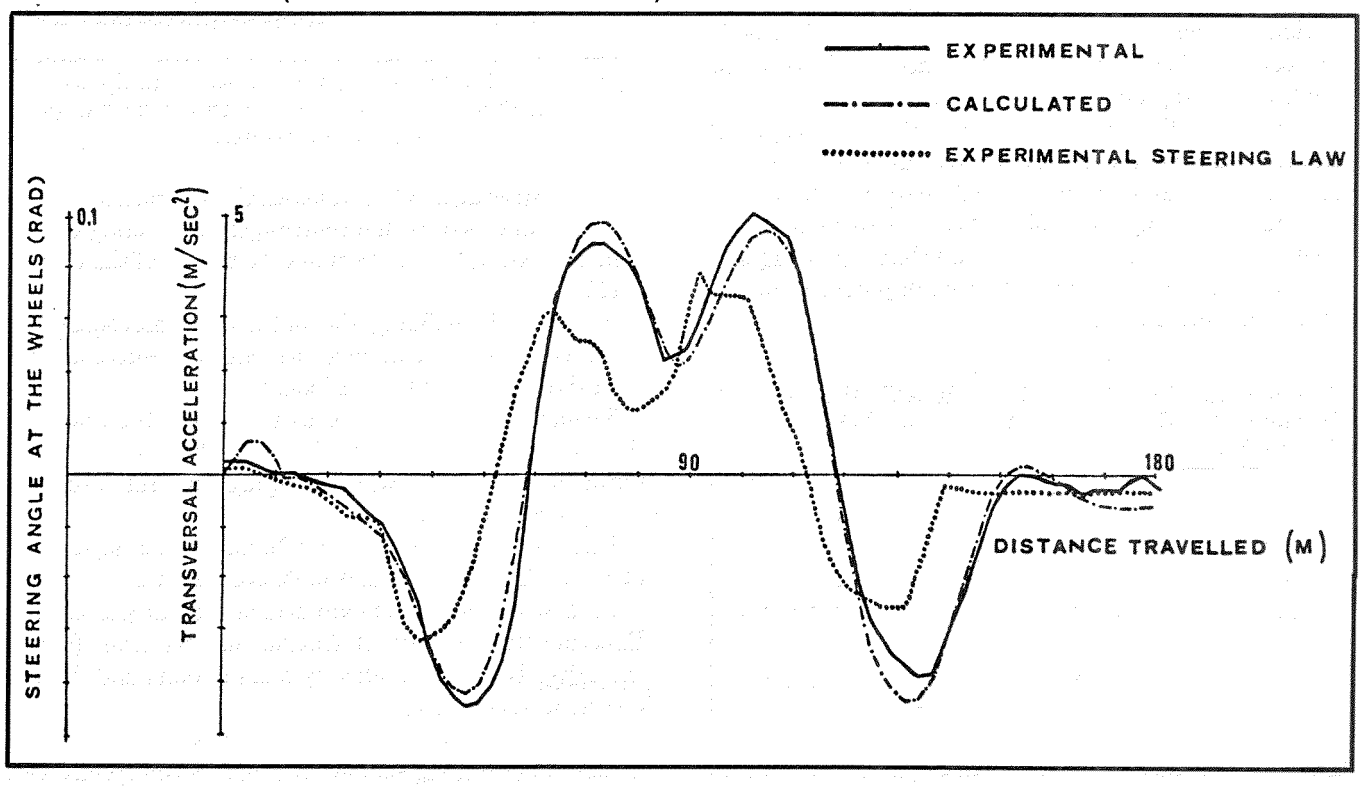
ALFA ROMEO INSTRUMENTED VEHICLE FOR ACTIVE SAFETY RESEARCHES



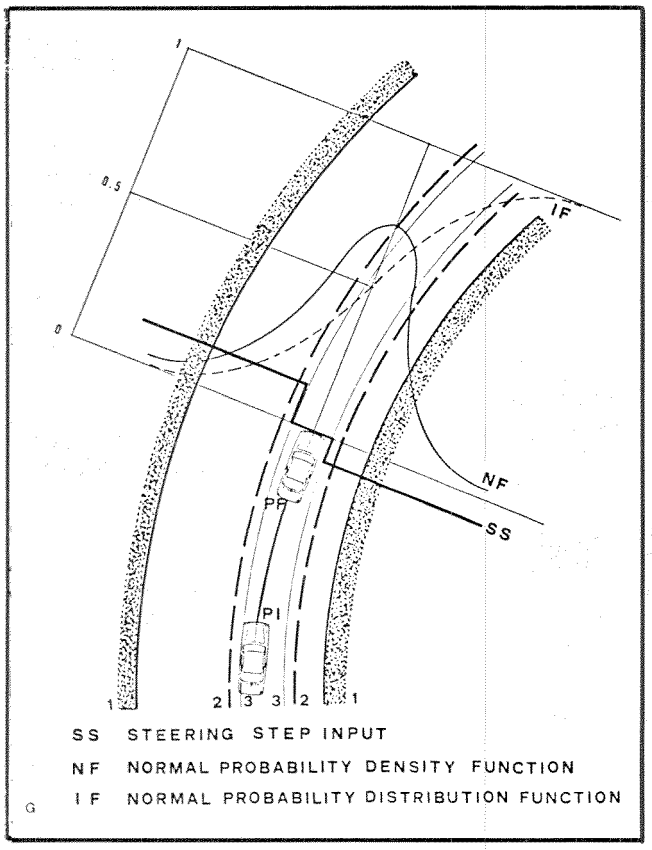
ALFA ROMEO INSTRUMENTED VEHICLE
FOR ACTIVE SAFETY RESEARCHES



VEHICLE RESPONSE – (TRANSVERSAL ACCELERATION)



DRIVER'S MATHEMATICAL MODEL

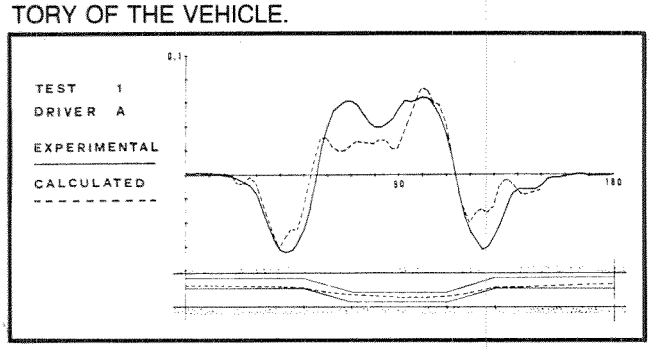


In this particular case we have a comparison between the calculated response to transversal acceleration and that measured experimentally in a test of overtaking at 100 kilometres an hour with superimposed steering law.

In this way we are able to establish the dynamic behaviour of the vehicle and its suspensions and tyres in manoeuvres that utilize the adherence available to its limit, and to reproduce it by calculation.

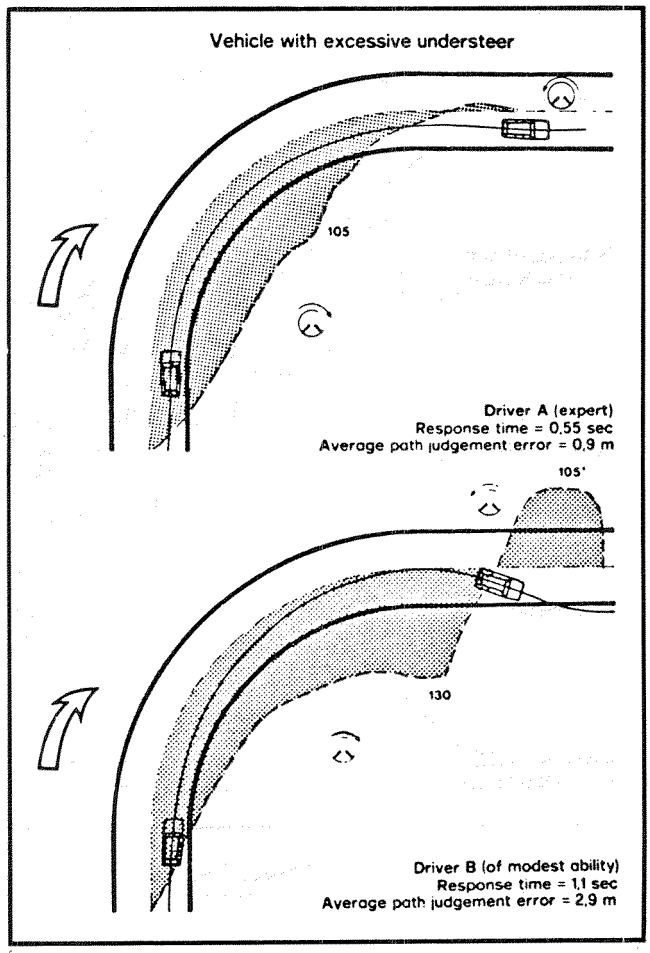
What is particularly significant is the high degree of lateral hold achieved by the vehicle, in that the higher this is, the greater the margin of safety for the driver. And this, not only to obtain a better performance, but above all, to be able to control the vehicle in emergency conditions or those created by errors of judgment on the part of the driver.

COMPARISON OF THE CALCULATED AND AVERAGE EXPERIMENTAL STEERING LAWS. CALCULATED TRAJECTORY OF THE VEHICLE.



MATHEMATICAL MODEL OF THE VEHICLE/DRIVER SYSTEM

Simulation of an impegnative manoeuvre of insertion while cornering r = 100 m; v = 92 km/h (57,5 mph), lateral acceleration corresponding = 0,65 g



Bad road-holding caused by excessive understeer inhibits driver B to keep this car on the road when leaving the corner.

In this steering pad test transversal acceleration exceeds 0.9 g: in other words, the centrifugal force acting on the vehicle is equivalent to 0.9 times the weight of the vehicle itself.

However, in defining the optimum compromise between stability and handling, the variable represented by the driver must not be overlooked.

Thanks to this familiarity with the vehicle's possibilities, the expert driver can obtain the best possible performance from it, while keeping control even in emergency situations.

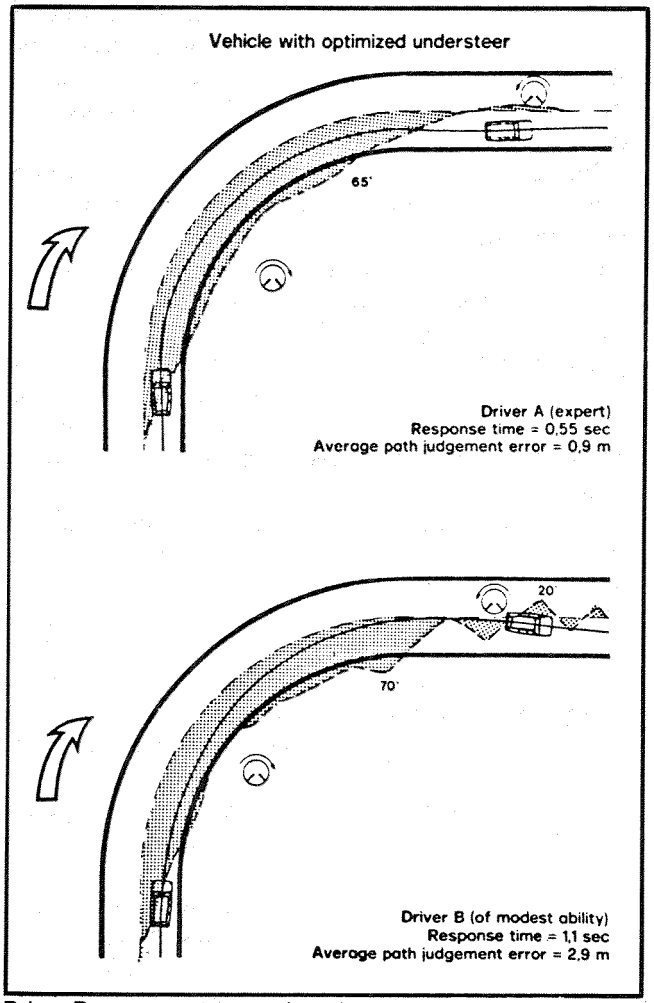
Such is these case with the Italian Police squad car drivers, who must undergo intensive training.

In these courses, which are held at the Car and Engine Experimental Institute at Anagni, not far from Rome, the driver is taught to identify a car's limits and, if necessary, to reach them.

By practising special manoeuvres drivers become proficient in performing slaloms, S-bends, cornu spirals, etc.

MATHEMATICAL MODEL OF THE VEHICLE/DRIVER SYSTEM

Simulation of an impegnative manoeuvre of insertion while cornering r = 100 m; v = 92 km/h (57,5 mph), lateral acceleration corresponding = 0,65 g



Driver B manages to complete the manoeuvre but is obliged to apply opposite lock and make use of all the available road surface.

But the training and equipment required to achieve this degree of skill in driving (which is professionally necessary for this category road-user) are not available to the vast majority of drivers.

Who exactly is the average driver, and how does he react, especially in emergency manoeuvres?

Unfortunately it is not possible to measure either the degree of experience or the psycho-physical state of a driver. We have, therefore, tried to define, as for vehicles, a calculation model that simulates, through reasonable hypotheses, a driver's real behaviour.

In our model it is assumed that the driver uses the steering wheel in an attempt to follow as far as possible the course he regards as ideal, so as not to go out of his lane and, even more imperative, off the carriageway altogether.

The extent to which the steering can be corrected is limited physically on the one hand by the adherence available at the front wheel, and mentally by the precision with which the driver receives and analyzes data concerning the road.

The validity of the model is checked in exhaustive transient state manoeuvres by comparing the average course of the steering law observed experimentally with that obtained by calculation. In this instance the comparison refers to an overtaking test: the correspondence between the steering angle data observed and those calculated is quite good, especially in the light of the dispersiveness of experimental data and of the relative simplicity of the calculation model.

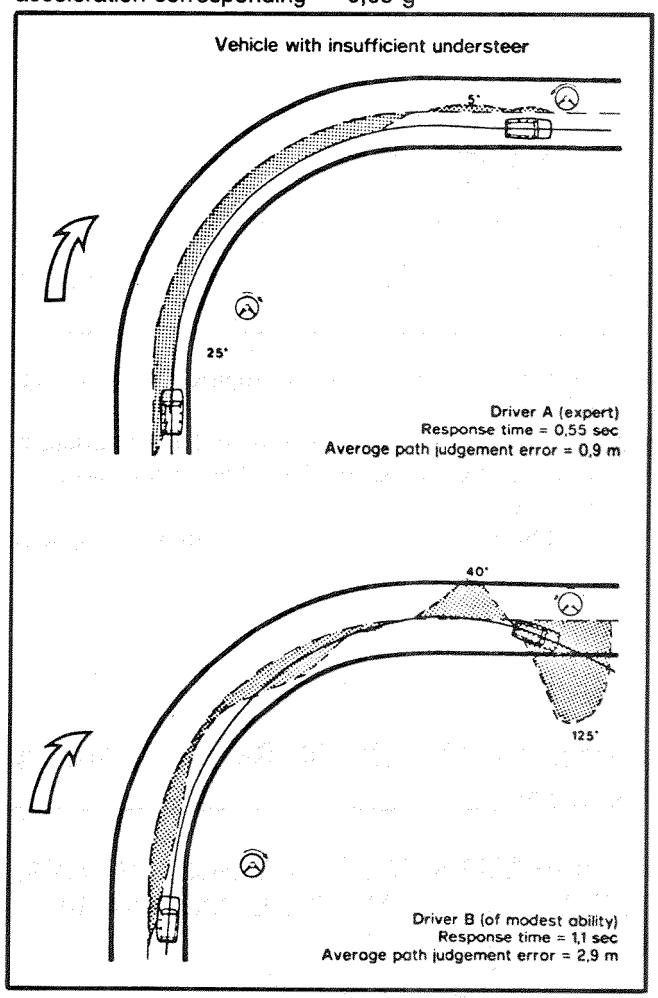
By means of models based on experimental observations we are thus able to recreate by calculation manoeuvres that are not repeatable experimentally, for reasons of space or driver safety, or because of the unpredictability of environmental factors such as wind, aquaplaning, etc.

Such is the case with a bend mistakenly taken at an excessive speed.

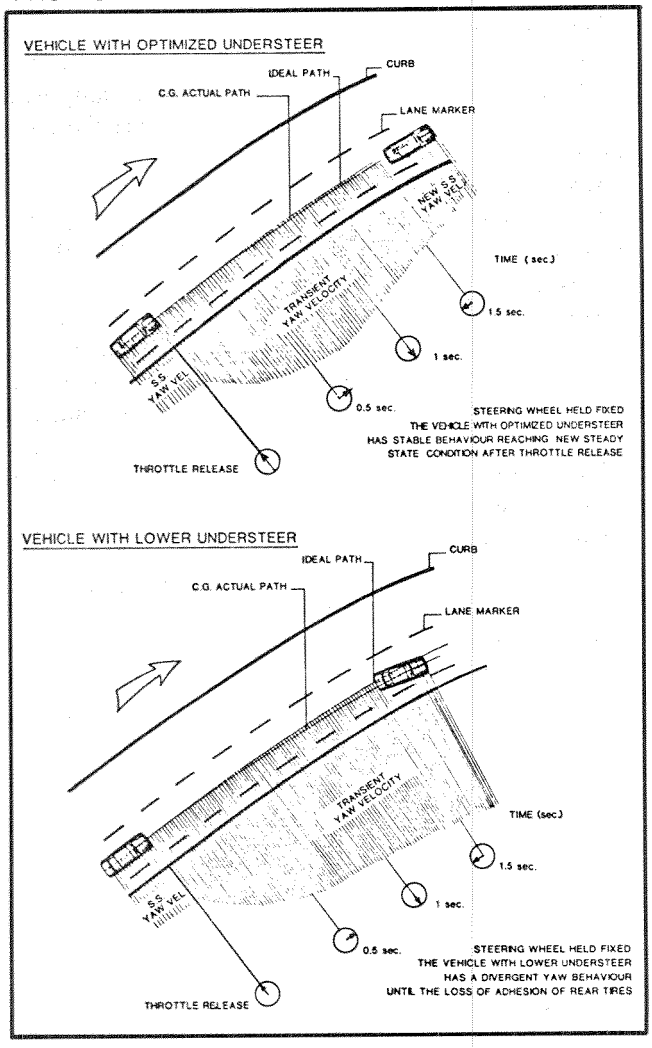
This manoeuvre is simulated by the computer with

MATHEMATICAL MODEL OF THE VEHICLE/DRIVER SYSTEM

Simulation of an impegnative manoeuvre of insertion while cornering r = 100 m; v = 92 km/h (57,5 mph), lateral acceleration corresponding = 0,65 g



THROTTLE RELEASE WHEN CORNERING BEGINNING FROM STEADY STATE CONDITION



varying degrees of understeer as applied by drivers of different levels of proficiency.

As is to be expected, the expert driver has no difficulty in controlling the course of the vehicle with adequate steering laws.

The differing degree of understeer of the vehicle is reflected in the extent of the steering corrections.

In the same conditions the inexpert driver is able to complete the manoeuvre only with the optimized understeer to compensate for his lack of driving skill.

The result of excessive understeer and insufficient understeer, as compared with optimized understeer, is going off the road. However, control of the vehicle is influenced not only by manoeuvring errors but also by unforeseeable external circumstances.

One such case is the abrupt release of the accelerator on a bend, caused, for example, by a sudden obstacle on the carriageway.

The greater the initial transversal acceleration of the vehicle, the more dangerous this manoeuvre is.

In this case, too, the vehicle's understeer is of fundamental importance. Following throttle release the vehicle with optimized understeer tends first of all to close the bend and then to enter a circular course with a reduced radius. The vehicle with less understeer, on the other hand, presents an unstable behaviour.

The vehicle with optimized understeer thus calls for only a modest intervention on the part of the driver to maintain control of its course.

To conclude, we may say that only limited number of drivers are experienced enough to make full use of the potential of present-day vehicles, to adapt to changing environmental conditions, and to carry out instinctively the most effective manoeuvres needed in emergency conditions.

But it is as much true that higher levels of cornering properties represent for the "normal driver" a reassuring margin of safety.

It is, then, up to the sense of initiative and responsibility of the individual car-maker to reconcile stability and handling requirements so that control of the vehicle is reasonably for drivers of differing experience and skill, even in the eventuality of errors of judgment and emergency situations. These are the goals that have always inspired Alfa Romeo, and which specifically determine the orientation of the company's present research on the Driver-Vehicle System.

Increase of Driving Safety Through New Concept Four Wheel Drive Vehicle

REMPEI MATSUMOTO, GYOICHI HATAYA, TETSUO SATO, MAMORU MORINAGA, and YOICHI DESAKI
Subaru Engineering Division
Fuji Heavy Industries, Ltd.

ABSTRACT

Four wheel drive vehicles have superior performance in driving safety on mountainous terrain and snowy roads. They have usually in the past, however, been inferior to conventional vehicles in stability in the high speed range,

quietness and riding comfort, and maneuvering ease, accompanied by disadvantages in price and fuel economy.

The growth of motorization has brought recently an increasing number of motorists who wish to drive safely and comfortably under various circumstances. The four wheel drive vehicle we introduce here (referred to hereafter as NC4V-A) is an answer to such a demand in the market; it is designed on the basis of a front wheel drive car and has a part-time 4WD system, with which the driver can switch from FWD to 4WD and vice versa without stopping the car. This new model of four wheel drive vehicle is provided with greater security in driving on hilly, snowy or rainy roads, and also with directional stability, quietness and riding comfort in high speed driving on ordinary paved roads, comparable with those of conventional passenger vehicles. Price and fuel economy also compare well with other conventional cars.

An automatic transmission model is also available, in which instantaneous and easy switching of the drive mode is possible with the push button control, on any road and at any speed. It enables the driver to select the drive mode freely, and makes possible a safer car, which can be easily driven in various circumstances even by an unskilled driver.

On the same basis of design concept, a cab-over type mini car, wagon and truck models, with part-time 4WD system (referred to hereafter as NC4V-B) was developed as a derivative of the RWD mini car, which is propelled by a 550 cc engine.

In this paper, construction of these "New Concept Four-Wheel-Drive Vehicles" is outlined, and their driveability on rough roads, stability, controllability, and crashworthiness are discussed, as well as fuel economy and quietness.

BACKGROUND OF THE DEVELOPMENT OF NC4V

Four-wheel-drive vehicles in Japan before 1970 were constructed principally for the purpose of off-road driving. They were stout and excelled in rough road driveability. Their hard suspensions, however, made them uncomfortable and unsuitable for high speed cruising. Moreover, 4WD controls were rather difficult to handle and were not always accepted by the average driver. The expansion of motorization in this country since then brought a strong demand by the increased number of motorists for safer and more comfortable driving under various circumstances. This came on one hand from the increase of snowy road driving for winter sports, on the other hand from the situation that about seventy percent of this country is mountainous and a large number of houses are built on hillsides, as shown in Figure 1. These illustrate one of the extreme snow-fall districts, where in

Figure 1. Sample of houses on slopes.

winter roads are covered with snow for about half the year.

To cope with this situation, the NC4V-A, was developed as a vehicle which has both the rough road driveability of 4WD cars and the roominess and comfort of passenger cars, and which also has good stability on snowy or slippery roads. Production began in 1972 and has steadily increased year by year. Nowadays it wins wide acceptance by consumers as a general purpose passenger vehicle and as their means of daily transportation in the snowy and/or mountainous regions.

NC4V-B is derived from a small RWD commercial vehicle, and was developed with the aim of improving driveability on snowy roads or muddy surfaces, which was a relatively weak point of its predecessor, while the advantages in the utility, total economy and riding comfort were not diminished. In 1980, it was brought into production and now it is very popular, especially in the snowy districts.

OUTLINE OF NC4V

Model Line-up

The NC4V-A has a line-up of four models: station wagon, 4 door sedan, hatchback and open type MPV, as shown in Figure 2. There are two engine families, 1600

Figure 2. NC4V-A lines.

Figure 3. NC4V-B lines.

cc and 1800 cc; this light curbweight (915 kg to 1090 kg) and accordingly small displacement contribute to the lower fuel economy and price.

The NC4V-B has two models, cab-over wagon and truck, as illustrated in Figure 3. Engine displacement is 550 cc and the curbweight is so small (670 kg to 795 kg) that it is very economical.

NC4V User Attributes

The NC4V-A is, as described above, designed as a multipurpose means of transportation which can be driven safely by the average driver under various climate and road conditions, accompanied by the ordinary performance of a passenger car. This design concept is reflected in the NC4V-A user attributes. For the sedan, commuter use is the most common at 61%, followed by 17% for recreation, 13% for business, and 9% for shopping or visiting. For the station wagon, business use leads at 43%, next 35% for commuting, and 19% for recreation. Personal use leads business use in both cases (Fig. 4).

The NC4V-B is used mainly in snowy districts for daily transportation; market research has revealed that it is employed widely not only for business use but also for personal use. In particular, the high-roof wagon model's recreational use is about 40% and illustrates its multi purpose utility (Fig. 5).

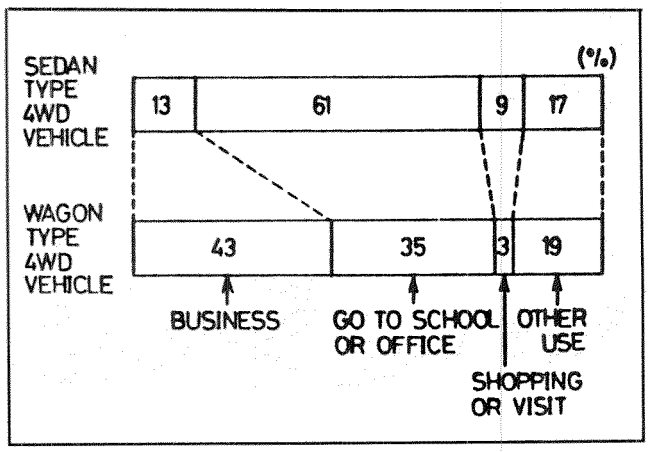


Figure 4. General use of the NC4V-A in Japan.

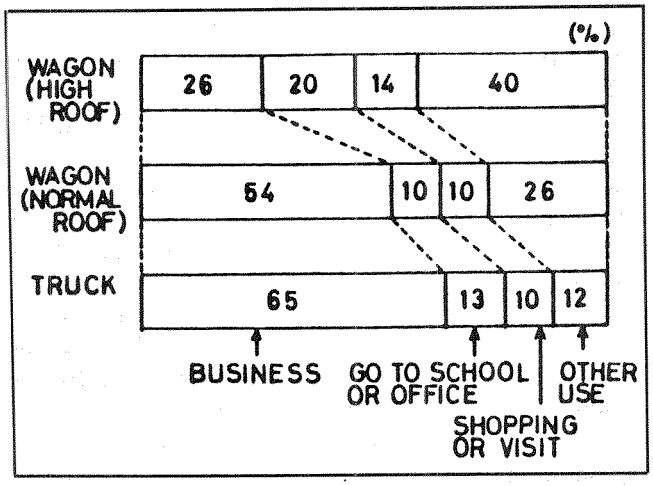


Figure 5. General use of the NC4V-B in Japan.

Construction of NC4V

Basic construction of the NC4V-A consists of transaxle (transmission of the original FWD passenger vehicle combined with additional rear wheel drive mechanism), propeller shaft, rear differential gears and rear axle shafts (Fig. 6). Front suspension is a MacPherson strut type, which employs a leading rod link to lessen the distortion of wheel alignment even in the case of a slight impact. Rear suspension is a semitrailing arm type.

The dual range transmission of the NC4V-A is illustrated in Figure 7, in which secondary two-stage (high and low) transmission with synchromesh mechanism is assembled between clutch and main gearbox. In most examples of the traditional 4WD design, the selector mechanism is set up behind the transmission gearbox, so that the driver has to stop the vehicle in order to select the dual range gear position. With the NC4V-A's dual range gearbox configuration, it is possible to select the position when the clutch is disengaged without stopping the vehicle. FWD = 4WD switching and control of secondary gearbox are performed by means of a single lever that the driver may operate without any confusion or difficulty.

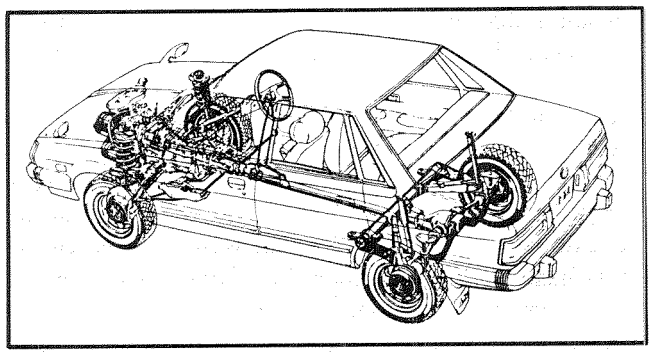


Figure 6. Phantom view of the NC4V-A.

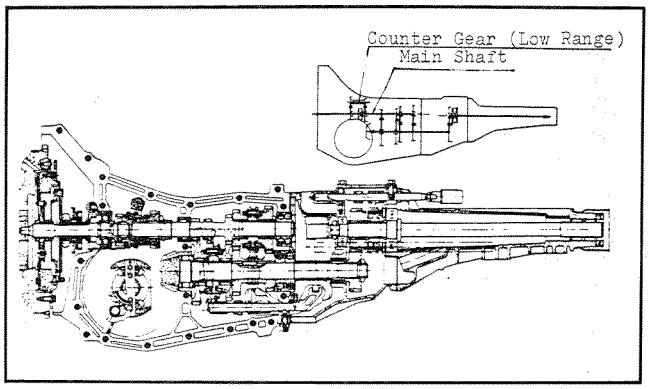


Figure 7. Transmission, transfer and dual range system of the NC4V-A.

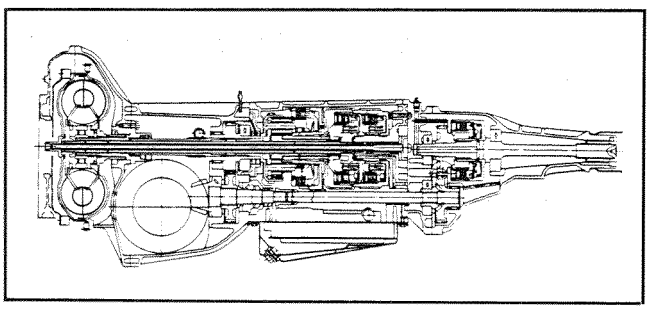


Figure 8. Automatic transmission and transfer system of the NC4V-A.

Automatic transmission of the NC4V-A is illustrated in Figure 8, where the transfer for 4WD is composed of a hydraulic multi-disc clutch and solenoid valve. FWD = 4WD switching is instantaneously performed by pushing the button located near the automatic transmission control knob (Fig. 9). With this system the braking effect due to the difference of front and rear wheel revolutions is eliminated by means of regulating the capacity of the transfer clutch to correspond to engine load.

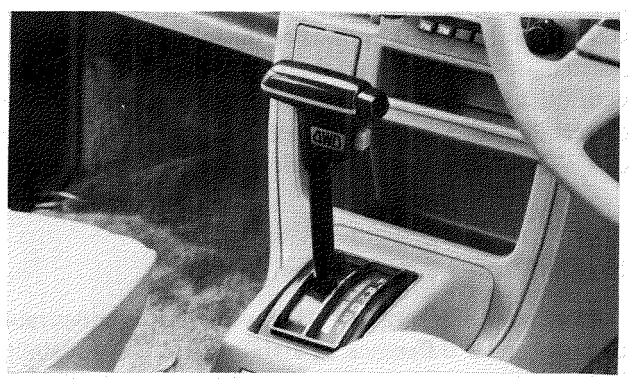


Figure 9. (Left) FWD-4WD switching button located near the automatic control knob of the NC4V-A.

Figure 10 is an outline drawing of the NC4V-B. Here the FWD system is added to the original RWD system, with maximal consideration to preserving the space utility of a RWD vehicle and to avoiding deterioration of vibration, noise and controllability factors. The engine and transaxle units are located transversely in the rear and ordinarily propel the rear wheels. Power output for driving the front wheels comes from the transfer in front of the transaxle and is transmitted through the propeller shaft located forward along the center line of the body, to the front differential gear under the driver's seat. RWD = 4WD switching is performed by means of a push-pull cable connecting the transfer and the drive selector lever under the driver's seat. Figure 11 shows the 4WD transaxle of the NC4V-B.

SAFETY OF NC4V

Driveability

Superior driveability of 4WD vehicles on snowy, icy or gravel roads is one of the most distinguished factors

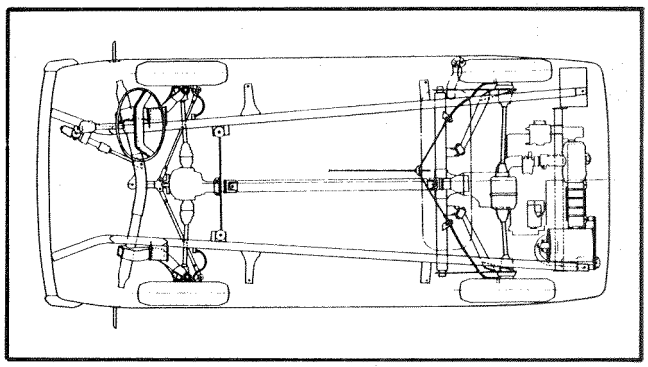


Figure 10. Chassis, suspension and driveline of the NC4V-B.

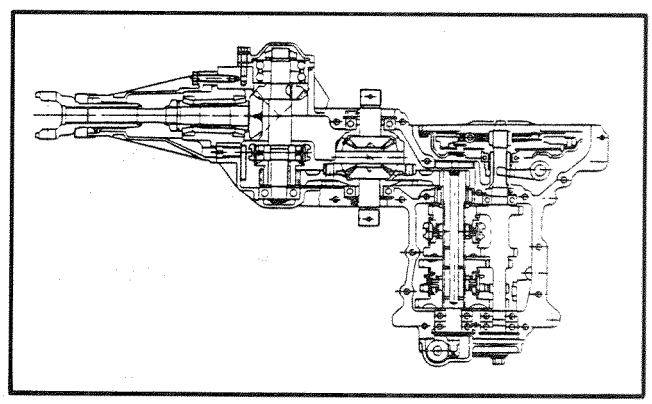


Figure 11. (Right) Transmission, transfer-system of the NC4V-B.

of their better safety performance compared with 2WD vehicles. In the case of the NC4V, in which even unskilled drivers can easily switch from 2WD to 4WD, this factor is most effective for safety.

where
Rf_o: normal load on front wheels on level
Rr_o: normal load on rear wheels on level
μ : coefficient of friction between the driving wheel and road surface
μ_r : coefficient of rolling resistance

The climbing ability limit might be generally decided by the vehicle weight and engine output, when the coefficient of friction between tire and road surface holds satisfactory value. Actually, however, it is in most cases limited by wheel spin, where the limit gradient is given as Figure 12.

As explained by equation (1), FWD is not as good as 4WD or RWD regarding climbing ability; therefore much consideration must be given to weight distribution on front and rear wheels.

Comparison of climbing ability of 4WD and FWD, using the data of the NC4V-A, is shown in Figure 13, where the ratio of maximum climbable grade of 4WD and FWD is 1.5 to 1.7.

Though RWD has better climbing ability, as explained by equation (2), the difference between 4WD and RWD becomes greater as μ decreases.

In Figure 14, driveability on snowy surface is evaluated, comparing FWD with 4WD by the NC4V-A and RWD with 4WD by the NC4V-B, respectively. In the case of somewhat greater gradients than are encountered ordinarily, 4WD has the ability to climb both on frozen surfaces with hard snow, and on surfaces covered with thick hard snow, and to drive easily on flat roads covered by 250 to 300 mm thick fresh snow, and it can overcome 400 mm of thick fresh snow. For the inhabitants of snowy districts, it is an everyday matter that roads are covered with fresh snow or that they become icy; therefore these driveability data prove the excellent safety performance of 4WD vehicles in such districts.

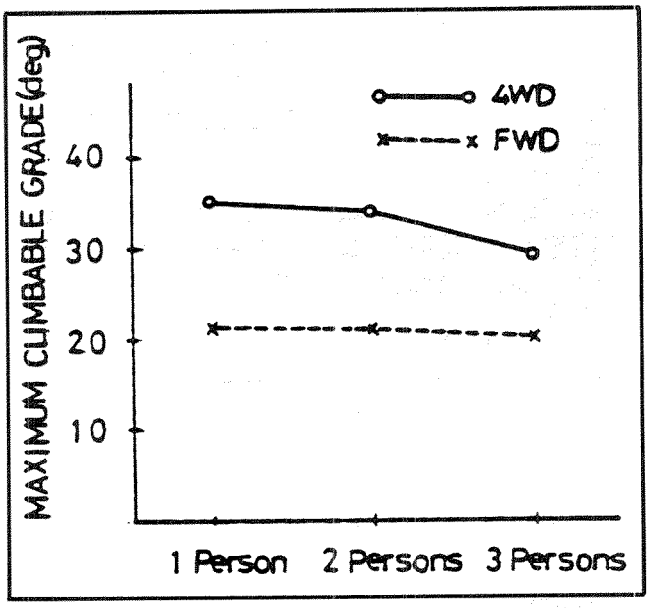


Figure 13. Climbing ability of 4WD and FWD.

Car Name / Gradient & Surface	NC4V-A		NC4V-B	
	FWD	4WD	RWD	4WD
6 ~ 8 deg Frozen & Hard Snow 5 mm	×~△	○	△	○
7 deg Hard Snow 50 mm	×~△	○	△	○
Flat Fresh Snow 250 ~ 300 mm	△	○	×	○
Flat Fresh Snow 400 mm	×	△	×	△

Figure 14. Driveability on snowy surface of 4WD and 2WD.

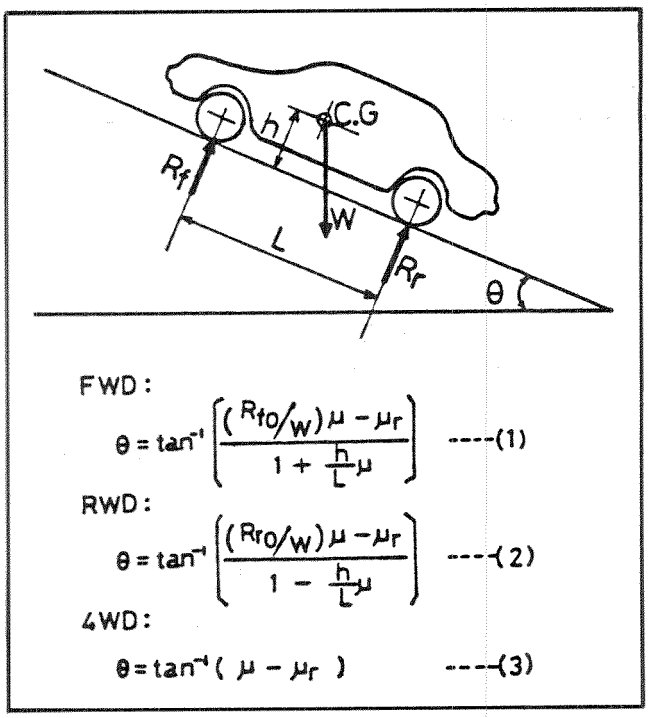


Figure 12. (Left). Equation of the climbing ability.

Stability and Controllability

In the case of a part-time 4WD vehicle, it is undesirable to have much difference in stability and controllability between the two drive modes. Stability and controllability are strongly affected by the basic vehicle dimensions (location of center of gravity, wheelbase, and track, etc.)

and suspension setting. Here these factors are identical and the effects of drive mode on turning behavior are examined.

Mathematical simulation analysis was carried out first, by means of a simulation program called SSPVD (SUBARU Simulation Program of Vehicle Dynamics), which involves a vehicle suspension model having front MacPherson strut, rear semitrailing arm, and rack and pinion steering, as illustrated in Figure 15. Fundamental degrees of freedom of this model is 32; that is, the sprung mass (6 about center of gravity of vehicle), the unsprung mass (6 × 4 about center of gravity of each wheel), and steering system (2, rack translation and steering wheel rotation). One hundred twelve basic equations, including 76 for constraint conditions and 4 for equilibrium of force, and approximately 300 auxiliary equations, such as those for tires, rubber bushings, springs and transformation of variables, compose the total system, by which comprehensive analysis and evaluation of vehicle dynamic behavior could be carried out.

Some of the results of analysis are shown in Figure 16. In a case of 50/50 weight distribution on front and rear

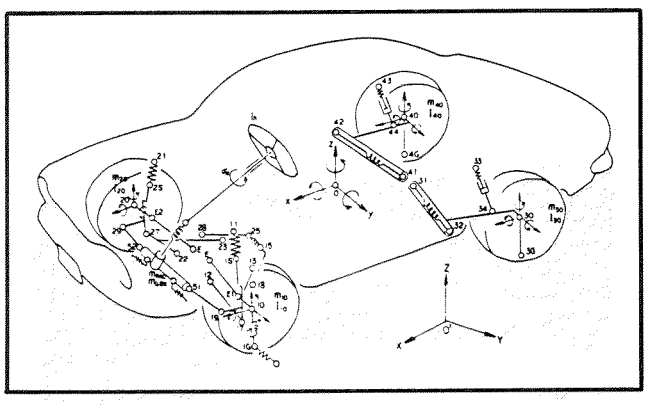


Figure 15. Subaru simulation program of vehicle dynamics (SSPVD).

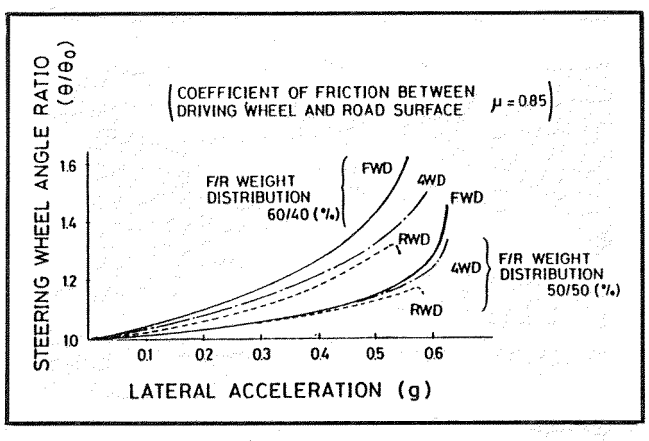


Figure 16. Steady state cornering characteristics (results of analysis).

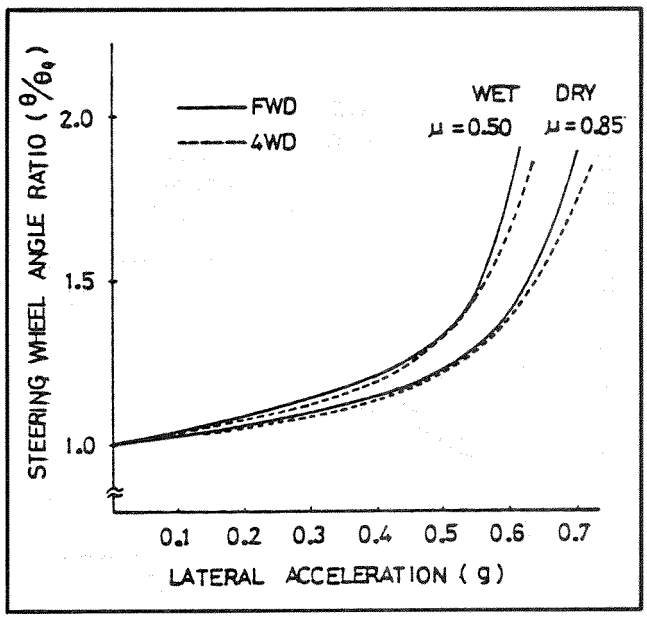


Figure 17. Steady state cornering (result of experiment; NC4V-A).

wheels, there is little difference among the drive modes. Near the limits of lateral acceleration, however, understeer increases for FWD and 4WD and spin out trend occurs in RWD. Next, other factors being unchanged, and with weight distribution of 60/40, understeer increases and differences among the drive modes become more apparent; FWD shows stronger understeer than RWD, with 4WD in between.

Some results of experiments are shown in Figures 17 and 18. Comparison is made of FWD with 4WD using the NC4V-A (Fig. 17), and of RWD with 4WD using NC4V-B (Fig. 18), on both dry (μ=0.85) and wet (μ=0.50) surfaces in both cases. In the case of the NC4V-A, similar to the simulation analysis, 4WD experiences less understeer than FWD; the difference is so slight that it could not be detected in actual driving. For the NC4V-B, the difference between RWD and 4WD is also small (below 0.4 g lateral acceleration). As it approaches the limit, RWD has a reverse-steer tendency and 4WD has increasing understeer; that is, in the critical state, the difference between the drive modes for the NC4V-B is greater than for the NC4V-A.

On low μ surfaces such as gravel or snowy roads, especially on winding roads, the influence of spinning of the driving wheel becomes remarkable, and it causes great differences among the drive modes. FWD shows a tendency to drift out, and RWD shows a tendency to spin out, while 4WD maintains its grip on front and rear wheels to a higher range of lateral acceleration; therefore 4WD will give a feeling of comparatively easy driving to an average driver, especially when he switches from RWD to 4WD.

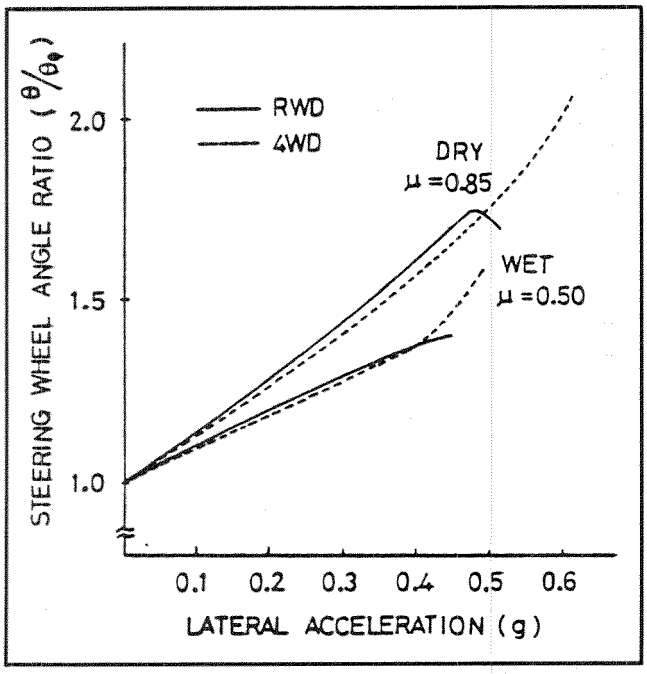


Figure 18. Steady state cornering (result of experiment; NC4V-B).

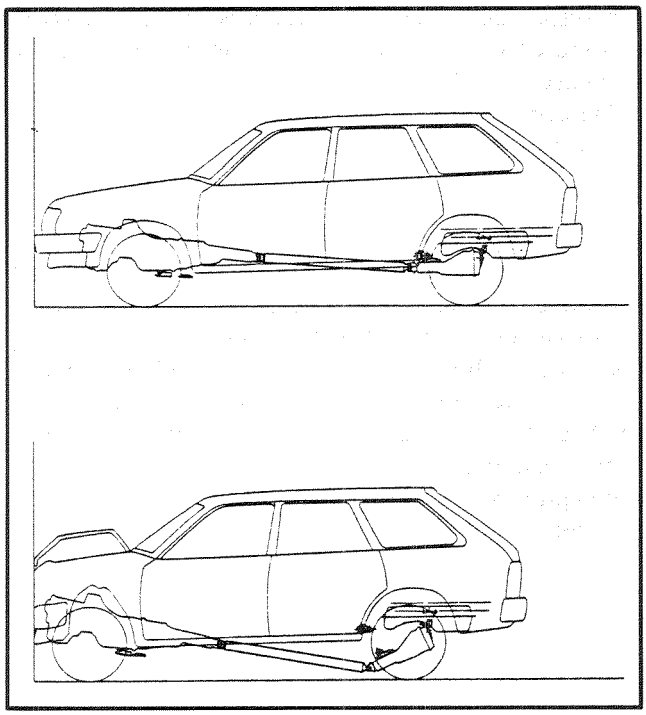


Figure 19. Differential carrier dropping after frontal collision to protect fuel tank.

Crashworthiness

Body construction of NC4V-A is identical with that of the original FWD passenger vehicle, which complies with FMVSS regulations, No. 204, No. 212, No. 219, and No. 301. Because the fuel tank is located under the floor to improve utility of passenger room special consideration is given to the interference of the differential case and fuel tank at impact.

In a case of frontal collision, in order to prevent the mutual interference of differential case and fuel tank, the impact load cuts the front support of the differential carrier so that the drive train bends down at the point of the propeller shaft joint (Fig. 19), while rearward displacement of the power plant is restricted by the interaction between a hook attached to the transmission case and the center crossmember; also on the rear side of the differential carrier a protecting cover is attached to prevent impact on the fuel tank. Figure 20 shows the result of the crash test at 30 mph of the NC4V-A.

In a case of rear-end collision, impact energy is absorbed satisfactorily through utilizing completely the crash stroke between rear end and fuel tank while the protecting cover of the differential case described above is also effective.

As cases of a pedestrian crash, victim's head striking the hood are very frequent. Location of the engine under the hood is very important to absorb crash energy. Lower position of the horizontally opposed engine and appropriate location of the spare wheel contribute to decreasing the impact on the pedestrian.

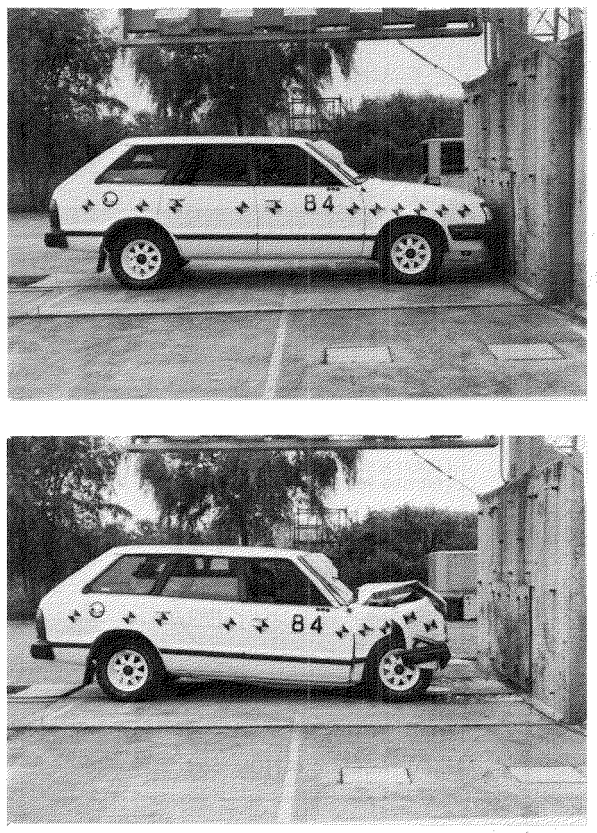


Figure 20. Result of NC4V-A crash test.

NOISE AND FUEL ECONOMY OF NC4V

Noise

As the NC4V-A is derived from a passenger vehicle, it is the quietest of all 4WD vehicles. In Figure 21, two other makes, representative of the average Japanese domestic 4WD van-type vehicle, are used for comparison. This figure shows that the interior noise level of the NC4V-A is lower than that of other makes by about 10 dB, and the difference increases especially in the higher speed range, over 90 km/h. Compared with the original FWD vehicle, the noise level of the NC4V is higher by about 1db, because of the lower gear ratio of 4WD. The drive train has little influence on noise level, as simple unitized construction of the transaxle with less gear noise is employed. The little difference of noise level between two cars, one with and one without rear wheel drive train, proves this fact.

Similarly, with NC4V-B, comparison of noise level of 4WD with RWD is shown in Figure 22, where the difference between the two modes is also negligible.

Fuel Economy

On this point 4WD vehicles are considered to be at a disadvantage due to weight increase and, mechanically, to loss of the additional drive train. The NC4V-A has, however, good fuel economy thanks to light weight body construction, which is made possible by careful configuration of the 4WD system, as mentioned above. Fuel economy of the NC4V-A under various road conditions is illustrated in Figure 23. On ordinary paved roads, the difference between the two drive modes is quite small, while on rough roads., 4WD has better fuel economy than FWD. This difference increases as road surface friction decreases. On hard gravel roads, 4WD is better by 4% than FWD, while on soft sand, 4WD gets fully 100% better fuel economy than FWD.

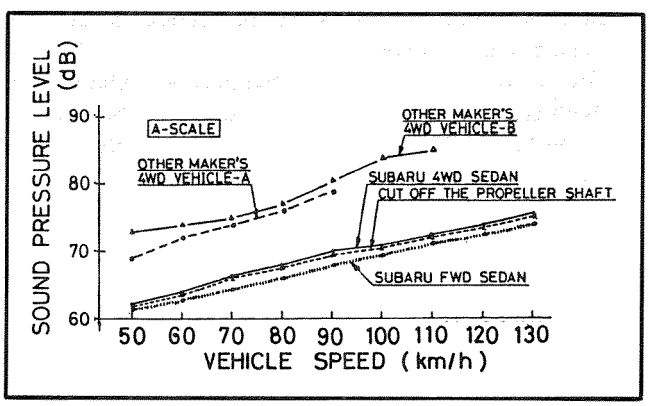


Figure 21. Relations between vehicle speed and interior noise (NC4V-A and other vehicles).

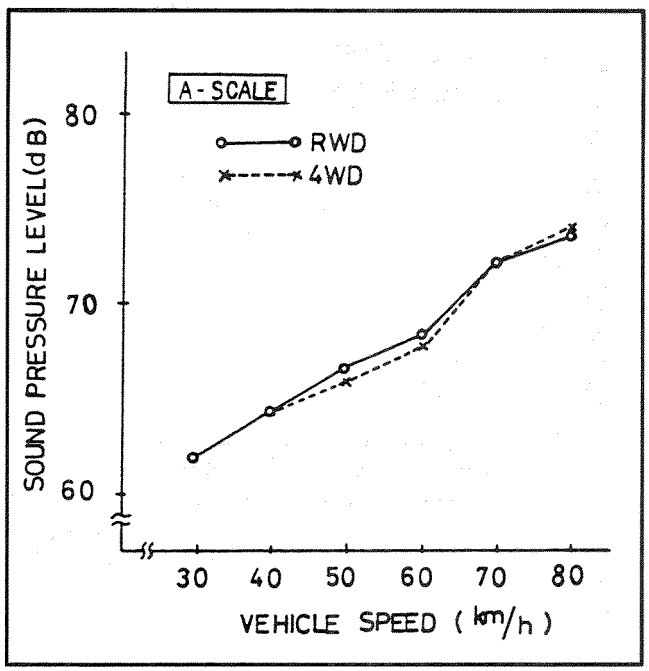


Figure 22. Noise level of 4WD and RWD (NC4V-B).

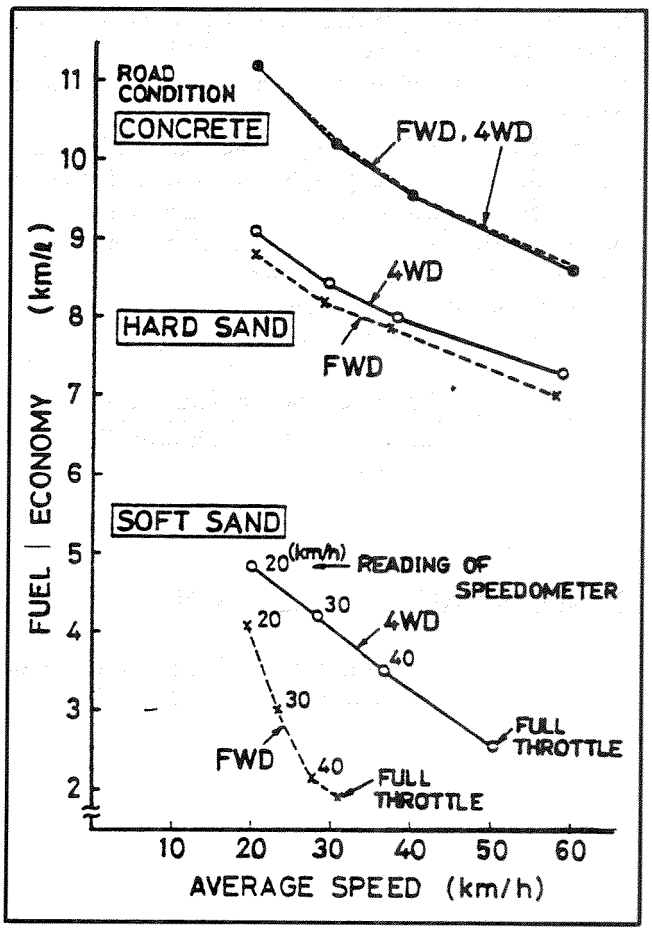


Figure 23. Comparison of fuel economy between FWD and 4WD under various road conditions.

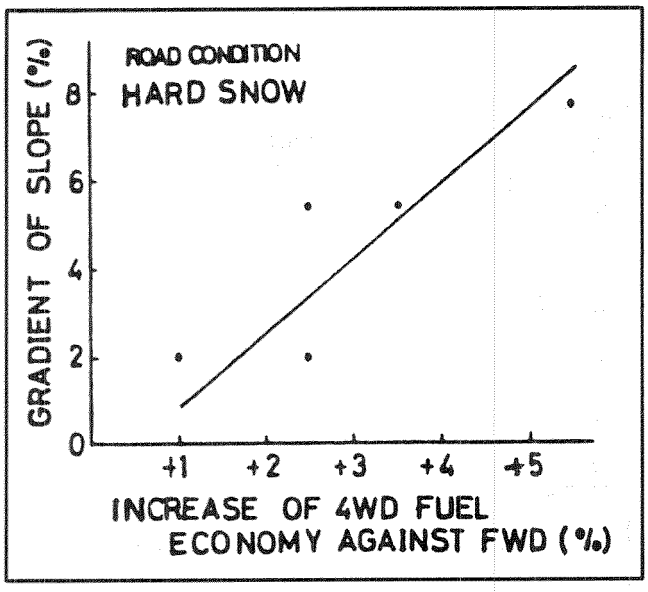


Figure 24. Comparison of fuel economy between FWD and 4WD on snowy upgrade road.

Figure 24 illustrates that the ratio of fuel economy of 4WD to FWD increases according to the increase of gradient of snowy upgrades. These figures show that on snowy roads, 4WD drive gets better fuel economy than FWD, and this difference expands as the gradient increases.

Slip ratio and fuel economy of the NC4V-B on snowy roads with 2deg. to 3deg. gradient for both RWD and 4WD modes are shown in Figure 25. Because slip ratio increases with vehicle speed under such road conditions, 4WD exceeds 2WD in fuel economy by 30% or more, and in maximum climbing speed by about 10 km/h.

Slip ratio is defined as follows:

$$\text{Slip ratio} = \left[\left(\frac{\text{Odometer reading during trial}}{\text{Odometer reading with zero slip}}\right) - 1\right] \times 100\ (\%)$$

SUMMARY AND CONCLUSION

4WD has generally superior driving performance on mountainous, snowy, and rough roads. In addition, the

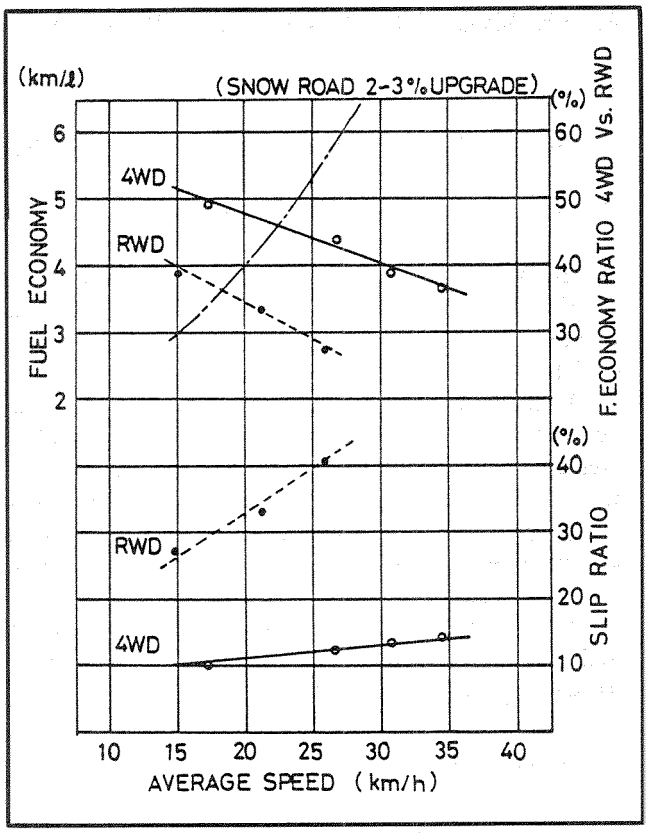


Figure 25. Fuel economy and slip ratio of RWD and 4WD on snowy road (NC4V-B).

NC4V-A has the same crashworthiness as normal passenger vehicles, and has better handling characteristics on low frictional surfaces.

Furthermore, the NC4V has the same interior noise level, riding comfort, and airconditioning provision as normal passenger vehicles.

Therefore, anybody can drive it comfortably on various roads and in all weather conditions.

Also, the NC4V is a very economical vehicle, because of its low price and good fuel economy, as good as those of normal passenger vehicles.

Besides all this, the NC4V can be operated as easily as a conventional vehicle.

Because of the above mentioned many advantages, such as high safety and multi purpose utility, we believe that demand for the NC4V type vehicle will steadily increase all over the world.

Performance of a Simplified Control Technique for Antilock Brakes

MAKOTO SATOH
SHUJI SHIRAISHI
Honda R & D Co., Ltd.

INTRODUCTION

Antilock brakes can be broadly divided into two types.

- Rear-wheel only antilock brakes; and
- Four-wheel antilock brakes.

The rear-wheel antilock brake can greatly improve straight line stability during panic braking or on a low coefficient surface, but it does not serve to preclude loss of vehicle steerability resulting from front wheel locking. The four-wheel antilock brake, on the other hand, additionally allows vehicle steerability during panic braking. Generally the antilock brake is most frequently needed on a snow-covered or iced slippery road where long stopping distances are normally required, and also this is where the system's advantages are fully demonstrated. Therefore, capability to maintain adequate steerability even during panic braking is an important factor in precluding an accident, particularly when the vehicle is running on a slippery road. This is exactly why the four-wheel antilock brake system has come to be installed in automobiles.

However, it would be desirable for future systems to be improved with respect to:

(1) Braking performance on rough or gravel roads, and
(2) System complexity, size, weight, and cost.

This report discusses a new four-wheel antilock brake system that, employs "select high" logic for the front wheels and "select low" logic for the rear wheels. This new brake system is capable of retaining sufficient vehicle stability and steerability even during panic braking. And unlike its predecessors, this system does not result in significantly greater stopping distances on rough or gravel roads, and its structure can be simplified.

MAJOR FACTORS AFFECTING THE BRAKING PERFORMANCE OF FOUR-WHEEL ANTILOCK BRAKES ON ROUGH OR GRAVEL ROADS

Four-wheel-control antilock brakes now in use can be broadly divided into:

(1) Four-wheel independent control system: and
(2) Composite system with an independent control subsystem for the front wheels and "select low" subsystem for the rear wheels.

The brake system (1) independently controls all the four wheels to keep their braking torque at a near optimum level.

In the second system, the right and left front wheels are controlled independently, but the rear wheels are both controlled simultaneously in response to a signal from either of them which is predicted to lock first. This means that when the vehicle is running on a road surface with different adhesion coefficients (μ) for the right and left wheels, the braking torque on the side with a higher μ becomes somewhat smaller than in the independent control system because it is controlled to the same level as for the other side with a lower μ. However, the reduction of braking force is small for front-drive cars which depend relatively little on the rear wheels for stopping capability.

A major factor affecting the braking performance of these two antilock brake systems on a rough road is the possible "over-control" of the front wheels. As noted earlier, both systems independently control the right and left front wheels; more specifically, they are designed to automatically reduce a wheel's braking torque when a change in wheel speed indicates that the wheel is likely to get locked. The prediction of wheel locking is generally determined by the formulas below:

(1) $\lambda > \lambda o$ and (2) $\dot{V}w < \beta o$

Where

λ = slip ratio of the wheel as computed by the formula $\lambda = 1 - Vw/V$, where V represents vehicle speed (km/h) and Vw represents circumferential wheel speed (km/h)

$\dot{V}w$ = circumferential acceleration of the wheels

λo = reference standard for slip ratio—usually $\lambda o \simeq 10\%$

βo = reference standard for circumferential acceleration of the wheel—usually -9.8 through -15.0 (m/s^2)

On very rough road, however, wheel speed becomes irregular at random and pulsations of wheel speed occur due to differing conditions of tire contact with the road surface even if the brakes are applied so lightly that none of the wheels will actually become locked.

Figure 2 presents an example of wheel speed pulsations that occur when the brakes are applied lightly on a rough road whose spectrum is shown in Figure 1. The definitions of a rough and very rough road in this diagram are based on the ISO/TC108 specifications.

Figure 2 shows wheel speed Vw, vehicle speed V, circumferential acceleration of wheel $\dot{V}w$, slip ratio λ and straight lines for $\beta o = -15$ (m/s^2) and $\lambda o = 10\%$.

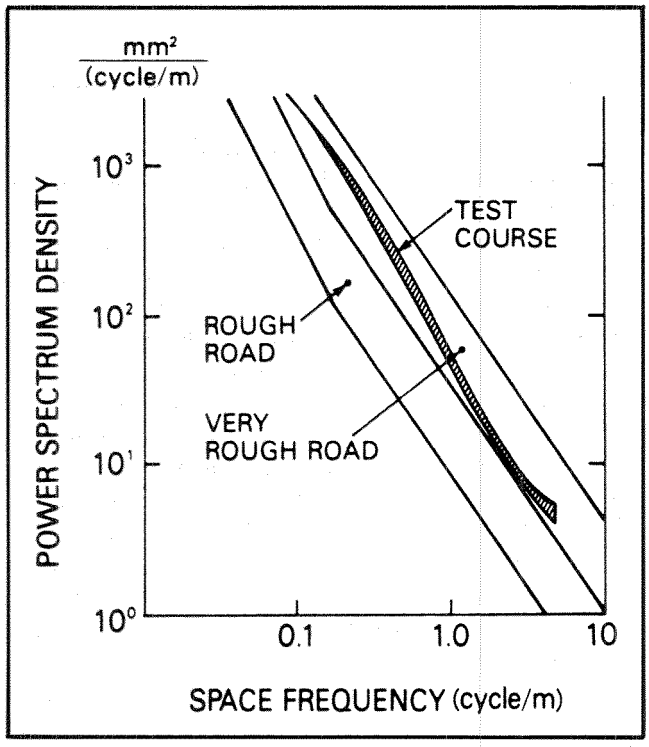


Figure 1. Characteristics of the rough road used for the test.

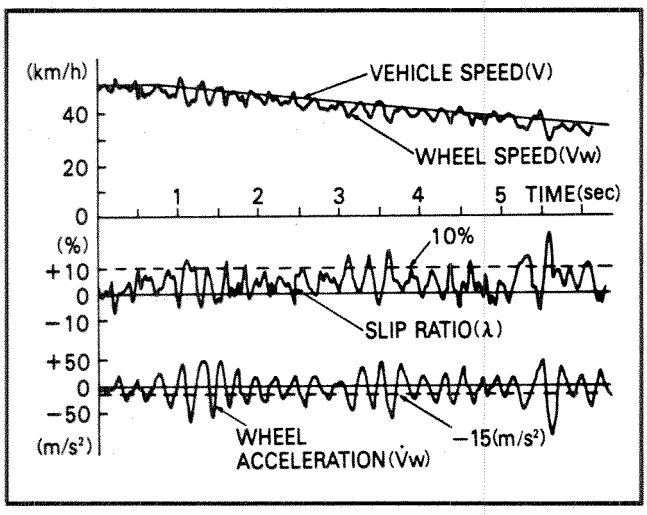


Figure 2. Example of wheel speed pulsations.

As is apparent from the diagram, operating conditions represented by formulas (1) and (2) above may sometimes occur on a rough road even when the driver steps on the brake pedal so lightly that none of wheels will actually become locked.

This causes system over-control and reduces the braking torque unnecessarily. On a split road with a rough surface on one side and a smooth one on the other, the antilock brake system may over-control only the wheel on the rough surface, putting the braking forces for the right and left wheels out of balance. Under such circumstances, there are possibilities the vehicle may sometimes tend to pull to one side. Over-control of braking force could also occur with the rear wheels, but its effect may be practically negligible because automobiles, particularly those with front-drive, depend relatively little on the rear wheels for their stopping capability.

"SELECT HIGH" TECHNIQUE FOR THE FRONT WHEELS

The "select high" technique, in contrast with the "select low" technique discussed above, controls the right and left wheels simultaneously by a signal from either of them which is predicted to be the least likely to get locked. Not surprisingly, application of this technique for the front wheels may sometime allow one or the other to become locked, but never both at the same time. System over-control is avoided even if the pulsations appear in wheel speed due to a rough road surface except in the rare case where the right and left wheels simultaneously meet the conditions represented by formulas (1) and (2). The select high front wheel control technique will, therefore, improve braking performance on a rough road compared to an independent front wheel control system.

As to the question of whether the select high technique can maintain adequate vehicle steerability for practical purposes when one of the front wheels gets locked during hard braking, the front wheel which can generate a smaller cornering force will tend to lock, while the other wheel that affects vehicle steerability to a greater degree will never be locked. On a split road surface with different adhesion coefficients on the right and left sides, for instance, the wheel on the side with a lower adhesion coefficient will be locked. If the driver steps hard on the brake while the vehicle is turning on an even, uniform road surface, for another instance, the wheel on the inside of the curve that receives smaller load may be locked. In either instance, the wheel on the other side which produces the greater effect on vehicle steerability will never be locked. This suggests that the select high system can maintain adequate vehicle steerability for practical purposes.

PERFORMANCE OF THE FOUR-WHEEL-CONTROL ANTILOCK BRAKE WITH THE SELECT HIGH TECHNIQUE FOR THE FRONT WHEELS

To examine the above concept, a series of tests were conducted on the following two experimental systems, both prepared with exactly the same control logic, to compare their braking performance

(a) Antilock brake "I-ALB" with independent control for the front wheels and select low technique for the rear; and
(b) Antilock brake "H-ALB" with the select high subsystem for the front wheels and select low subsystem for the rear.

The details of the test include:

(1) Stopping distance on a dry asphalt road, wet concrete road and rough road as described in Figure 1;
(2) Directional stability during braking on a split road with a rough surface on one side and smooth surface on the other;
(3) Directional stability during braking on a split road with dry asphalt surface on one side and wet concrete on the other;
(4) Braking performance during turning on a dry asphalt road; and
(5) Evasive maneuverability during fall braking on a wet concrete road.

Tests (1) through (3) were also applied to a conventional vehicle without antilock system (N-ALB). All tests were performed under the following conditions:

- Test vehicle: Front-drive, four-door sedan with a 1.8 litre engine;
- Occupants: 2 persons; and
- Force applied to the brake pedal: 882 N (90 Kgf).

Stopping Distance Test

The adhesion coefficient (μ) between the tire tread and each of the selected road surfaces was:

Dry asphalt road: $\mu = 0.80$
Wet concrete road: $\mu = 0.40$
Rough road (as in Fig. 1): $\mu = 0.65$

As shown in Figure 3, both H-ALB and I-ALB achieved a shorter stopping distance than N-ALB on the dry asphalt road, but the difference was little.

On the wet concrete road, H-ALB showed a stopping distance some 10 percent longer than that of I-ALB. However, the results of H-ALB are considered satisfactory as the stopping distance was more than 10 percent shorter than that of N-ALB. On the rough road both H-ALB and I-ALB required a longer distance for stopping than N-ALB. Compared with I-ALB, however, H-ALB achieved a much shorter stopping distance, demonstrating the select high technique produces favorable effects in this respect.

Stability Test on Rough/Smooth Split Surface

Test method: Yaw angles of the three test vehicles were compared when they came to a stop under full braking

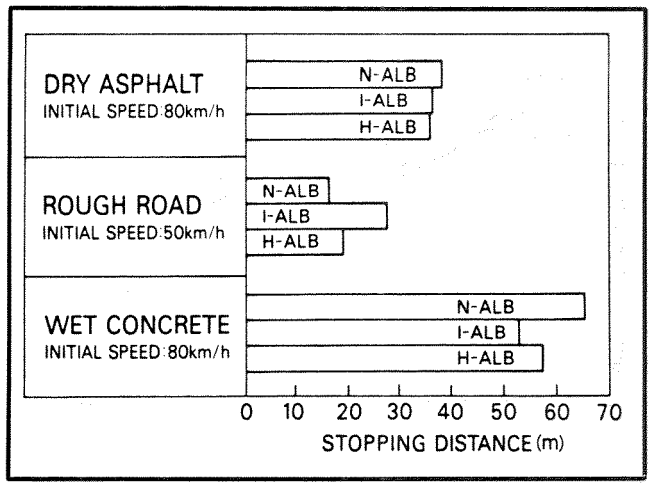


Figure 3. Comparison of stopping distance.

with the steering wheel fixed in the straight-ahead position on the split road surface shown in Figure 4. The initial speed was set at 50 km/h.

Results

As shown in Figure 5, H-ALB was subject to a smaller yaw than I-ALB apparently because of the favorable effects of the select high technique for the front wheels. It may be assumed that I-ALB also has practically satisfactory capabilities since it can stop the vehicle under the specified conditions with only an 8 or 9 degree yaw.

Stability Test on Dry/Wet Split Surface

Test method: Exactly the same test as discussed in 4.2 was conducted on the three vehicles with the initial braking speed 80 km/hr on a split road surface described in Figure 6.

Results

As is apparent from Figure 7, both I-ALB and H-ALB proved to maintain sufficient stability with only small

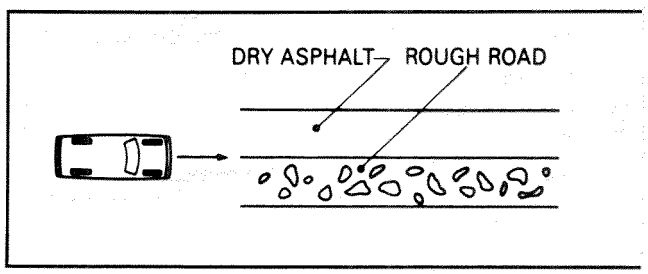


Figure 4. Rough/smooth split road.

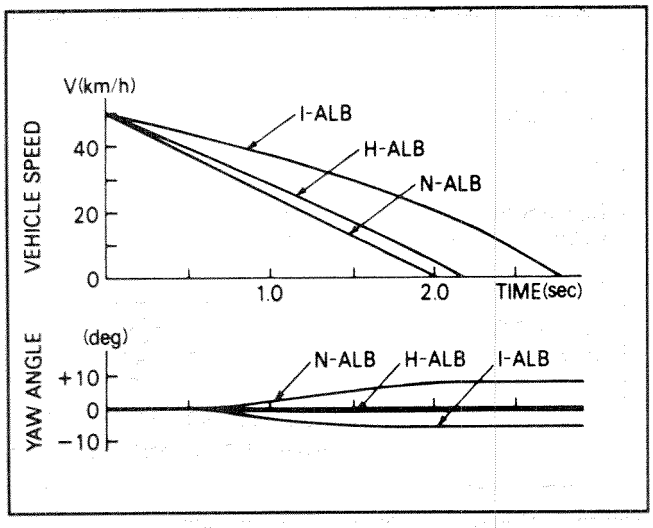


Figure 5. Results of stability test on rough/smooth split road.

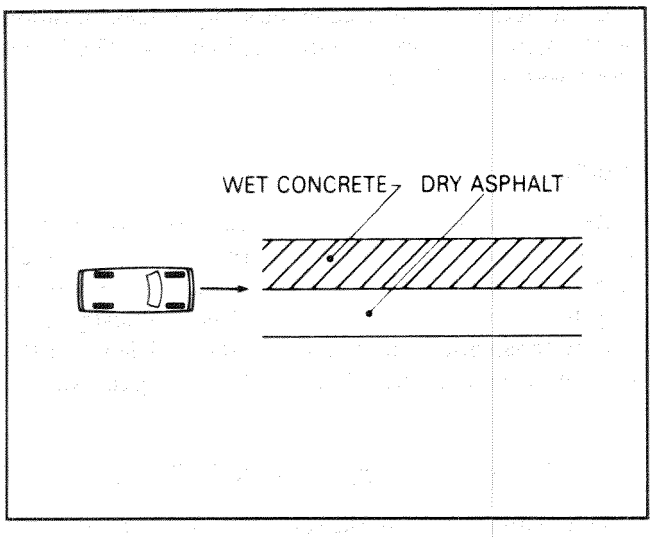


Figure 6. Dry/set split road.

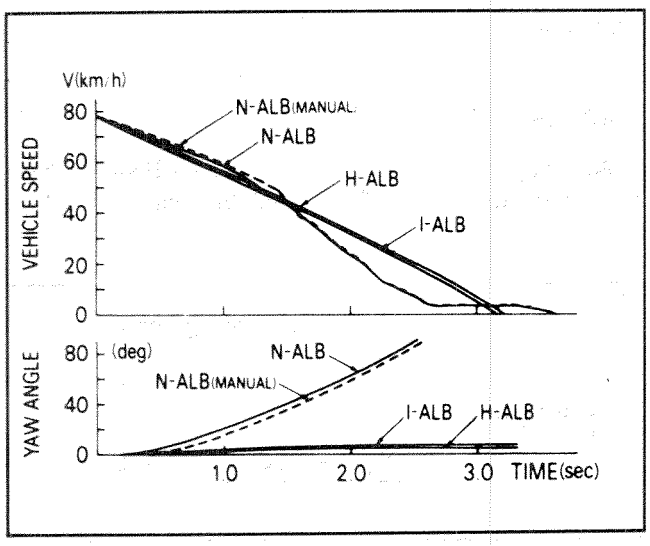


Figure 7. Stability on dry/wet split road.

yawing during full braking. With N-ALB all wheels locked, and the vehicle was naturally subject to a very large amount of yaw; this did not decrease appreciably even with corrective steering. "N-ALB (Manual)" in Figure 7 shows the behavior of this vehicle when correction steering was performed to help stabilize it. The data indicate that the vehicle was out of control during braking.

The apparent rapid slow down of the vehicle (N-ALB) during braking was due to the measuring method used in this test which recorded only the speed along the longitudinal axis of the vehicle; it does not mean that the test vehicle actually slowed down rapidly.

Braking Performance Test during Turning

Test method: The position and heading of each test vehicle were recorded when it came to a stop under full braking applied while it was turning with a given radius at a given speed on a dry asphalt road with the steering wheel fixed in that turning position. The test was conducted with the initial speed set at 80 km/h and turning radius set at three different lengths, i.e., 168 m, 112 m, and 84 m. These radii, in the decreasing order, are equivalent to an initial lateral acceleration of 0.3 g, 0.45 g, and 0.6 g, respectively.

Results

The test findings are as shown in Figure 8. The white and black circles indicate where the vehicles stopped, while the arrows show their heading. As is apparent from the diagram, H-ALB deviated little from the specified course and kept heading tangentially; it could maintain sufficient turning capability even during full braking.

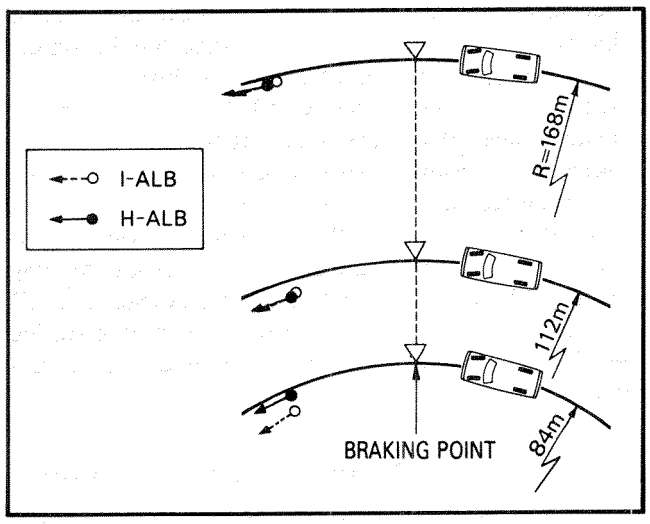


Figure 8. Test results on braking performance during turning.

It was found that both H-ALB and I-ALB can easily stop with their heading kept on the specified course if the driver is permitted to perform corrective steering.

Evasive Maneuverability Test under Full Braking on Wet Concrete Surface

The evasive maneuverability of the test vehicles were compared during full braking to examine their steerability on a slippery road. N-ALB was excluded from this test because it was not able to complete the maneuver during full braking.

Test method: Full braking was applied at a given point on a test course described in Figure 9 which the vehicle was running at a specified speed. Distance ℓ between the braking point and the obstacle was gradually reduced until it became too short for the vehicle to avoid a collision. Then the range of ℓ in which the test vehicle could avoid hitting the obstacle was determined. Five rounds of test were carried out for each distance, and the vehicle was considered to have sufficient evasive maneuverability if it could stop without touching the obstacle at any one of the five tries.

Results

Figure 10 shows the test findings. H-ALB, although liable to lock one of the front wheels, proved to have evasion capability nearly equal to that of I-ALB. It was found that the difference in the distance ℓ between the two systems is only about 10 percent.

Typically, evasive maneuvers on actual roads are lane changes which have to be immediately followed by correction of vehicle heading. In such operations, the difference between H-ALB and I-ALB in evasion capabilities will no doubt become still smaller because the steering wheel is not turned so sharply as in a test course evasive maneuver.

DESCRIPTION OF EXPERIMENTAL SYSTEMS

Figure 11 shows the general construction of H-ALB used in this test. The four-wheel-control antilock system

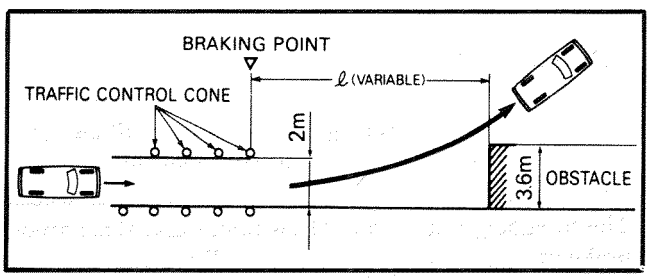


Figure 9. Maneuverability test course.

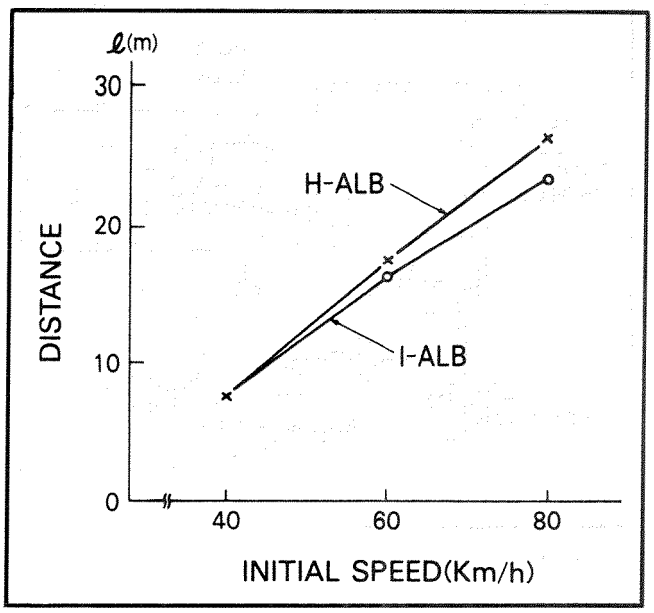


Figure 10. Results of evasive maneuver test.

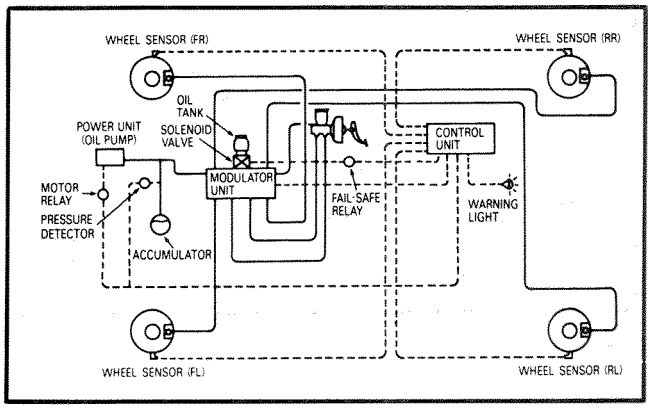


Figure 11. General construction of the test system.

with the select high technique for the front wheels and select low technique for the rear wheels has an electronic control unit that receives a signal on wheel speed from a sensor attached to each wheel. Then the control unit regulates the brake pressure modulators through solenoid valves.

To ensure high responsiveness, the system uses a hydraulic control modulator as shown in Figure 12 which can respond to a command from the control unit with only about 5 ms delay.

Figure 13 presents the inside structure of the control unit. Wheel speed signals from each wheel sensor are first sent to the select circuit which picks out signals on either the most likely to lock (select low rear system) or least likely to lock (select high front system).

Based on the results of calculating the selected signals, the decision circuit gives the solenoid valve a command to actuate it. Since highly accurate control of hydraulic

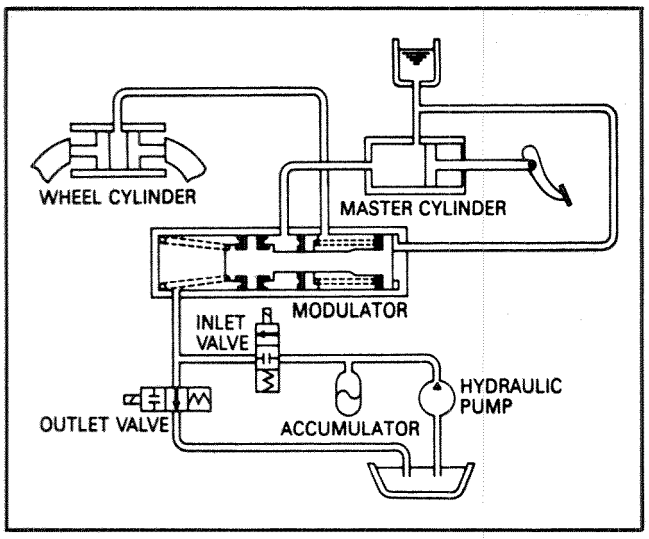


Figure 12. Modulator.

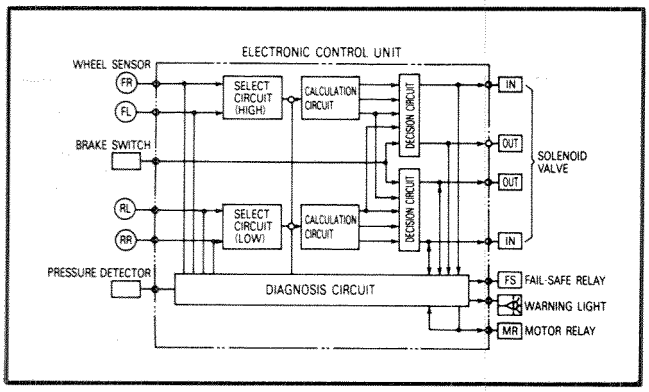


Figure 13. Electronic control unit.

pressure is required in a four-wheel antilock brake, the control unit is designed to regulate the solenoid valve in five different modes:

(1) Rapid increase of pressure
(2) Gradual increase of pressure
(3) Maintenance of pressure at a constant level
(4) Gradual decrease of pressure, and
(5) Rapid decrease of pressure

By comparison, I-ALB has separate calculation and decision circuits for each of the front wheels to control them independently. However, the control logic of these circuits is exactly the same as the assembly used for H-ALB.

Figures 14 and 16 describe how the antilock brake system operates. The first diagram gives an example of system operation for the front wheels when running on a course with sharply differing surface conditions as described in Figure 15. The wheels get locked alternatively depending on the road surface. Figure 16 shows system

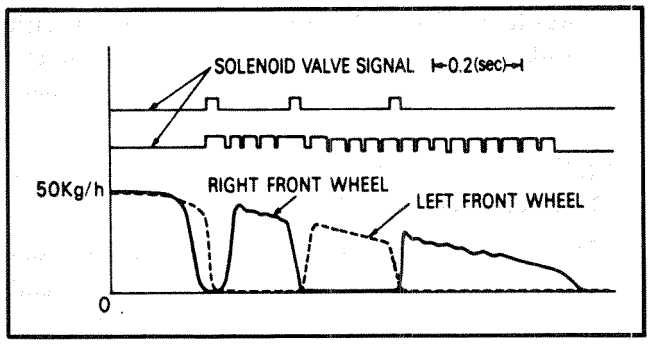


Figure 14. Example of system operation (1).

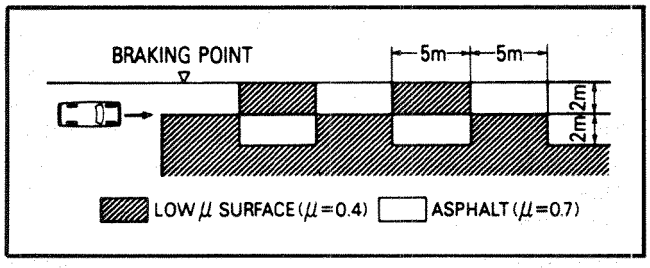


Figure 15. Road with sharply differing surface.

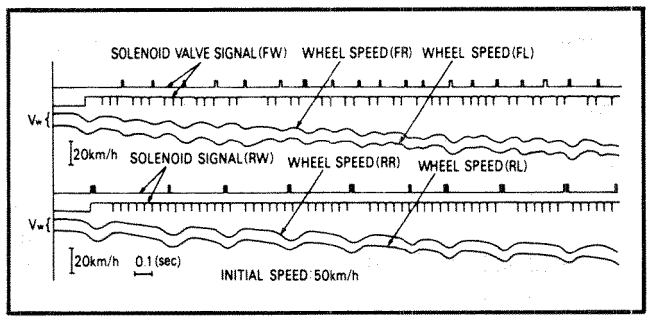


Figure 16. Example of system operation (2).

operation when the brakes are applied during straight-ahead driving on a smooth, iced road with an extremely low adhesion coefficient.

As is apparent from the diagram, the select high system seldom lets either one of the front wheels get locked when the vehicle is running straight ahead on an even, uniform road surface on both sides.

CONCLUSION

As noted earlier, the new four-wheel antilock brake system utilizes the select high technique for the front wheels and the select low technique for the rear wheels. The foregoing tests and analysis found that this antilock brake system is subject to only a small reduction in braking force on a rough road, while it can maintain sufficient

vehicle stability and steerability during panic braking. System over-control for the front wheels on a rough road is undesirable as these wheels play a major role in providing stopping ability. The loss of braking force on a split road surface due to the installation of a select low subsystem for the rear wheels is not significant since the rear wheels provide a minor portion of stopping capability. This suggests that the new system is particularly suitable for front-drive cars which depend more heavily on the front wheels for their stopping capability.

REFERENCES

1. Leiber, H. and Czinczel, A. "Antiskid System for Passenger Cars with a Digital Electronic Control Unit" SAE Paper, No. 790458.
2. Harned, J. L., Johnston, L. E. and Scharph, G. "Measurement of Tire Brake Force Characteristics as Related to Wheel Slip (Antilock) Control System Design" SAE Paper, No. 690214.

Stereo Radar System for Automobile Collision Avoidance

AKIRA TACHIBANA, NORIO FUJIKI, MASAO SAKATA, MASAMI KIYOTO and TOSHIHISA FUJIWARA
Nissan Motor Co., Ltd.

ABSTRACT

Various radar systems have been proposed to avoid or mitigate the effects of automobile collisions. In these systems, one of the most critical problems is that of identifying potentially dangerous objects as opposed to those alongside the road or in an adjacent lane, especially on curves.

The authors have devised an improved pulse-Doppler radar with two antennas which are used alternately in scanning. In addition to range and range-rate information, the radar can obtain the lateral component of the relative motion of an obstacle by detecting the phase difference between two Doppler signals, each of which corresponds to the relative velocity between the obstacle and the respective antenna.

Test results show that the phase difference signal effectively discriminates between an impending collision and an object which will safely pass by.

INTRODUCTION

Most traffic accidents on the highways are rear end collisions which result from the drivers' miscalculations concerning the possibility of a collision and then a delay in taking corrective action.

In many countries various collision avoidance systems, such as radar collision warning and/or radar automatic braking systems, have been studied since the early 1970's. The intent is to avoid or mitigate the effects of automobile accidents by eliminating drivers' errors and delay in taking corrective action.

In these systems, however, false alarms and/or erroneous readings, especially on curved roads, remain one of the critical problems to be solved. These radar systems are not capable of identifying potentially dangerous objects in the road as being different from objects such as guard rails and sign posts alongside the road or vehicles in an adjacent lane (Fig. 1).

Several methods for solving this problem have been attempted. The usual method is to shorten the radar detection range on curves (1) (2) (Fig. 2). Another method is to change the radar beam direction proportionate to the steering angle (Fig. 3).

However, shortening the radar range may delay the detection of an impending collision and changing the

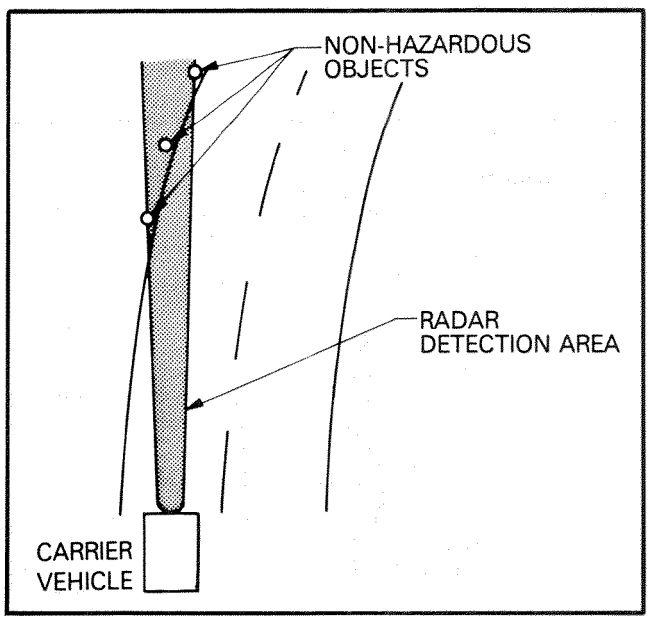


Figure 1. Detection of non-hazardous objects.

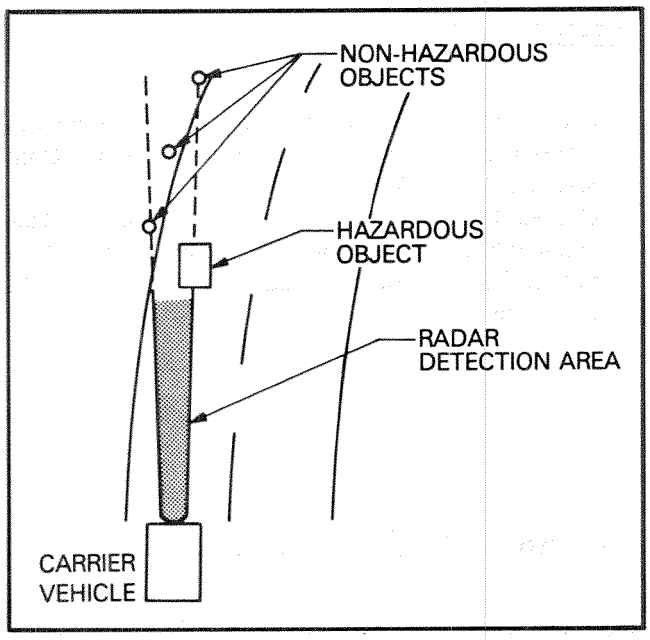


Figure 2. Restriction of radar detection range.

radar beam direction requires complicated devices to control the radar beam.

The third method proposed uses two radars (10 GHz CW radars), (3) and discriminates between an object approaching at an angle and from straight-ahead by the lateral motion of the object as determined by the difference in the relative velocity (Doppler frequency) between the object and the respective radar. However, in this method, the determination of an impending danger is delayed because it takes a long time to detect the Doppler frequency difference.

The authors have developed a binaural radar system using two pulse-Doppler radars which are to be mounted on the front of each side of the vehicle. The system can detect the lateral motion of an object from changes in the phase difference between the two Doppler signals from the two radars. It determines whether or not the object will collide with the vehicle by using this new information, phase difference, as well as the distance to the object, carrier vehicle velocity, etc. Experimental results confirm that the system can discriminate a potentially dangerous object from others passing by. This paper discusses the binaural radar system on the basis of the experimental results as well as the underlying principle.

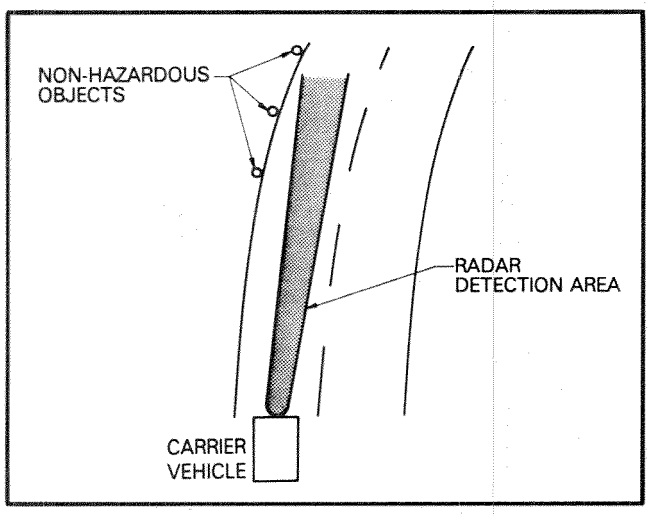


Figure 3. Change of beam direction.

DANGER DECISION LOGIC BY PHASE DIFFERENCE

Principle of Detection of Lateral Motion

In Figure 4, when $\overline{PA} \sim \overline{PA'} = K$ (K: constant, $a > 0$) holds, the locus of the point P (x,y) becomes a hyperbolic line, which can be expressed by equation (1).

$$\frac{x^2}{p^2} - \frac{y^2}{q^2} = 1 \qquad (1) \qquad (p, q > 0)$$

Here, a and p, q are given by equation (2), and K and p by equation (3), respectively.

$$\begin{cases} a = \sqrt{p^2 + q^2} & (2) \\ K = 2p & (3) \qquad (K \neq 0) \end{cases}$$

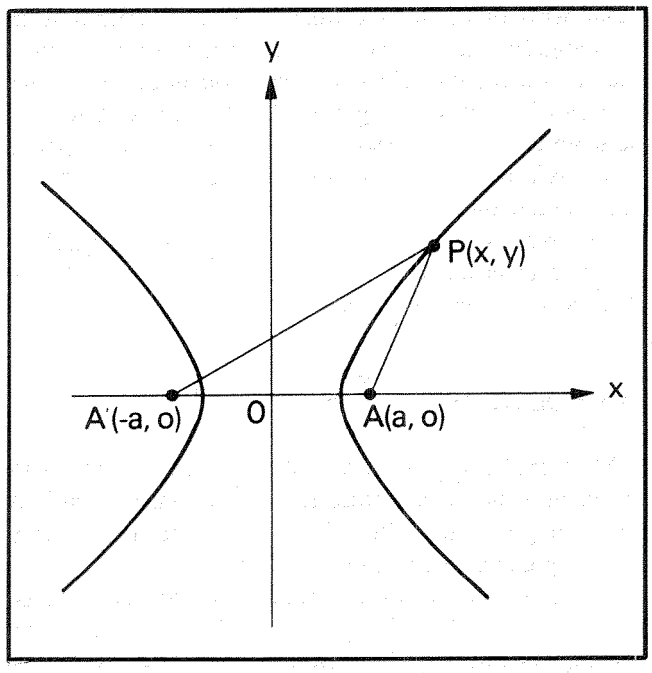


Figure 4. Hyperbolic line.

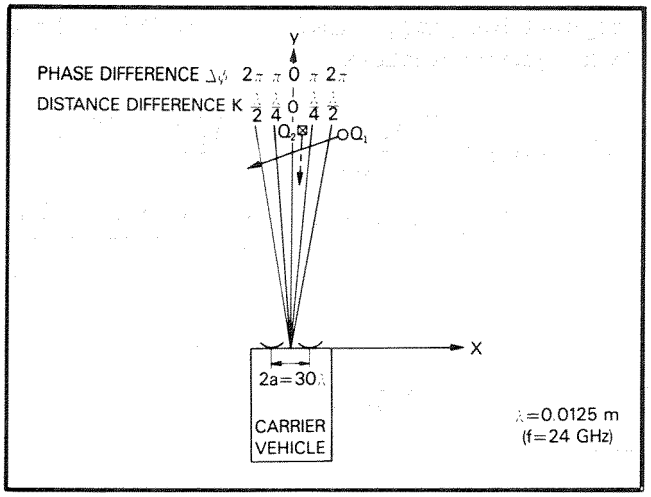


Figure 5. Lines of same phase difference.

From equations (2) and (3), p and q are expressed as follows:

$$p = \frac{K}{2}$$

$$q = \sqrt{a^2 - \left(\frac{K}{2}\right)^2}$$

Also, when $\overline{PA}$ becomes equal to $\overline{PA'}$ ($K = 0$), the locus of the point P (x,y) is expressed by:

$$x = 0 \tag{4}$$

Therefore, when the difference between the distances from the two points, A (a, 0) and A′ (−a, 0) becomes K, the locus of the point P (x, y) is expressed by:

$$\begin{cases} x = 0 \quad (K = 0) & (5) \\ \text{or } \dfrac{x^2}{\left(\frac{K}{2}\right)^2} - \dfrac{y^2}{a^2 - \left(\frac{K}{2}\right)^2} = 1 \quad (k \neq 0) & (6) \end{cases}$$

Here, each antenna is set at the point A, A′ respectively and an object is set at the point P. When the phase difference between the two Doppler signals received by the two antennas becomes constant, the locus of the object becomes a hyperbolic line, which is expressed by equations, (5) and (6). If a (= 15λ, λ: wavelength) and K (= λ/4, λ/2 . . . nλ/4) are applied to equation (6), equation (6) can be approximated by the linear equation (7):

$$y = \pm\frac{120}{n}x \tag{7}$$

Figure 5 shows the lines swept out by the objects when the phase difference $\Delta\phi$ is 0, π and 2π (distance difference $K = 0, \lambda/4, \lambda/2$).

In Figure 5, the signal from an object alongside the roadway Q_1, such as a guard rail, which approaches at an angle to the vehicle, shows that the differential value of the phase difference $\Delta\phi$ to the distance y, $d(\Delta\phi)/dy$, becomes large. On the other hand, an object in the roadway Q_2, such as a vehicle running ahead, which approaches the vehicle head on, has a small $d(\Delta\phi)/dy$ value. Accordingly, whether or not the object will be dangerous can be determined from the value of $d(\Delta\phi)/dy$.

Threshold of Danger for Collision Avoidance

Even when the value of $d(\Delta\phi)/dy$ is small, the object may not be dangerous if the object is far from the vehicle. Further, if $d(\Delta\phi)/dy$ is large, the object can be dangerous if the object is near the vehicle. It is, therefore, impossible to determine the potential danger of an object from the value of $d(\Delta\phi)/dy$ alone.

In Figure 6, T_0 assumes the position of an object at an instant. OP is a straight line of position with an equal phase difference that passes through T_0. L and R are both sides of the vehicle, and A and A′ are the antennas.

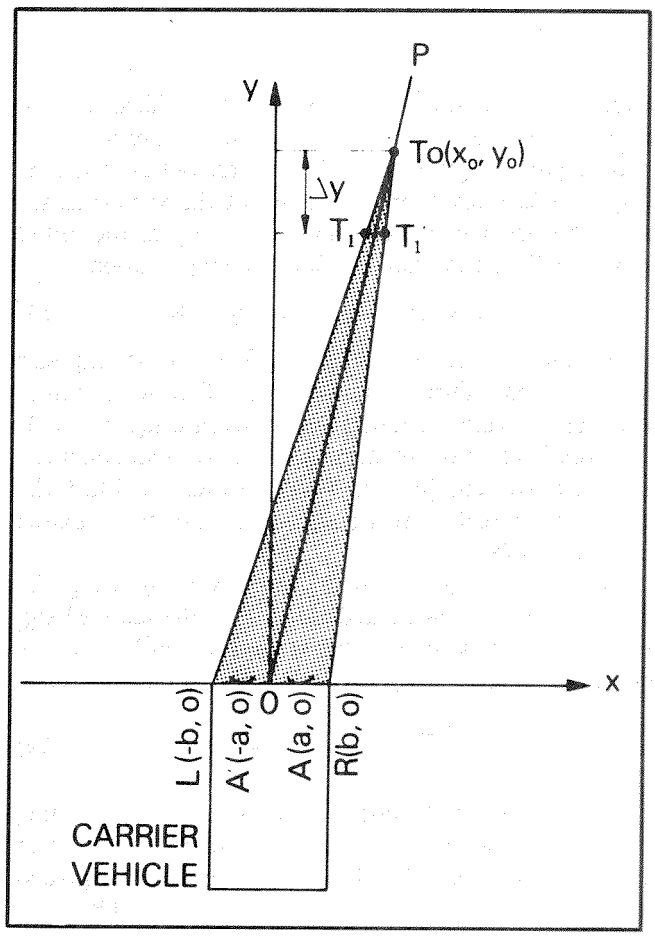


Figure 6. Danger decision logic.

The object is defined as dangerous if it is between T_1 and T_1' when it moves Δy from T_0 in the direction of the vehicle. That is, as stated under the heading "Principle of Detection of Lateral Motion," when $\Delta\phi_0$, $\Delta\phi_1$, and $\Delta\phi_1'$ denote the phase difference between the right and left Doppler signals at T_0, T_1, and T_1', respectively, if $d(\Delta\phi)/dy$ is smaller than $(\Delta\phi_1 - \Delta\phi_0)/(-\Delta y)$ or $(\Delta\phi_1' - \Delta\phi_0)/(-\Delta y)$, the object may be determined to be dangerous. Next, $(\Delta\phi_1 - \Delta\phi_0)/(-\Delta y) = (\Delta\phi_0 - \Delta\phi_1)/\Delta y$ is expressed as follows:

$$\Delta\phi_0 - \Delta\phi_1 = \frac{\overline{T_0 \cdot A'} - \overline{T_0 \cdot A}}{\lambda/2} - \frac{\overline{T_1 \cdot A'} - \overline{T_1 \cdot A}}{\lambda/2} = \frac{(\overline{T_0 \cdot A'} - \overline{T_1 \cdot A'}) - (\overline{T_0 \cdot A} - \overline{T_1 \cdot A})}{\lambda/2}$$

If λ is 0.0125 [m],

$$\Delta\phi_0 - \Delta\phi_1 = \frac{2\left\{(\overline{T_0 \cdot A'} - \overline{T_1 \cdot A'}) - (\overline{T_0 \cdot A} - \overline{T_1 \cdot A})\right\}}{0.0125} \times 360 \text{ [deg]} \quad (8)$$

where,

$$\overline{T_0 \cdot A'} = \sqrt{(x_0 + a)^2 + y_0^2} \quad (9)$$

$$\overline{T_1 \cdot A'} = \sqrt{\left(x_0 - \frac{x_0 + b}{y_0} \cdot \Delta y + a\right)^2 + (y_0 - \Delta y)^2} \quad (10)$$

$$\overline{T_0 \cdot A} = \sqrt{(x_0 - a)^2 + y_0^2} \quad (11)$$

$$\overline{T_1 \cdot A} = \sqrt{\left(x_0 - \frac{x_0 + b}{y_0} \cdot \Delta y - a\right)^2 + (y_0 - \Delta y)^2} \quad (12)$$

Here, let us consider a case where the vehicle moving forward on a curve with a radius of curvature R.

In Figure 7, given that there is an object which is displaced laterally from the course of the vehicle as far as S, the position of the object T_0 (x_0, y_0) at the initial instant will be expressed by the following relation:

$$x_0 = (R - \sqrt{R^2 - y_0^2}) - S \quad (13)$$

Here, let a be 15λ or 0.1785 [m] ($\lambda = 0.0125$ [m]) and b be 0.85 [m]. Further, if the value of x_0 at the initial value of y_0 is calculated by substituting into equation (13) the experimental parameters, $R = \infty$ (straight running), 1000, 500 and 250 [m] and S = 0, 0.9 and 1.75 [m], the change of phase difference $(\Delta\phi_0 - \Delta\phi_1)$ can be calculated by equation (8).

The object is judged to be dangerous by using the criterion that the calculated value from the received signal, $d(\Delta\phi)/dy$, is smaller than an estimation level to the collision, $(\Delta\phi_0 - \Delta\phi_1)/\Delta Y$, as shown by equation (14).

$$\frac{d(\Delta\phi)}{dy} < \frac{\Delta\phi_0 - \Delta\phi_1}{\Delta y} \quad (14)$$

Here, the calculated values of $(\Delta\phi_0 - \Delta\phi_1)$ by changing R or S, are found to be almost the same. As shown in Figure 6, because ΔRT_0O and ΔLT_0O can be regarded as nearly equal to each other, the following holds.

$$(\Delta\phi_0 - \Delta\phi_1') = \Delta\phi_0 - \Delta\phi_1 \quad (15)$$

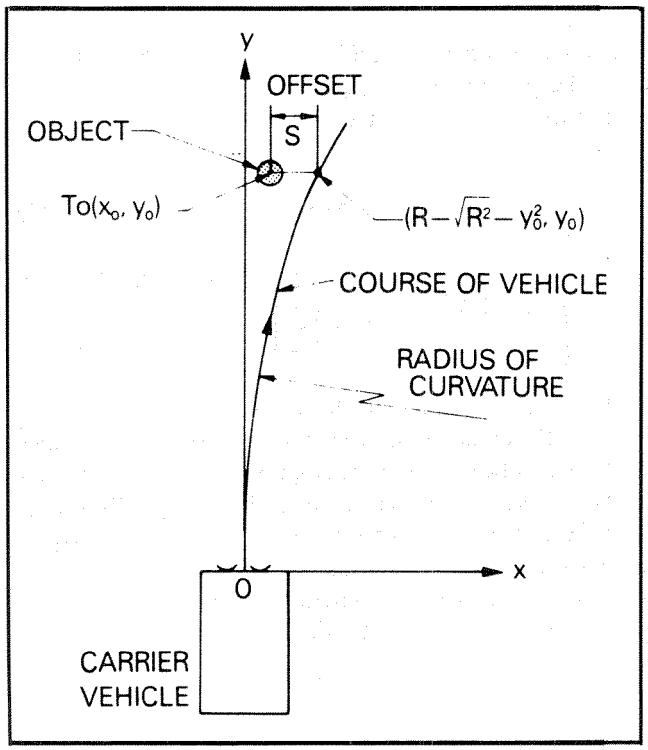


Figure 7. Calculation of estimation level.

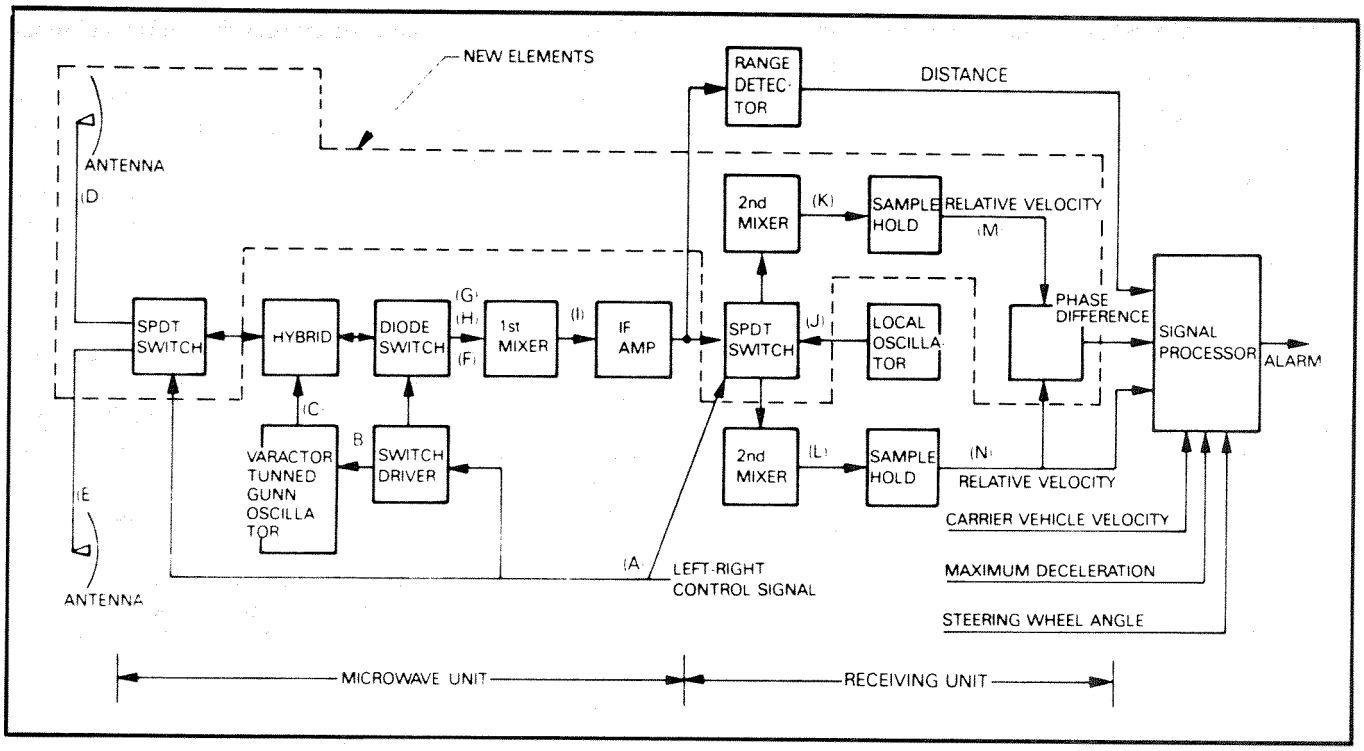


Figure 8. System block diagram.

Therefore, the criterion of danger is expressed by a single curved line of estimation level irrespective of the radius of curvature R and the offset S (Figs. 19, 20 and 21).

BINAURAL RADAR SYSTEM

System Composition

As the use of two radars makes the system more complicated in composition and larger in size, this radar system adopts one microwave unit and two antennas and receiving units. Figure 8 shows a system block diagram and Figure 9 the signal waveforms of the microwave unit and receiving units. The signals (A) through (N) in Figure 9 correspond to the signals (A) through (N) in Figure 8. In Figure 8, the components and elements enclosed by the broken line are what have been added to our radar system (2).

Operation of Radar System

In Figures 8 and 9, the varactor diode modulates the frequency of the Gunn oscillator into the RF signal (C) of f_1 [Hz] synchronously with the control signal (A). This RF signal passes through the hybrid to the diode switch. However, because the diode is short-circuited at this time, the RF signal is perfectly reflected from the diode and passes through the hybrid to the SPDT switch, where the signal is transmitted alternately to the left and right antennas.

The RF signal radiated at f_1 [Hz] from the left (or right) antenna is reflected by an object, so that the reflected signal enters the diode switch through the left (or right) antenna, SPDT switch, and hybrid. As the diode switch is now open, the RF signal passes through the switch to the 1st mixer. Also, the frequency of the Gunn oscillator, which has become f_2 [Hz], passes to the 1st

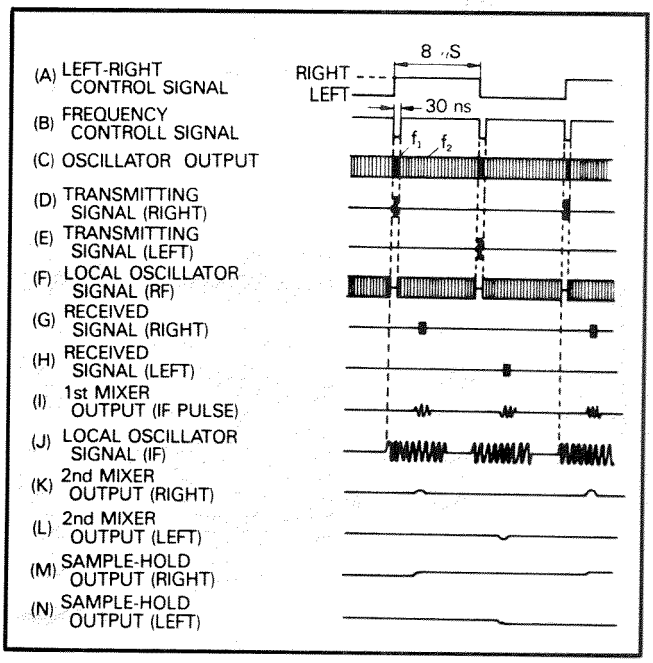


Figure 9. Waveforms of each circuit of radar unit.

Table 1. Characteristics of binaural radar system.

ITEM	DESCRIPTION
1. TYPE OF RADAR	PULSE DOPPLER RADAR
2. MICROWAVE UNIT	
OSCILLATOR	GUNN DIODE
FREQUENCY	24 GHz
PULSE WIDTH	30 ns
PEAK POWER	20 mW
PULSE REPETITION CYCLE	62.5 kHz (16 μs)
DETECTION	SUPER HETERODYNE
3. ANTENNA	
TYPE	PARABOLIC (2)
GAIN	32 dB
BEAM WIDTH (HORIZONTAL × VERTICAL)	4° × 5°
DISTANCE BETWEEN TWO ANTENNAS	37.5 cm (30□)
4. SIGNAL PROCESSOR	
INPUT SIGNAL	•DISTANCE •RELATIVE VELOCITY •PHASE DIFFERENCE BETWEEN TWO DOPPLER SIGNALS •CARRIER VEHICLE VELOCITY •MAXIMUM DECELERATION •STEERING WHEEL ANGLE
OUTPUT SIGNAL	•ALARM (LAMP)

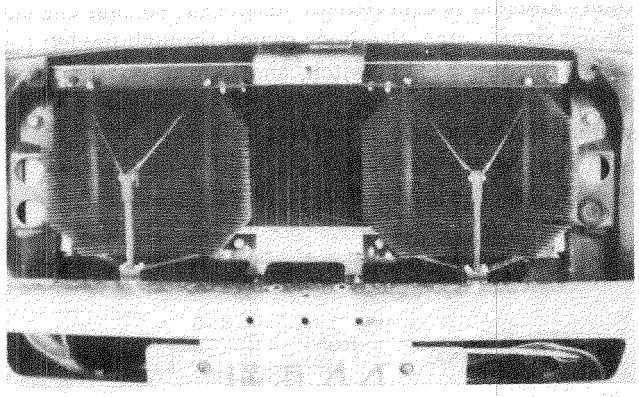


Figure 10. Radar antennas.

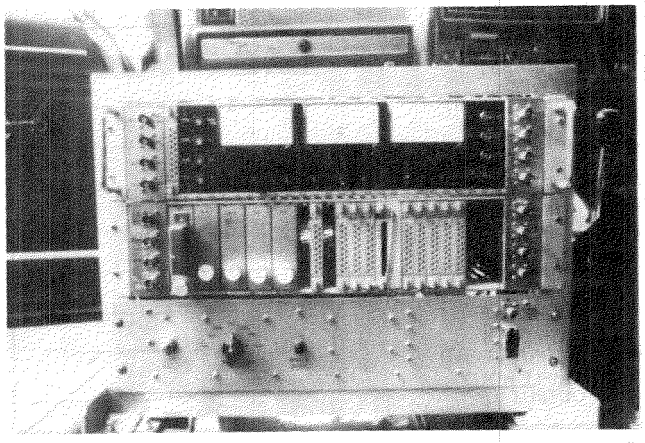


Figure 11. Receiving unit and signal processor.

mixer as a local oscillator signal past the hybrid and diode switch.

The 1st mixer mixes the reflected RF signal of f_1 [Hz] with the local oscillator signal of f_2 [Hz], and puts out the 1st IF signal of $f_1 - f_2$ [Hz].

The 1st IF signal and a coherent 2nd local oscillator signal are transmitted to the left (or right) 2nd mixer by the 2nd switch.

As a result, the 2nd mixer produces a voltage which corresponds to the phase difference between the 1st IF signal and the 2nd local oscillator signal, and a Doppler signal can be obtained by the sample hold of this voltage.

The phase difference between the right and left Doppler signals is transferred to a signal processing unit. In addition to the criterion of danger expressed by equation (14), information on the distance to the object, relative velocity (Doppler signal), carrier vehicle velocity, maximum deceleration, and steering angle is fed to the signal processing unit, which makes a final decision on the potential danger of the object according to this information.

Table 1 gives the major specifications of the binaural radar system. Figure 10 shows the two antennas mounted on the front of the radiator. There is a microwave unit behind the bumper. Figure 11 shows the receiving and signal processing unit placed in the assistant's seat. A waveform of the 1st IF signal is shown in Figure 12.

EXPERIMENT

In this study, experiments were conducted to confirm the following three objectives:

(1) The possibility of discriminating objects in the road

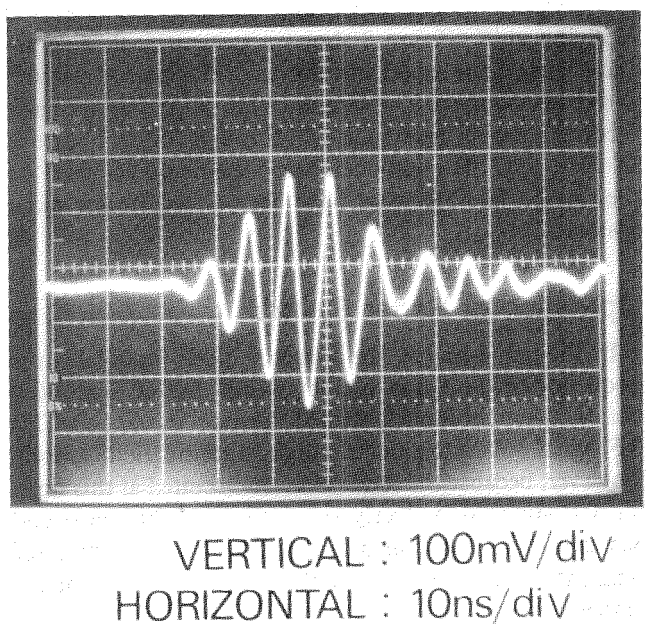


Figure 12. If signal (object-spherical reflector).

from objects alongside the road or in an adjacent lane on curves.

(2) Whether or not continuous phase difference signals can be obtained from objects with a complex shape such as vehicles.

(3) How the phase difference signal changes in the case of a plurality of continual objects such as guard rail posts.

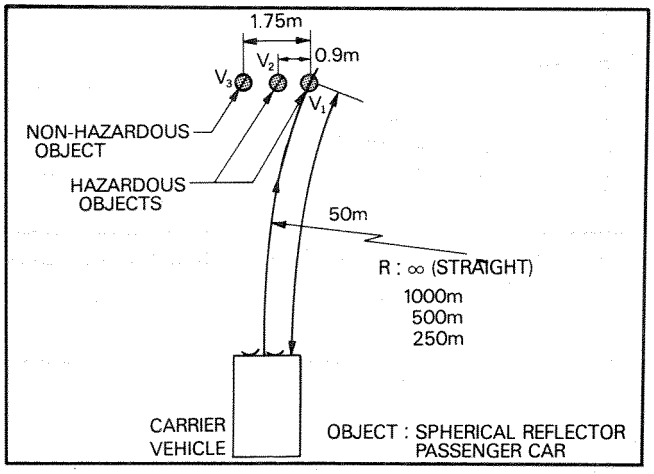


Figure 13. Parameters of experiment.

Figure 14. Experiment.

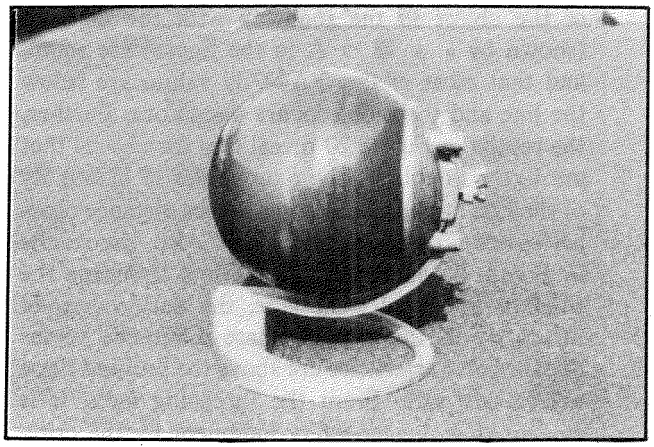


Figure 15. Spherical reflector.

Experimental Method

As regards (1) and (2) above, the parameters were the radius of curvature R, offset S, and object shown in Figure 13. In Figure 13, offset-0 (V_1) indicates an object in the roadway, offset-0.9 m (V_2) is half of the vehicle width and indicates an object that may collide, and offset-1.75 m (V_3) is an object alongside the road or in an adjacent lane.

A spherical reflector (σ = 1500 m^2, at 24 GHz) or a passenger car (Cedric) was used for the object. Figure 14 shows the condition of the experiment, and Figure 15 the reflector. Objective (3) was examined by using actual guard rails.

Experimental Results and Considerations

(1) When the passenger car located in the position of V_3 in Figure 13 was used as the object in an adjacent lane on a curve with a 500 m radius, the phase difference versus distance characteristics were as shown in Figure 16. From these results, it is known that a succession of phase difference signals can be obtained from a passenger car in an adjacent lane in spite of its complex shape; that the phase difference signal changes regularly; and that the changing rate of phase difference with the distance to the object becomes larger as the distance is closer.

(2) Likewise, the phase difference versus distance characteristics of a passenger car as an object in a straight road are shown in Figure 17. The experimental result discloses that if a passenger car is in the road, the changing rate of phase difference with distance to the object is small.

(3) Fig. 18 shows the phase difference signals obtained when guard rails were the objects. It is clear from the results that the phase difference changes irregularly in the case of a plurality of objects like guard rails, and that the changing rate of phase difference with the distance is large where the phase difference changes regularly.

(4) The changing rate of phase difference versus distance characteristics, $d(\Delta\phi)/dy$ were calculated

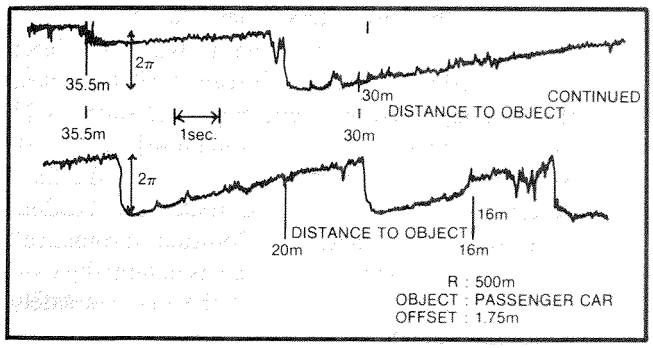


Figure 16. Phase difference characteristics.

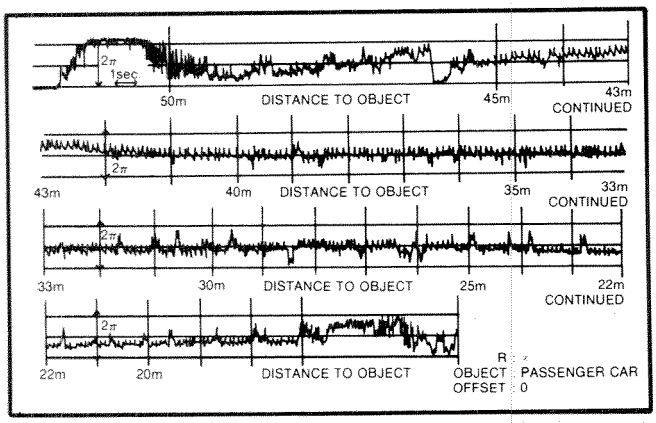


Figure 17. Phase difference characteristics.

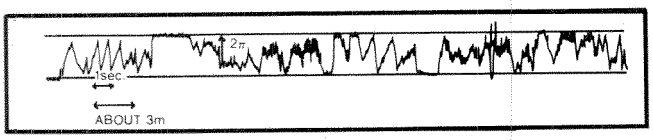


Figure 18. Phase difference characteristics object: guard rails.

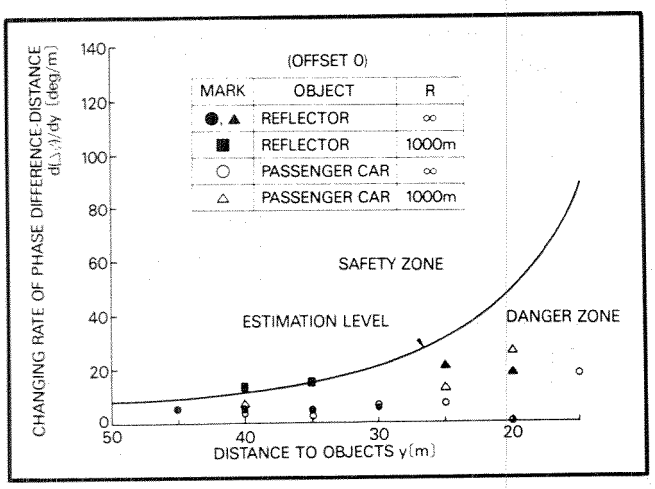


Figure 19. Changing rate of phase difference—distance characteristics.

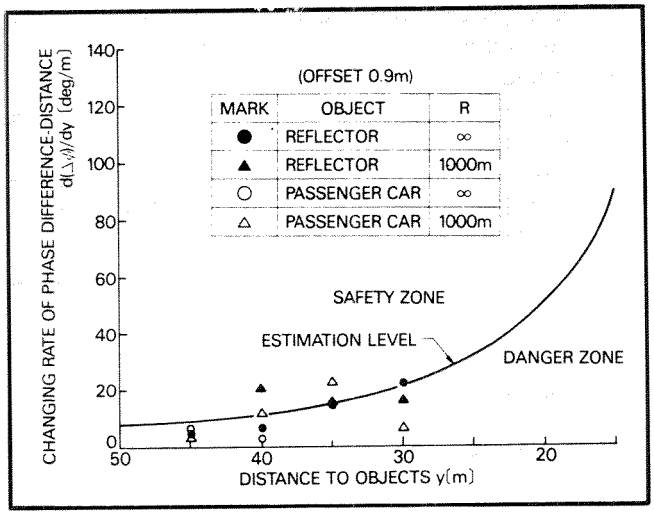


Figure 20. Changing rate of phase difference—distance characteristics.

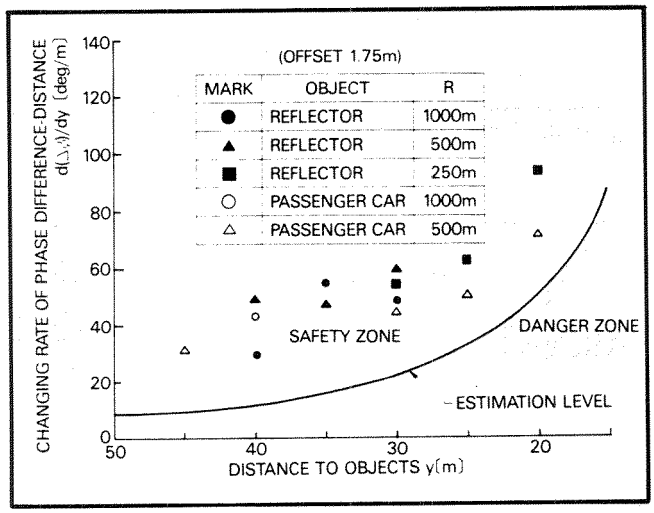


Figure 21. Changing rate of phase difference—distance characteristics.

from various phase difference-distance characteristics with the object, radius of curvature R, and offset S as the parameters. Their classifications by the offset are shown in Figure 19 (offset-0, object in the roadway), Figure 20 (offset-0.9 m, object that is likely to collide), and Figure 21 (offset-1.75 m, object alongside the road or in an adjacent lane). The curves in Figures 19, 20 and 21 are the lines of estimation level described under the heading "Threshold of Danger for Collision Avoidance" that determine whether an object is potentially dangerous or not. The area above the line is a safety zone and that below the line the danger zone. From the results in Figure 19, it is found that the data values of $d(\Delta\phi)/dy$ of the rate of phase difference of the object in the roadway with the distance (shown by • ▲ ■ ○ △ in the figure) are small, and that most of the $d(\Delta\phi)/dy$ values are below the line and these objects are dangerous. Further, the results in Figure 20 reveal that for objects that are likely to collide, the data values of $d(\Delta\phi)/dy$ of the rate of phase difference versus distance characteristics are very near the line. Also, the results in Figure 21 show that for objects alongside the road or in an adjacent lane, the data values of $d(\Delta\phi)/dy$ of the rate of phase difference versus distance characteristics are above the line and these objects are safe. From the foregoing facts, it is evident that danger-safety judgment by the criterion of danger described previously is effective.

CONCLUSIONS

(1) Using the phase difference between the right and left relative velocities in addition to the conventional information of distance, relative velocity, carrier vehicle velocity, maximum deceleration, and steering angle, the binaural radar system has proved to be capable of discriminating potentially dangerous objects in the road from objects alongside the road or in an adjacent lane. The system also extends the radar detection range on curves.

(2) A single radar unit could be used by connecting a microwave unit alternately to two antennas. This eliminates errors in the phase difference caused by fluctuation of the right and left microwave frequencies, so that the lateral motion of an obstacle can be accurately detected.

(3) This type of binaural radar can reduce the cost increase resulting from an increase in the size and weight and is easy to install, paving the way to miniaturization, weight reduction and cost reduction. The following points are left for future consideration:

* Confirmation of the applicability of this binaural radar system to objects of more complicated shape than the passenger car's, such as large-sized trucks.

* Because the binaural radar system requires two antennas to be mounted on the front of the vehicle, another problem may arise with the actual mounting of the antenna.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the parties concerned of Mitsubishi Electric Corporation, Communication Equipment Works for frequent and stimulating assistance.

REFERENCES

1. Takehana et al., "Automotive Radar Using mm Wave," C178/81, IMech E 1981.
2. Kiyoto et al., "A Study of the Automatic Braking System," June, 1979, 7th International Conference on ESV.
3. Mark K. Krage, "Binaural Automobile Radar," Automotive Engineering and Exposition, Feb. 24-28, 1975, (750089).

Automotive Warning System Using 50GHz Band Radar

T. NOGAMI
Toyota Motor Corporation
T. SAKAMOTO
Fujitsu Ten Limited

ABSTRACT

A compact 50GHz band radar system for keeping safe headway and for warning has been developed.

A simple FM-CW is adopted using a varactor tuned Gunn Oscillator and a narrow beam 2° × 2° is obtained by use of a Mill's Cross Antenna System of compact size. A microcomputer interfaced with the radar used to discriminate between the valid targets and false targets and to handle the warning algorithm.

An indicator announces audible and visible warnings according to the signal from the microcomputer.

In this paper, an outline of the system, some experimental results of sensitivity tests and road tests are described.

INTRODUCTION

The main problems in practical use of this kind of system are due to the difficulties of realizing reliable system operation in complicated road geometries and traffic flow, cost, frequency allocations and radiation hazards. We have been developing 50GHz radar systems, since they offer the sharp beams which are effective in reducing malfunctions and physical size that permits easy installation in a compact car, combined with reasonable cost and manufacturing technology.

Among radars reported elsewhere, the highest frequency is the 35GHz band used by VDO Adalt Schindling AG and Bendix Corp.

We, however, consider the optimum frequency to be 50 to 60 GHz to make the system more compact.

Our radar model features simple construction, with the transmitter and receiver antenna in the shape of a V, with the RF circuit and amplifier at the base of the V.

With this model, performance degradation due to weather conditions such as rain or snow, detection probability and false alarms occurring due to various kinds

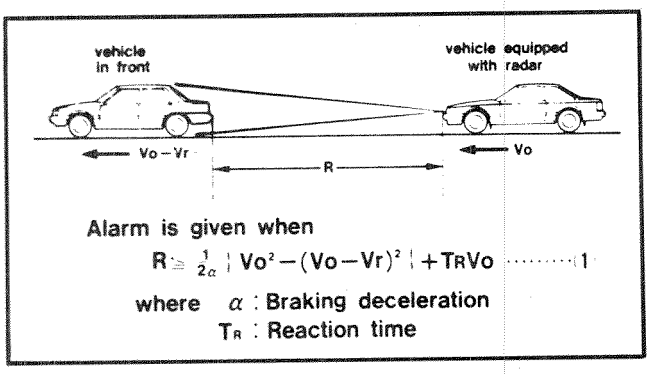


Figure 1. Principle of the system.

of road geometries and under the congested conditions in Japan have been tested.

Since radar range limitation is considered to be the most effective way to suppress false alarms, some considerations of collision mitigation are also conducted in relation to the radar range reduction.

OUTLINE OF THE SYSTEM

A traffic situation is shown in Figure 1. When a radar equipped vehicle is closing on a vehicle in front at speed Vo, the alarm is calculated according to the equation (1).

In equation (1), the value of α should be determined for various kinds of road conditions, though it should be noted that 73% of rear-end collisions occur on dry roads in Japan.

So we used $\alpha = 7$ m/s^2.

The value of TR is determined to be 1.0 second.

Figure 2 shows the system block diagram. The system consists of a radar sensor, signal processor, indicator and vehicle sensors. FM-CW radar sends out the beat signals obtained by the antenna-transceiver to the signal processor. The signal processor executes range and range rate calculation, false target discrimination and warning decision according to equation (1). The indicator announces alarms by sound and LEDs. Distance to a vehicle in front is also displayed by LEDs all the time.

In addition to the above, other information from the vehicle sensors, such as steering angle, brake ON or OFF are input, and the alarm output is restricted as occasion demands.

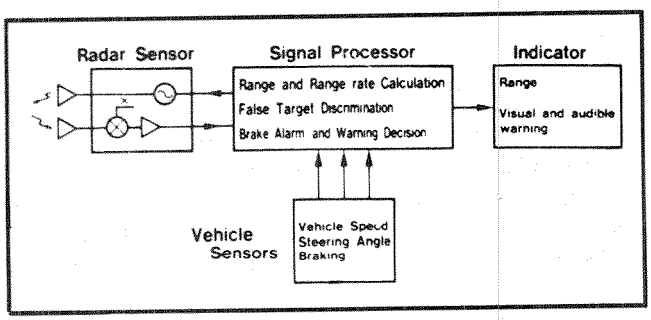


Figure 2. System block diagram.

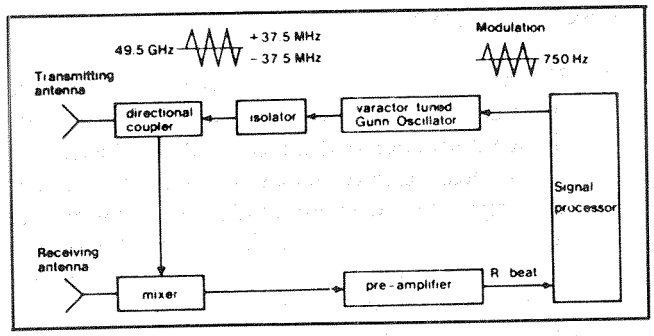


Figure 3. Block diagram of fundamental FM-CW radar.

BASIC CONSIDERATIONS OF RADAR SENSOR

50GHz Band FM-CW Radar

In automotive radar installations, the size of antenna is, in particular, a decisive factor with regard to the ease of installation on vehicles.

Since the space for antenna installation in a compact car is limited to a diameter of 100 to 200 mm, a frequency of 50GHz was selected to obtain 2° to 5° beam width in this size. In view of production engineering cost, 50 to 60GHz is considered to be the upper limit at present.

There are various radar systems, such as FM-CW, Pulse, etc. The FM-CW system was selected because the system is simple in configuration, hardware is easy to develop compared with other systems and, with the development of microcomputers, highly sophisticated signal processing functions can be incorporated in the system to facilitate false alarm prevention at a comparatively low cost.

Figure 3 shows the block diagram of the fundamental FM-CW radar system. The Gunn Oscillator output is coupled to the transmitter antenna through the directional coupler and, at the same time, fed to the mixer as the local oscillator signal.

The received signal is input directly into the mixer from the antenna.

For the parameters of FM-DW triangular modulation, we chose a frequency modulation of $\Delta f = 75$MHz, a sweep rate of $fm = 750$Hz and center frequency of $fo = 49.5$GHz. For these parameters, a range of 1m corresponds to 750Hz and a relative velocity of 1m/sec to 333.3Hz.

MILL'S CROSS ANTENNA SYSTEM WITH 45° POLARIZATION

Figure 4 shows the photograph of the antenna transceiver. For better air-flow and design at the front of the car and to obtain a sharp beam, a Mill's Cross Antenna System is adopted.

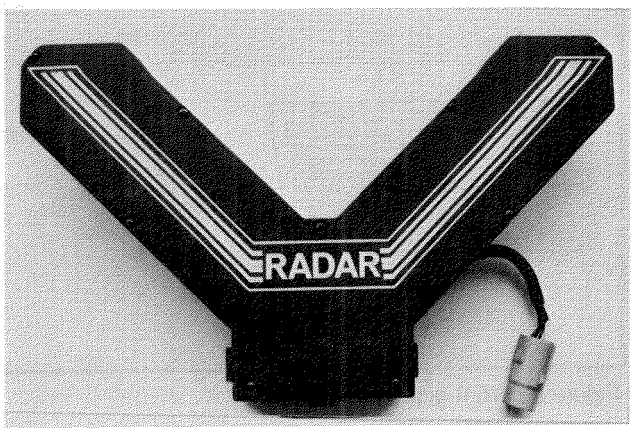


Figure 4. Photograph of 50 GHz band radar.

In addition, this antenna system employs 45° polarization, thereby reducing mutual interference with cars running in the opposite lane.

MODULAR TRANSCEIVER CIRCUIT AND MILLIMETER WAVE INTEGRATED CIRCUIT.

More detailed configuration of the antenna-transceiver is shown in Figure 5. The transmitting antenna consists of a longitudinal-shunt-slot array and parabolic-cylinder reflector, while the receiving antenna is an edge-shunt-slot array with a similar reflector.

The Gunn oscillator, directional coupler and mixer are built in a block at the base of the V-shaped transmitting/receiving antenna.

We have developed a Millimeter Wave Integrated Circuit mixer with a special structure, the so-called In-Line Type mixer, in which the received signal is supplied from one side and the local oscillator from the opposite side. Since the received signal and local signal differ in plane of polarization, the cross coupling element is inserted at

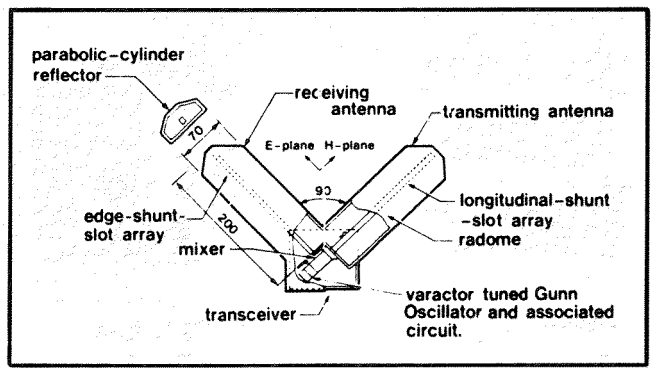


Figure 5. Configuration of the antenna-transceiver.

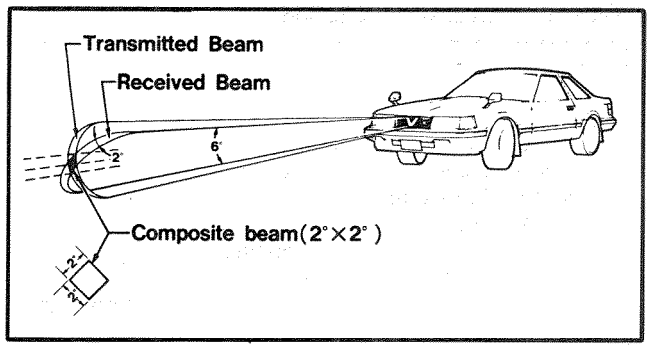


Figure 6. Illustration of composite beam.

the local signal side. As shown in Figure 6 the beam width is 2° × 6° for either the transmitting antenna or the receiving antenna, and the polarization is 45°, the crossed beams giving a useful beam width 2° × 2° when installed in a car.

Figure 7 and Figure 8 show typical receiving antenna pattern data.

DESIGN OF FRONT GRILL

Since the front grill in front of the radar is located in the propagation path of mm wave, materials and structure of the front grill influence the radar performance significantly.

Many considerations were given to phase distortion, gain drop, enlargement of beam width and deterioration of side lobe.

In this system the front grill is designed so that a dielectric board of resin is in the propagation path of the mm wave. Figure 9 shows configuration of the front grill.

The thickness of board t is determined according to the following equation.

$$t = \frac{n\lambda}{2\sqrt{\xi r - \sin^2\theta}} \qquad (2)$$

where λ : Free-space wavelength
ξr : Relative dielectric constant
θ : Angle of incidence
n : Integer

We select t = 4mm (n = 1).

When this front grill is installed in the vehicle, gain drop is 0.1 dB, enlargement of beam width is 0.2 degree and deterioration of side lobe is approximately 0.1 dB. These are negligibly small.

Coating materials for front grill include aluminium and carbon powder which are considered to influence the propagation of mm wave, but as shown in Table 2, it is proved that sensitivity deterioration is 0.7 dB at most, and also negligible in practice.

Table 1. Technical specification.

General	
Radar System	Non-cooperative Bistatic Radar
Frequency	49.5GHz
Modulation	FM-CW
Radar performance	
Antenna	V shaped Mill's Cross Antenna
Beamwidth	2° × 2° (composite beamwidth of transmitting and receiving antenna)
Polarization	45°
Gain	32 dB (for transmitting or receiving antenna alone)
Transmitter output power	30 mw
Range	3 to 60 m
Range rate	0 to 120 km/h
Size of antenna transceiver	204 334 × 66 mm (H × W × D)

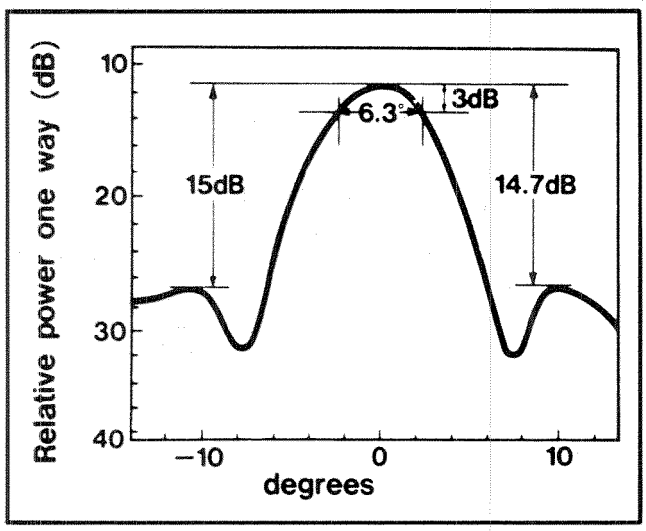


Figure 7. Typical data on receiving antenna (H-plane).

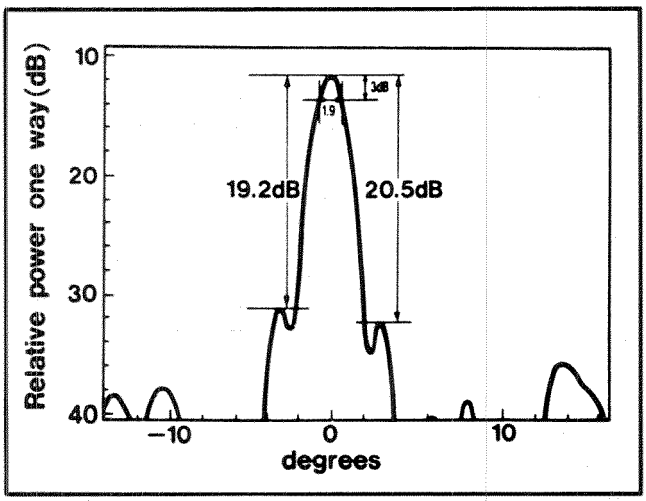


Figure 8. Typical data on receiving antenna (E-plane).

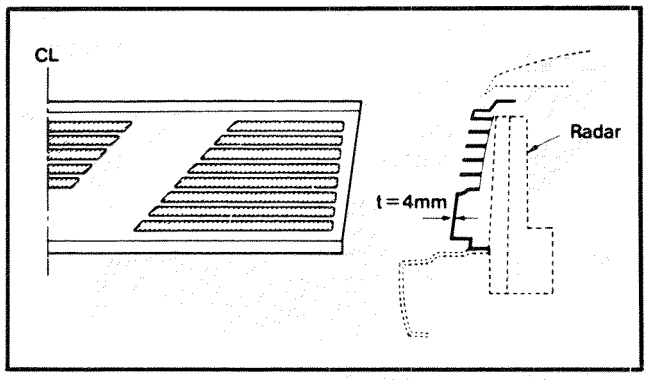


Figure 9. Front grill for the radar.

Table 2. Influence of front grill coating materials on radar performance.

Coating materials	Pigment composition	Attenuation
A	A1:2%, carbon:0.6%	0.1 dB
B	A1:3%, carbon:0.9%	0.3 dB
C	A1:4%	0.3 dB
D	Carbon:3%	0.3 dB
E	Carbon:2%, organic pigment	0.7 dB

MICROCOMPUTER-CONTROLLED SIGNAL PROCESSING

The Signal Processor consists of 1 chip CPU, 2KB ROM and 3 I/O LSIs (Fig. 10), and operates according to the flow chart shown in Figure 11.

Range and closing rate are calculated from the beat frequency during the modulation up and down swing.

Since false alarms caused by false targets must be minimized, received signals are analyzed from various angles to discriminate between the valid targets and false targets.

That is, since very frequent false alarms are sent out if the equation (1) is calculated just from the beat signals, we plan to decrease the number of false alarms by the following methods:

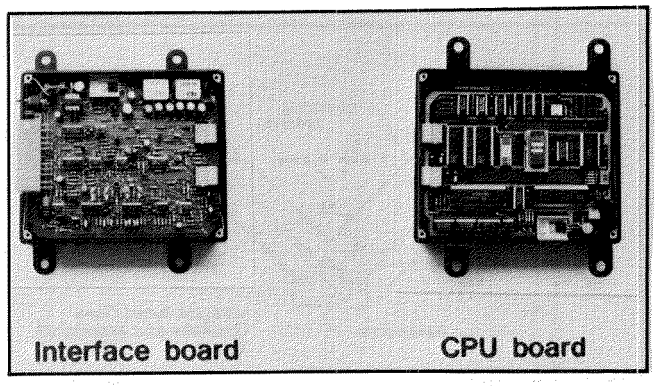


Figure 10. Photograph of signal processor.

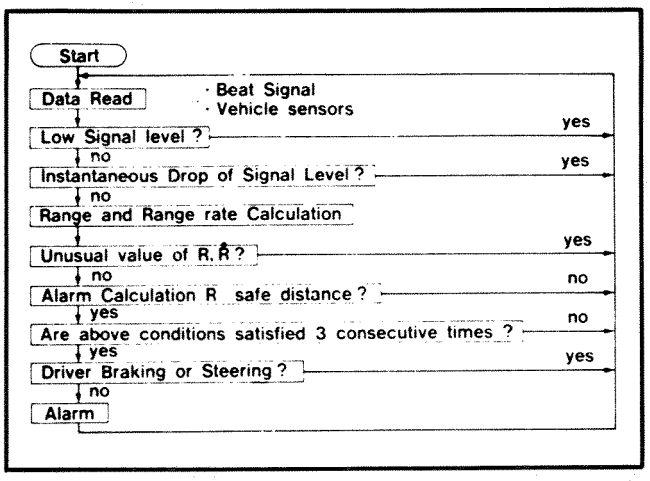


Figure 11. Outline of signal processing.

(1) False target discrimination according to the received signal level.
(2) Distance and velocity output hold whenever there is an instantaneous drop in receiving level.
(3) Alarm calculation output inhibition whenever there is a sudden change in the distance or velocity.

Alarm calculations are executed every 50ms according to equation (1) and when the equation is satisfied three times in succession without braking or steering maneuvers, visible and audible alarms are triggered.

RADAR RANGE CUT

It is reported that selection of optimum beam width and radar range cut is effective in suppressing false alarms.

In this system, a narrow beam 2° × 2° is obtained by use of Mill's Cross Antenna System. In relation to the beam width, when the radar equipped vehicle runs nearby roadside obstacles such as guardrails on a straight road, the range selected should be 45m.

As shown in Figure 12, when the vehicle runs along the curved road where the maximum lateral acceleration is assumed to be approximately 0.3g, the distance to obstacles is calculated as 40m at 100km/h (situation B in the figure). So we adopted 40m for the radar range.

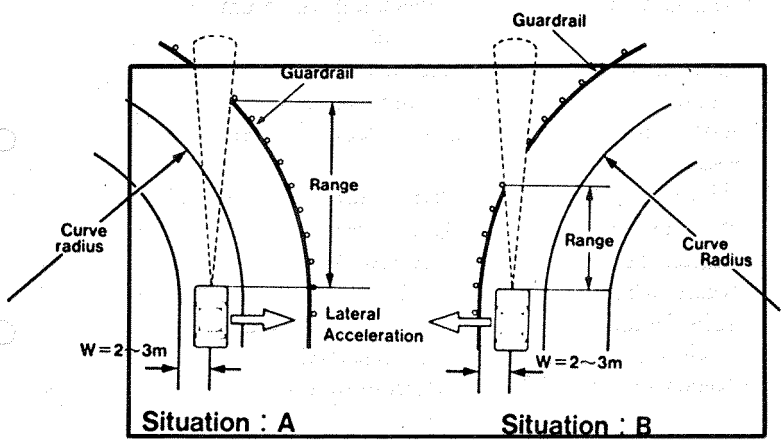


Figure 12. Range reduction required in curves.

That is, alarms are restricted when the distance between vehicles is more than 40m.

We investigated the distance in normal traffic flow and the distance at which drivers activate the brake when they recognize dangerous conditions in city traffic, urban traffic and on the expressways in Japan.

Test results are shown in Figure 13.

Drivers do not keep their distance on the assumption that the vehicle in front will suddenly stop with no stopping distance, and the assumption in equation (1) that the radar car can stop at the same deceleration as the vehicle in front is confirmed to be suitable.

Recognition of dangerous conditions occurs at a distance corresponding to reaction time of 0.9 ~ 1.1sec; well within the 40m range in normal traffic flow, for example at 25 ~ 27m when vehicle speed is 100km/h. Test results also show reaction time TR of 1.0sec matches the typical driver's driving habits.

We selected the 2° × 2° beam width and 40m range for false alarm problems and reaction time TR = 1.0sec after some experiments.

Therefore, under certain conditions, the system becomes only a collision mitigation system which reduces the impact velocity and impact energy. The safe distance as a function of relative velocity is shown in Figure 14. For example, if the vehicle is closing on a fixed obstacle at more than 63km/h, a collision is unavoidable.

Impact velocity Vc is calculated according to the following equation.

$$Vc = \sqrt{2\,V_o\,V_r - V_r^2 - 2\,\alpha\,(R_o - T_R \times V_R)} \quad (3)$$

where R_o : Radar range
Vr : Closing speed
Vo : Own vehicle velocity
α : Braking deceleration

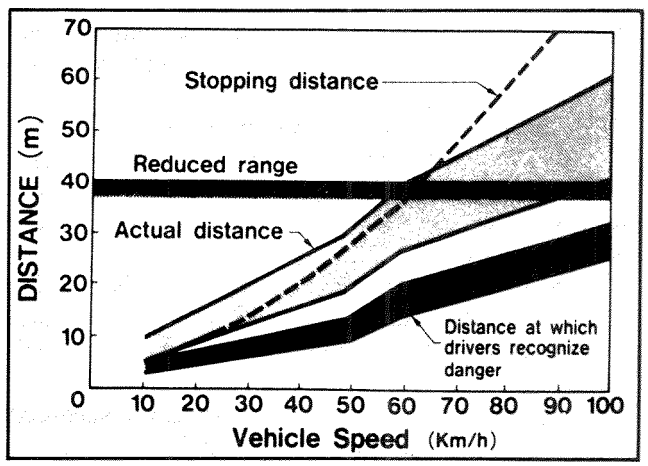


Figure 13. Actual distance in normal traffic flow.

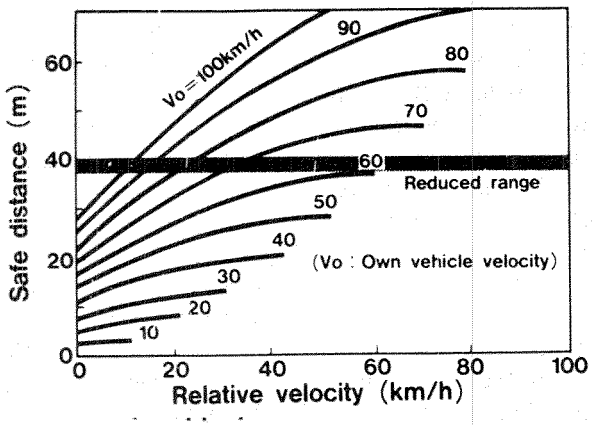


Figure 14. Relationship between relative velocity and safe distance.

As shown in Table 3, if the radar equipped vehicle is closing on a fixed obstacle at 80km/h and the driver activates the brake not later than 1.0sec after the recognition of alarm, impact velocity is reduced to 56.3km/h which reduces impact energy 50%.

Table 3. Impact velocity and energy reduction as function of closing speed.

Closing speed	Impact velocity	Impact energy reduction
65 km/h	15.6 km/h	93%
70	34.2	76
80	56.3	50
90	73.3	34
100	88.2	22

EVALUATION TEST

Detectable Range

Shown in Figure 15 is the record of range outputs when the experimental vehicle runs toward a fixed corner reflector (σ = 22.8 dB).

The figure shows that the maximum detectable range is 170 to 180m on a straight road under good conditions.

For actual passenger cars, the radar cross section is presumed to be 10 to 20 dB, and the detectable range is approximately 80m.

Figure 16 shows the data collected under the running conditions of both radar equipment and target vehicles, and with maximum range limited to 60m to reduce malfunctions.

This figure reveals that sensor performance is such that even compact cars can be detected satisfactorily up to a range of 60m.

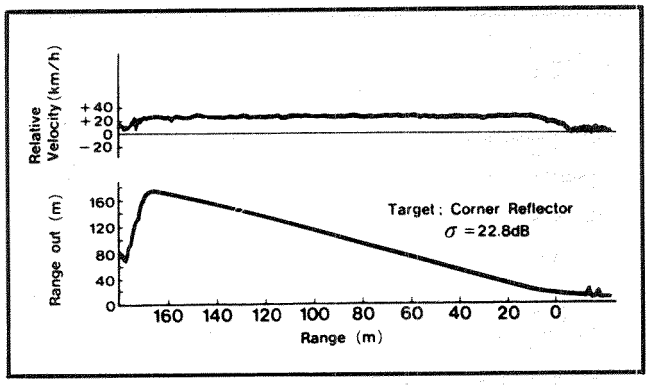


Figure 15. Detection range.

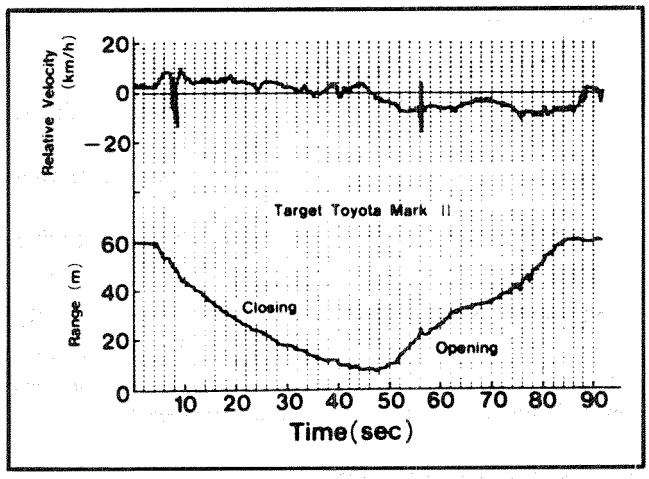


Figure 16. Typical road test data.

WEATHER EFFECT

Regarding the effect of rain and snow which are supposed to pose the most serious problem with millimeter waves, the following performance test was conducted:

Deterioration of sensitivity caused by rain or snow, through their adhesion to the front grill, attenuation in the air and back scatter are considered. In actual running conditions, decisive degradation of sensitivity caused by rain or snow was not observed at all.

Figure 17 shows the range data gathered by making use of an artificial rain facility in order to evaluate back scatter by rainfall.

The detectable range is significantly reduced due to clutter, but this value is only a reference, since the precipitation at the test site registered about 150mm/h, an amount of rainfall such as we hardly ever encounter in nature. In an actual road test when there was a normal rainfall, no poor sensitivity was observed.

Regarding some 20 to 30mm/h of rainfall, we have not had the opportunity to carry out such a test and results are still awaited.

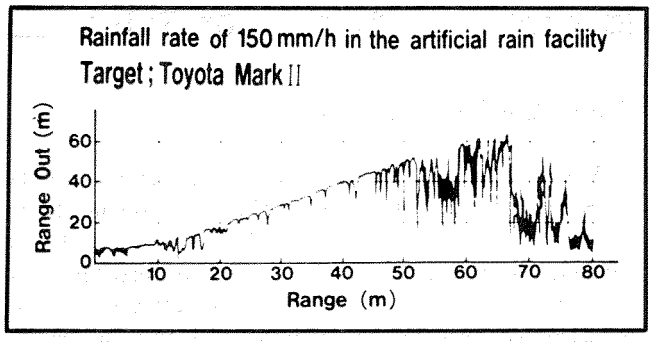


Figure 17. Detection range.

ROAD TEST

Target Discrimination and false alarms have been evaluated by use of the test vehicle in various road geometries and traffic conditions. Because of the narrow 2° × 2° beam and alarm restriction at more than 40m, few false alarms occurred: merely several alarms per 300km.

Almost all these false alarms were acceptable to a driver, for they occurred, for example, when the radar equipped vehicle passed another vehicle very recklessly or when the vehicle ran very close to the guardrails on a curved road.

As a result of the basic evaluation testing we have gained confidence that the system performs suitably for practical use, in view of false alarm problems. In addition, the road tests have been conducted over a few thousand kilometers, and we have not had any trouble with the millimeter wave device, which has been found to be highly reliable.

CONCLUSION

We selected a frequency of 50GHz and obtained a radar sensor with beam width of 2° × 2° and small size of 204 × 334 × 66mm (H × W × D).

(1) Under good conditions, the detectable range is approximately 80m for a compact car, and attenuation due to rain or snow in the air was not found. Considerable back scatter due to rainfall was found when the rainfall rate was a very heavy 150mm/h. But in rainfall such as we normally experience, no poor sensitivity was observed, so we consider this to be no problem in practical use.

(2) We investigated the target identification caused by roadside obstacles on curved road.
Since it is considered that maximum lateral acceleration of the vehicle is approximately 0.3g, we adopted a short radar range of 40m, to suppress false alarm occurrence.
All false alarms were acceptable to a driver, for they occurred when the vehicle was passing other vehicles very recklessly or running very close to the guardrails in a curve.

(3) Because of the short radar range, however, under certain conditions, the system becomes only a collision mitigation system.
For example, if the radar car is closing on a fixed obstacle at 80km/h and the driver activates the brake not later than 1.0sec after alarm occurrence, impact velocity will be 56km/h and impact energy will be reduced to 50% of initial energy.

(4) Even the system at present is considered to be effective because probability of fatal accidents or severity of injuries sustained by the driver will be significantly reduced.

(5) Trade-off of false alarm suppression and collision avoidance is a subject for future study.
In terms of hardware, it is necessary to follow up on enhanced reliability under various environmental conditions such as temperature, vibration, EMI etc. and for cost reduction.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the many contributions of H. Komizo of Fujitsu Laboratory in developing the millimeter wave devices.

REFERENCES

1. Jones, T. O. and Grimes, D. M. "Some Automotive Radar System Considerations", Second International Conference on Automotive Electronics, London, November 1979.
2. Hahn, L. "Advances in the Development of Headway Radar Using Pulse Techniques" Second International Conference on Automotive Electronics, London, November 1979.
3. Chandler, R. A. and Wood, L. E. "System Consideration for the Design of Radar Braking Sensors" IEEE VT-26, May 1977.
4. Troll, W. C., et al. "Results from a Collision Avoidance Radar Braking System Investigation" SAE 770265, Detroit, March 1977.
5. Dull, E. and Peters, H., "Collision Avoidance System for Automobiles", SAE 780263, Detroit, March 1978.
6. Belohoubec, E. F., et al. "Microcomputer Controlled Radar and Display System for Cars", SAE 770267, Detroit, March 1977.
7. Belohoubec, E. F., et al. "Radar Control for Automotive Collision Mitigation and Headway Spacing" IEEE VI-31, May 1982.

Accident Avoidance—How Age Deterioration Can Affect Car Safety

M.A. JACOBSON, M.SC C ENG;
F. I. MECH E; M. I. PROD. E.
Chief Automobile Association
Fanum House, Basingstoke, Hants, England

INTRODUCTION

It is in the nature of things that the majority of motorists ride about in cars that are older and less well cared for than the shiny new models in dealers' showrooms. The average age of cars in regular use in the UK is 5½ to 6 years and is rising as Companies and private purchasers delay replacing vehicles by a year, in an effort to save on capital expenditure.

This paper concerns itself with some of the inevitable age deterioration effects and how they may affect vehicle safety. Age deterioration in the form of metallurgical changes, from fatigue cracking in steel to crack propagation in high strength aluminium alloys, and above all corrosion of high temperature turbine blades, is well understood by the aircraft inspectorate as potential safety hazards. All aircraft operators accept rigorous and fairly frequent replacement of age expired structural parts and moving components as a sensible, although costly, safety measure. After all they are professionals. Yet there would be an outcry by millions of motorists if they were compelled, by law, to replace tyres, suspension elements, engine and transmission mounts, fuel tanks, as a preventive measure on an age or mileage basis, for this would probably be long before they have reached the point of unserviceability *in the eyes of their owners.* Owners are, of course, generally lacking any expertise in such technical matters.

ARE AGE-DETERIORATED COMPONENTS A MAJOR CAUSE OF ACCIDENTS?

There appears to be conflicting documentary evidence on whether age and mileage deterioration is a major factor in real life accidents. It is a bit like the case of the old cracked jug, which sometimes outlasts a new whole one—owners take extra care when using it and made due allowance for its imperfect condition.

Under normal operating conditions most drivers can and do compensate for the progressive deterioration of clutch, brakes, wear in steering linkages, even the partial collapse of hydraulic dampers. Only in emergency accident avoidance manoeuvres is it likely to cause serious problems.

NEW CAR DEFECTS

It should not be forgotten that a substantial number of cars are delivered with material or assembly faults, and poor driving technique is often blamed for short component life or loss of control incidents. Persistent complaints by a number of our members are typical. They experienced difficulty in changing gear and the inability of the dealers to trace and rectify the cause. The typical sequence of events runs something like this: After several months of unsatisfactory motoring and the fitting of one or two new clutches, a complete strip of the power unit would be undertaken, revealing the absence of the proper thrust washer in the engine.

Mechanics and reception engineers, even the manufacturers' representative, never experienced a great deal of difficulty with gear changes on this car, for they were skilled in clutchless changes, using the synchromesh to best advantage.

DIFFICULTY OF DIAGNOSIS OF DEFECTS

The garage trade, in many instances, fails to diagnose correctly the causes of customer complaints. They may use the same jargon, but this may describe very dissimilar occurrences. A common complaint is: "The car is running rough, particularly at speed". We have on record a number of cases where repeated attention to engine tune, including systematic replacement of sparking plugs and then the complete HT system, even re-conditioning of carburetors, were undertaken, all to no avail. In others clutch and flywheel were removed and dynamically balanced. Replacement of brake discs and hydraulic dampers, new steering joints, all figure prominently. Yet in many cases the cause was nothing more fundamental than a rear wheel tyre which no longer had uniform steel belt stiffness. Casual inspection, check for legal tread depth, even re-balancing on standard wheel balancing machines would not reveal that the tyre was approaching the state of imminent failure. A few of the tyres had built-in shortcomings such as poor bonding of different layers or lateral run-out, but the majority had just become age deteriorated.

Whereas vehicle inspectors have been given fairly clear guidelines on the extent of tolerable deficiences in steering, brakes, and suspension (which of course includes structural strength of their attachment points) beyond which they must fail the vehicle in its MOT or equivalent safety test, no proper guidelines exist when it comes to age affected tyres. There is also some doubt whether the Vol-

untary Recall System operated by the vehicle manufacturers is the most cost effective way to ensure safety.

RECALL CAMPAIGNS

Despite ever more sophisticated quality control procedures being adopted by the majority of vehicle and component manufacturers, far too many vehicles leave the factories with safety related defects.

In the UK the number of cars, light vans and pick-ups recalled for safety checks and rectification between April 1st 1980 and March 31st 1981 was 560,880, or around 36% of the annual new car registration. This is under an Industry Voluntary Recall Code and most of the cars affected were still within their one year warranty. Even so only 78% of these were actually traced, checked and/or rectified by April 1982.

This represents a very good response by the motoring public and is much better than that found in, for instance, the USA. But so it should be, for if the manufacturer cannot encourage an owner/operator to take his vehicle back to his franchised dealer whilst the full warranty cover operates, he has far less hope of success thereafter—particularly as an ever larger proportion of owners skimp on maintenance, attempt some DIY repairs and no longer regularly entrust their vehicles to the recognised franchised dealers for maintenance and repair, once the car is over 3 years old.

FASTENER DEFECTS

24½% of the recalled cars and car derivatives had nothing more fundamentally wrong than inadequate fasteners, which ranged from incorrect, or missing, locking washers or circlips to the wrong rivet material, from inadequate pre-loading to material of nuts and bolts not being up to specification.

It is all too easy to dismiss these as minor problems, which owners will have attended to as soon as an assembly becomes sloppy or rattles a bit, in other words long before a real safety hazard occurs. But that argument loses all credibility when it comes to suspect seat belt fixings which could affect some 15,370 cars, for they could fail at well below their design load, and at the first time they were called upon to perform.

What possible reason should induce an owner of a factory new car to check after a bit of brisk motoring whether the self locking nuts on his front suspension are starting to come undone or suspect that there is a likelihood that the purposeful growl of the sportier version of a popular family car is due to hub flange bolts stretching under the increased loading? Would he not be entitled to expect that the material specification for securing front brake calipers on a high price, high performance car is such that they will neither stretch, come loose, nor snap during repeated braking from high speed? And why should he be expected to realise that if he regularly motors across undulating corrugated roads, which are not uncommon in many parts of Europe after a severe winter, he must refrain from doing so at 50mph or above or expect the front suspension tie rods to come undone?

One would hardly expect that vehicles built in 1981 would suffer from such a basic lack of appreciation of fatigue loading. It is a regrettable fact that even in 1980/82 we come across examples of nuts being harder than bolts, the threaded portion of bolts being too long or too short to perform properly when engaging with the mating nuts.

Such signs of poor design were not confined to any one country of origin. Also production volume and cost of the vehicle are not a guarantee against plain human failings. Manufacturers believe that their feed-back via warranty claims, submitted through franchised dealers, is adequate and effective, yet this assumption may need re-examining from time to time.

IS THE VOLUNTARY RECALL SYSTEM THE BEST WAY TO DEAL WITH SAFETY DEFECTS?

It is probably still the only practical way in which we can tackle the complex problem of vehicular safety and reliability without creating a vast bureaucratic apparatus to monitor after-build rectification operations, which are carried out under such euphemistically titled schemes as: "Pre-delivery Inspection", "1st Free Service at 1000 miles", "Free Safety Check", "Extended Warranty Inspection", "Fine Tuning", "Voluntary Free of Charge Recall", "Personal Reminder". . . etc.

But the system leaves unanswered such questions as:

1. Why do we have an average of ½ million voluntary recalls in Britain every year, mostly on relatively new cars and often well before they are due for their first MOT safety check, i.e., at under 3 years or at less than ⅓ of the designed life?
2. Is this really the most cost effective way of dealing with such situations?
3. Whilst generally only a small fraction of all the cars sold would be at risk, who can determine with certainty which ones?

The tracing of owners, the follow up administration work, the provisioning of special tools, replacement parts, etc., under the Voluntary Recall System, on average, costs 20 to 100 times as much as getting it right first time, namely at the manufacturing and assembly stages.

THE EFFECTIVENESS OF COMPULSORY VEHICLE SAFETY CHECKS

While statistics exist about Recall Campaigns, little is known about the changes of primary and secondary safety of vehicles due to age deterioration or how effective MOT type safety checks really are. For reasons of cost, annual or biannual compulsory safety checks can only cover a limited number of essential safety features. The real value of such compulsory checks appears to be in persuading owners to replace doubtful and part-worn parts prior to submitting their vehicles to the MOT or equivalent test. Alternatively they may decide that the time has come to scrap their car, if they are afraid that the cost of the necessary repairs and parts replacement to ensure a pass is substantial or more than they can afford.

There are obvious economic limits to the scope and methods of inspecting cars. The costly procedures of properly recording and feeding back relevant data to the vehicle and component manufacturers (in such a detailed manner that these could be used by them to improve their products), has hardly ever progressed beyond the stage of discussion paper or feasibility study.

WHAT ARE THE REALISTIC RISKS OF FAILURE TO TRACE AND RECTIFY SAFETY DEFECTS?

Despite the excellent response to the recall campaign by the owners and the garage trade, over 150,000 cars were missed that year in the UK alone. It is not unreasonable to assume that they too followed the general pattern of vehicles recalled for safety checks, namely that only between 3% and 8% were really at risk of *imminent* failure. The number of new vehicles in circulation in the UK with such latent defects is therefore not likely to be in excess of about 12,000, or of the order of less than 1% of the annual registration of new cars.

The number of older or badly maintained cars which are at risk from latent defects is, of course, much greater. But little reliable data exist to quantify this. It thus becomes more a matter of extrapolation of limited in-depth investigations and "expert opinion", guesswork, even rumours freely circulating in the garage trade and insurance circles.

Fortunately, not every mechanical failure occurs at speed, nor does it generally result in injury accidents. These are the accepted reference standards by which to judge whether the various steps taken to minimise accidents have been really effective. For every recorded injury accident about 18 to 22 occur involving minor or quite extensive damage to the vehicle only. And a far greater number are near misses (1).

Many of the fastener failures on suspension and steering will occur when applied loads are relatively high, such as when moving in or out of side streets, going up or down ramps, on roundabouts, even reversing to park. These are usually fairly slow speed manoeuvres. Defective tyres, on the other hand, frequently fail at speed or when attempting a rapid lane change.

BRAKE DEFECTS

Can one be sure that of the recalls concerning hydraulic brake defects—in which the owners did not call on the franchised dealers to have them rectified, over 10,000 in 1980/81—none will manifest themselves later on in loss of control in situations where the driver brakes to avoid a collision, or attempts to slow down from high speed prior to changing direction?

Nearly 200 cars had rear brake slave cylinders of too large a diameter, which would cause premature locking up of rear wheels and thus could produce a rear end slide during emergency braking. Over 8,500 had suspect brake servos, and the remainder had wrongly assembled brake units or badly routed brake lines.

After Accident Investigation by a traffic accident investigating police officer would rarely establish that the car involved had a questionable braking performance due to "inherent manufacturing defects", particularly so in relatively new cars. For he would at best carry out a static test to establish whether the hydraulic braking system was still pressure tight or not. If the system held pressure, he would naturally assume that the driver rather than the vehicle manuacturer was at fault.

TYRE DEFECTS

When it comes to tyres, there is far less inclination by manufacturers to arrange for a voluntary recall. In recent years the quality control of several tyre manufacturers, as well as their skills, have improved considerably. Some tyre manufacturers act more responsibly than others. There remain, however, those manufacturers who rely on:

a) the difficulty of aggrieved motorists being able to prove manufacturing defects, for it is all too easy after a tyre failure to ascribe it to owner neglect or abuse,
b) suspect tyres tend to wear out fairly early in their life, or,
c) some suspect tyres are so difficult to balance that the motorist will return to the tyre dealer who will then make a concessionary adjustment and fit a replacement one.

Two or three tyre manufacturers have gone beyond the voluntary code commitment of the Tyre Industry and generously replaced substantial numbers of their high performance tyres as a precautionary measure, once certain manufacturing shortcomings have come to light. For

no manufacturer enjoys condemnation by the media following a series of unexplained serious accidents, even though he may be exonerated from blame in subsequent court proceedings.

ACCIDENT CONTRIBUTING FACTORS

It is always difficult in accident investigations to clearly identify and record *all* contributing factors, particularly if the vehicle is badly damaged. While it is generally accepted that mechanical defects are not the prime cause of injury accidents and that driver action may well be at least a major contributing factor in ⅔ to ¾ of them, one cannot ignore that, in real life situations, road layout, traffic conditions, other road users, wind and weather have considerable influence on the sequence of events leading up to or aggravating the accident.

WHAT CAN BE DONE TO IMPROVE THE SITUATION?

There is little that can effectively be done about varying climatic conditions, which play a major role in creating the pre-conditions for road accidents. The erection of wind breaks, better road layouts and improved traffic flow, lane segregation of slow and faster moving vehicles are desirable alleviating features, so are purpose built motorways and urban ring roads, but all cost money and it takes a good deal of time before they are fully implemented.

Better Driver Training, and Government Safety Propaganda is costly. Yet, despite persistent exhortations, good advice, even visual horror shock treatments on television, etc., it is difficult to detect signs of improvements in driving habits. Motorists still take unnecessary and unwarranted chances.

Even police prosecution and heavy fines for offenders against traffic regulations have only a temporary deterring effect. One must therefore accept that there will always be some careless, even reckless drivers about.

THE CONCEPT OF THE "FORGIVING" CAR

Cars should, therefore, be designed to be as forgiving as practicable to the incautious or erratic driver and not merely be approved by "expert" drivers as having a "sporty appeal". In other words, the maximum technically feasible may not be the ideal solution. It is, in my opinion, preferable to have a car with accelerating, braking and road holding performance of *below* the maximum technically feasible, but with little variation in performance in these vital characteristics over a wide spectrum of environmental and operating conditions. This is particularly important if ageing and lack of maintenance could drastically lower the effectiveness of brakes, tyre grip and predictable and crisp steering input response.

Superb performance for certain conditions and thereafter a dramatic loss of control, once a threshold limit has been reached or environmental conditions have altered, may well give a false sense of security to many drivers when motoring under favourable conditions. If the driver receives early warning of impending but progressive loss of control over a widely varying set of conditions, with time to take some corrective action, he has a better chance of surviving, with a bad fright or a minor dent to his ego or his car, than in the case of total controllability up to the limit of adhesion of tyres, followed by a spectacular spin, if he tries that little bit too hard. For tyre to road grip can vary substantially on any long distance trip.

It depends so much on the type of surface dressing, its harshness, macro and micro texture and state of polish, which in turn are greatly affected by level of heavy trucks travelling over it daily. Whether the surface is dry, damp or rainsoaked, is of major significance. In most loss of control accidents it takes only about ½ second for the transition from marginally safe to alarming and a further ½ to 1 second for the driver to perceive the danger and react as best he can. Yet in many instances the road layout could be such that total loss of control would take place within 1½ seconds.

TYRE TO ROAD GRIP

Most car tyre testing has been carried out on wet surfaces, for this gives a lower μ value (and hence longer braking distances), than in the dry. The aim throughout the last 15 years or so has been to give a new car tyre as near the same μ value as applies in the dry and it is no longer remarkable to find that for the same road surface (other than the Bridport Pebble with its very low μ value) the μ value (wet) is about $0.80 \times \mu$ value (dry). But there are considerable variations between certain makes of tyres. The range of μ (wet) $= 0.75 \times$ (dry) to μ (wet) $= 0.85 \times$ (dry) covers most West European quality tyres. But we have come across values as low as μ (wet) $= 0.63 \times \mu$ (dry) on car tyres from hot, dry countries.

While many tyre manufacturers are using similar types of polymers for their tread compounds, there are differences in "effective μ", particularly in the wet. Each manufacturer will tend to select a compound which suits his production plants and gives the best compromise in the quest for a low cost tyre which has good wear resistance, good braking charcteristics in the wet, high speed durability, and performs well over a wide temperature range. These are often contradictory requirements.

In order of significance the options of change open to a tyre manufacturer to optimise his new range of tyres are:

1. Tread Rubber Compounds.
2. Tyre Construction Details.
3. Tread Pattern.

In part-used tyres the tread wear pattern, and particularly the remaining depth of tread, is often of greater significance than the 3 factors listed above when operating on rain soaked roads.

Typical "μ" values obtained when braking from 50km/h on a dry concrete surface for 3 different 165SR13 steel belted radial tyres were:

PEAK	LOCKED WHEEL	TYRE TREAD COMPOUND
0.96	0.88 = .92 × Peak	23% High Hysteresis Styrene Butadiene (Most common on UK summer tyres)
0.93	0.80 = .86 × Peak	High Level of Natural Rubber
0.85	0.70 = .82 × Peak	High Level of Polybutadiene (Commonly found on European winter tyres)

The ambient air temperature was 18°C.

SKID RESISTANCE OF ROADS

Research on skid resistance of roads started in Britain in 1927 at the National Physical Laboratory (NPL), and has been continued ever since by the Transport and Road Research Laboratory (TRRL) and various Highways and Local Authorities reporting to the TRRL. It was decided quite early on to concentrate on the tyre to wet road grip during the summer months with a normalised temperature of 20°C. For this was considered to be the most hazardous road condition.

The first skid resistance measurements on wet roads were carried out by mounting a smooth tyred wheel set at a considerable angle on the sidecar of a specially modified motor cycle and sidecar combination, and recording via a mechanical linkage system the vertical reaction between tyre and road, as well as the side thrust of the wheel.

Test speeds were moderate: 25km/h up to 50km/h. For higher speeds modified road cars were used in the 1950's, front wheel drive Citroens up to about 1967, followed in 1965 by Austin 1800 cars, in use until about 1972. These have since been replaced by specially designed tanker lorries carrying water. All of these 4 wheeled cars and trucks have one feature in common—a separate 5th wheel mounted inside the wheel base and set at an angle of 20° to the direction of travel. The smooth tyre is similar to that used on the original sidecar, but has a different rubber composition.

The first of these special SCRIM vehicles was commissioned in 1968 and several have been sold overseas. In addition to this, a special braking force trailer has been used to record locked wheel braking and peak braking effort at speeds up to 130km/h. The advantage is that standard production tyres can be used and compared against the smooth reference tyre. Similar trailer units are in use in various parts of the world to facilitate tyre development work. All the above test vehicles suffer to a greater or lesser extent from several defects. On heavily trafficked routes road surfaces can have marked undulations and hence the vertical loading on the test tyre is not constant. It will be influenced by the vehicle suspension dynamics and these will differ from one type of test vehicle to another and will change with age and general lack of maintenance of such vehicles, which are generally standing idle for many months every year. With age and exposure to ozone and strong light, rubber hardens and the tyre will tend to bounce up and down more. A bouncing wheel does not develop full side thrust (SFC).

HOW RELIABLE ARE THE TEST RESULTS?

In 1978 the TRRL reported that, following the introduction of the SCRIM trucks for routine skid resistance measurements on the highways, an increase in side force coefficient (S.F.C.) had been recorded on sections of road on which no resurfacing work had taken place. But before taking these at face value one must be certain that changes in the test equipment and its associated instrumentation, test methods, and procedures, as well as the characteristics of the reference vehicles have not introduced a shift of the datum line.

Average skid resistance throughout the UK had apparently increased by 19%, when comparing 1973 and 1974 test data with those of the preceding 10 years, and was 28% higher for the period 1975/76. The increase in SFC closely follows the progressive phasing out of the older test vehicles (2).

In order not to lose continuity of records the TRRL results from 1972 onwards have been "adjusted" to bring them into line with the earlier data. But others using the same equipment have not done so.

It is arguable that it might have been more sensible to correct the earlier TRRL results and thereby avoid the confusion which will inevitably occur when current research data emanating from many different sources are being compared.

It would also explain why some of the author's earlier test results, when investigating loss of control and steady state critical speed cases, were giving tyre to road adhesion

values about 25% higher than the TRRL's. The fact that tyre construction differs from one manufacturer to another and the inevitable change of properties with age and usage might account for difference in recorded values of around 10%—a fact that was not appreciated until the late 1970's.

The skid resistance of a tread rubber in contact with a normal road surface can conveniently be separated into four rubber properties:

1) adhesion, 2) deformation, 3) tearing and 4) abrasion.

All of these are quite obviously affected by the road surface condition: whether it is rigid, such as brushed concrete or well embedded stone chippings in a tarmac binder, or broken and with loose debris: whether the surface temperatures are high or low: whether the surfaces are dry, damp, rainsoaked, flooded, snow or slush covered, icy or coated with a traffic film of oil, dust and rubber debris. Above all the degree of polishing of the road stones exerts a major influence. This in turn is affected by traffic flow. Buses and trucks in particular tend to polish most road surfaces and thereby lower their wet grip.

STATE OF TYRES AS ACCIDENT CAUSATION

Surprisingly little reliable accident investigation information exists in the UK on the relationship between injury accident frequency and the state of the tyres before the accident, particularly the depth of tread and whether tread wear is even. What little information does exist is generally pre 1968, i.e., before the minimum tread depth regulations became mandatory in the UK.

The BRMA has commissioned in 1982 a Research Project with Birmingham University to correlate their On the Spot Accident Investigation Analysis with tyre conditions, tread depth and road surface conditions, particularly depth of water. This is probably the first serious in-depth investigation along these lines ever undertaken in the UK. The factual data from other countries are "patchy" or circumstantial.

CHANGES IN TYRE TREAD WEAR OVER THE PAST 10 YEARS

On crossply tyres, tread wear is generally fairly even across the full tread width, provided correct tyre pressure is maintained. Too high an inflation pressure results in pronounced crown wear. Insufficient tyre pressure results in wear on both shoulders. More wear on one shoulder, usually the outside shoulder on the front tyres, was indicative of suspension characteristics of many cars, due to marked camber changes. For rear engined rear wheel drive cars, like the old VW Beetle, it was pronounced shoulder wear on the rear tyres.

Since then many changes have taken place in both car suspension and tyre design. Practically all new car models have radial construction tyres, more and more of them with steel reinforcing belts. These are essentially nonextensible reinforcing belts laid over a carcass of textile reinforcing cords at an angle of about 87° to 90°, running from bead to bead.

For car tyres the bias angle at which the reinforcing belts run relative to the circumference is currently about 18° for each of the 2 steel belts in typical car tyres of the SR and the higher speed HR rating. It has been steadily decreasing from about 24° to 26° for some early radial tyres. The lower this bias angle, the quicker the response to steering input. But there are practical limitations to ever lower bias angles, for too low an angle (below 10°) makes a car's steering over sensitive and, under the influence of suspension movement over a normal road surface with some undulations, would result in a lowering of the straight line stability back to the 1930 to 1950 type crossply tyres, where the driver had to constantly correct the steering at anything above moderate speeds.

OTHER TYRE DESIGN CHANGES

There has been a steady trend in making winter tyres have more ruggedly knobbly groups of tread blocks standing well proud of the large open channels which separate one group from the next. For the summer tyre the ribbed design is being replaced by more open yet interlocking blocks.

In the past the land to void ratio, i.e., the ratio of area of rubber ribs or blocks in a normal dry road contact patch to that of grooves and channels not making contact with the road was of the order of 80:20; currently it is about 60:40.

The purpose is to ensure adequate drainage of surface water, even at relatively high motoring speeds, which is essential for safety in handling and braking. If water is not drained rapidly, then a wedge of water builds up in front of the contact patch and the dreaded floating off of the tyre, known as aquaplaning, takes place.

CHANGES OF FOOTPRINT WITH CHANGES OF TYRE ASPECT RATIO

On the normal type of car tyre with an aspect ratio of around 80, the "footprint" of a tyre on a dry road is about that of a man's shoe and significantly longer than its maximum width.

As the aspect ratio is reduced to 70, 65, 60, 55, or more, then a progressively flatter sportier appearance is produced. Such lower aspect ratio tyres may or may not have a greater load carrying capacity, but they certainly affect ride and handling, for they alter the steering geometry.

Above all their dry and wet road footprint changes. As aspect ratio is decreased, i.e., as the tyre becomes fatter, the "footprint" changes from an elongated ellipse with its major (greater length) axis in the fore and aft direction to one with its minor (shorter length) axis in the fore and aft direction. This is not a desirable feature, for it reduces the pneumatic trail, which provides the self aligning torque and good straight line stability. Very low aspect ratio tyres tend to make a car more "jittery"; also they frequently tend to be more easily affected by water on the road surface, following a heavy rainfall, and can be more prone to aquaplaning, and hence a potential loss of control.

Low aspect ratio tyres tend to be fitted to the more powerful versions of saloon and sports cars, which are frequently driven with more verve and at higher speeds than their lower specification humbler counterparts. The transition from just manageable, i.e., marginally safe, to unpredictable (in which neither braking nor steering effort properly control the car's intended progress) is often brief and sudden, when owners wishing to improve and customise their vehicles go further in their modifications than the vehicle manufacturers thought wise. This applies particularly to the jacking up of the rear end and fitting of larger diameter and/or wider tyres. It is a mistake to fit extra wide tyres, willy nilly, to standard production cars, and can make a fairly docile car into one that is only marginally safe on twisty, wet roads.

THE EFFECT OF SUSPENSION DESIGN CHANGES

On early independent suspension cars dynamic camber changes used to be quite considerable, of the order of 8°. This was the reason for the domed appearance of early tyres, including the first generation of steel belted radial tyres, which tended to be fairly narrow by modern standards. It also made the definition of effective tread width a bone of contention in legal actions, and this in turn is partly the reason for the current arguments in the UK about minimum legal tread depth.

In the intervening years the car manufacturers have effectively given a more level ride to their more recent models and greatly reduced the dynamic camber changes. This allows wider tyres, and squarer shouldered ones at that, to be fitted. The effect of this is safer braking and higher safe cornering speed limits.

WHY LONGER TYRE TREAD LIFE POSES NEW PROBLEMS

Modern steel belted car tyres are now lasting so long under normal operating conditions that they should be replaced on grounds of safety, before being worn down to the legal minimum tread depth.

Whereas crossply tyres tended to wear out in under 25,000km of normal motoring, it is nowadays not uncommon to achieve twice that on most quality steel belted radials before they are worn down to the legal limit of 1mm tread depth. With an ever increasing proportion of cars being front wheel drive, the rear tyres can achieve a remarkably low wear rate, at least on well designed cars, and can last for many years on relatively low annual mileage cars.

In contrast to the front ones, which have to provide the forces and moments to effect steering and power transmission, the rear ones tend to carry less than half the weight and are primarily trailing. If the suspension system is reasonably well chosen, then the sideways guidance forces and braking provided by the rear tyres should never be more than a fraction of what the front tyres are called upon to provide.

Whilst there are some notable exceptions to this rule, (in which the rear tyres wear out all too quickly, almost regardless of tyre brand selection), in the vast majority of modern designs the service life of rear tyres can be 1½ to 2 times that of the front ones—barring kerbing damage or undiagnosed punctures. It is therefore not uncommon to see cars in circulation with some 6 to 8 year old tyres.

AGEING EFFECT ON RUBBER TYRES

Both sidewall and tread rubber are likely to harden, craze and crack with age, exposure to oxygen, ozones, strong sunlight and high temperature.

Whilst quality tyres have small quantities of fairly costly additives to counter these effects, mixed in with the respective rubber compounds likely to be so affected, the majority of tyre manufacturers did not anticipate that a substantial number of their tyres would still be in regular use 6 to 8 years after manufacture. At the time of their manufacture average life expectancy was very much shorter. So some of these car tyres probably did not have sufficient special additives to remain supple for such a long life.

Synthetic and natural rubbers are generally so formulated that modern car tyres have a reasonable shelf life, under careful storage conditions, of 2 to 3 years, plus a normal in-service life of at least 2 years. During these 5 years a degree of leaching out of oil extender to the surface is to be expected and this will generally manifest itself in fine surface cracks and some hardening of the running surface.

It will also mean that there will then be a greater difference between dry and wet road grip than that found on new tyres. This can affect handling and braking response when motoring on roads which are dry one moment and wet the next, if one of the tyres fitted is old, whilst the others are relatively new. A similar problem can arise if one new tyre only is fitted, the remainder being 6 or 7 years old.

Age on its own is not the main criterion. The condition of storage affects shelf life and the normal cyclic loading of a tyre in use can have a fatiguing effect on the carcass, in particular the rubber bonding strength.

Tyres are on display in garage forecourts and special depots. In the ordinary open site garage forecourt the following may be present to a greater or lesser extent: high ambient temperature, rain or high humidity, ozone, strong sunlight, fuel and oil vapours. Warehouses are often poorly ventilated and very hot in summer. Whereas the tyre manufacturer may control storage to minimise age hardening effects, the subsequent links in the chain, from newly manufactured tyre to ultimate disposal of same, are generally less scrupulous. It is a case of not spending any money—if at all possible.

The same applies to tyre use. Many are run with indifferent, infrequent or no checks at all on correct tyre pressure maintenance (3). Once rubber has been degraded, however slightly, due to neglect, over temperature, excessive flexing, etc., it will never recover its designed properties, even though the tyre may recover its general shape.

THE EFFECT OF UNEVEN WEAR ON TYRE TO ROAD ADHESION

One of the purposes of our investigation was to test whether tyres with pronounced shoulder wear suffered from loss of grip and whether there was any correlation with increased hardness.

Dunlop and Karlsruhe University (2) have demonstrated that there is a considerable loss of braking performance of car tyres with pronounced shoulder wear, once roads have a film of water of 1mm or more.

For about ⅓ of the time roads in the UK are wet or rain soaked, though not necessarily always to the depth which would cause aquaplaning at speeds in excess of 80km/h. There is little doubt that car tyres with pronounced shoulder wear tend to lose grip in the wet when motoring briskly, both in braking and in cornering. But our tests, which confirmed this, also established that the same applies when cornering in the dry, though straight line braking was not affected.

We also established that there can be a noticeable difference in hardness across the tread width of unevenly worn tyres. It is somewhat academic to the motorist whether this apparent increase in hardness is really due to the influence of the steel belt being closer to the running surface or the partial exposure of undertread or edge strip rubber. There is not the same degree of resilience and flexibility on a shoulder worn down below about 1½mm of tread depth. Up to around 2½mm tread depth there is no apparent hardening effect, even on 7 year old tyres, over and above that due to age-hardening. However, at below 1mm tread depth the effective hardness is significantly higher than on the less worn rest of the tyre.

When motoring briskly, tread shoulders tend to "bite" into the road and are providing the majority of sideways force required for safe cornering. We found that under these dry road surface conditions, the harder the tread surface, the lower the sideways grip. When driving briskly, a car with one tyre with just legal tread depth or badly worn shoulder—whilst the remaining ones have a fairly uniform tread depth of at least 3mm—may show peculiar handling characteristics. It will tend to run wide on left hand bends, yet will follow a neutral path on right hand bends when the shoulder worn tyre is on the right front wheel. Rotating the tyre to different positions demonstrated that, whenever such a tyre was on the outside of the bend and had to provide the largest amount of sideways guidance force, it tended to slide sideways until a new state of equilibrium was established, in which the flatter crown provided the restoring force.

Whilst such design features as track width and wheel base, roll stiffness, spring and damper rates, play important roles, we found that a relatively narrow rim would aggravate the situation. For they allow the tyre wall to flex to the extent that practically 40% to 60% of the cornering force of a tyre is provided by the shoulder region.

Our road testing programme has not reached the state where we can give categoric advice where it would be best to fit a tyre with a badly worn shoulder, for it varies from make to make and possibly model to model. Such tyres should generally be considered to fall into the category of "Get You Home—Slowly" spare wheels and not be pressed into long distance high speed motoring.

ROOT CRACKING AND CORROSION OF STEEL BELTS

One ageing factor which tends to be ignored is cracking of the rubber in the root of tread blocks. As long as the remaining tread depth is still legal, few motorists will change their tyres. The cracking may be due to ozone attack, polymer migration, or mechanical working of the tread blocks causing local fatigue degradation, or a combination of these factors. Whatever the causes, the condition favours flint cuts penetrating right through to the top belt and thereby allowing ready ingress for moisture and corrosive salts. Corrosion of single strands of wire or larger areas of the steel belt will then follow.

Depending on the detail design of wires and their coverage with rubber during the processing stage of the steel belt (including the hollow centre of the bundle), it is possible for wire bundles to act as a wick. Then rusting out of wires may take place 150mm to 250mm away from the local penetration. Moreover, such penetrations, even if they go right through to the lower belt, will generally not result in loss of inflation pressure. On tubeless tyres, which make up the majority of tyre fitments, even a

penetration right through both belts may not cause anything more noticeable than a slight air loss. This can go unnoticed for days and weeks. Undiagnosed steel breaker weakness can manifest itself in breaker edge loosening, uneven wear, tyre creaking, vibration, and in some cases in total structural collapse (CBU), or tread strip.

FACTORS AFFECTING AGEING OF TYRES

The properties of tyres change with ageing and condition of storage. Research by B F Goodrich (7) has indicated that there are two phases of changes of physical properties—a slow one from the day of manufacture to about day 30, and another more pronounced one thereafter. Both generally cover the period before tyres reach the ultimate user, at least, in the UK. This is true for both OE equipment on new cars and replacement tyres sold through retail outlets.

The question arises whether tyre manufacturers have put sufficient anti-oxidant, anti-ozonant and general anti-ageing additives into the composition and blending of rubber compounds (particularly tyre tread compounds) to ensure suppleness, resilience and hysteresis to be unaffected by time, indifferent storage and subsequent usage.

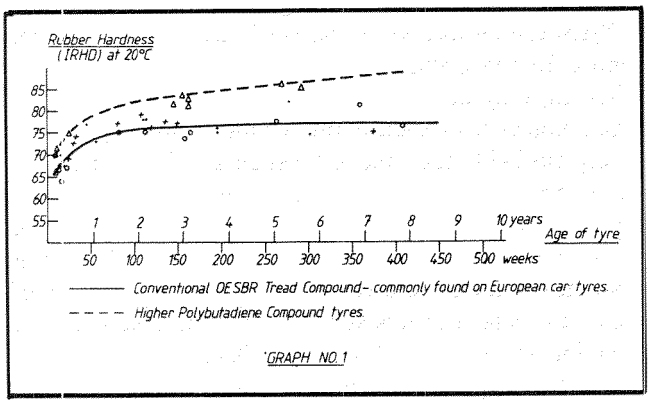
When assessing the age effects—particularly on hardness and elasticity—it is all too easy to forget that compound composition and processing details may well have changed over the years and that each new formulation is a compromise, with limited factory options to deviate from the original specification.

When we started on our investigations we were confident that one could establish a watershed type demarcation line, which would allow one to say that tyres over about 5 years old are age-expired and suspect on a variety of counts and should be discarded in the interest of road safety.

I am no longer convinced that such a clear demarcation line exists and yet feel that it is prudent to put a time limit on certain rubber based components, for the following reasons:

Rubber, unlike metal, is a material which, with time, gradually and progressively changes its elastic and other mechanical properties, including its strength of bond to metal or fabric. There may well be an undetected migration of oil extender polymer to the surface with consequent loss of resilience. In practical terms many 6 or 7 year old tyres will have become seriously age affected.

A convenient way of monitoring ageing effects for each brand of tyre is to record surface hardness in either Shore A or IRHD values against time lapsed since week of manufacture. We noticed a fairly rapid increase during the first few weeks and a very slow subsequent hardening at the rate of about ½° to 1° per annum for many of the fairly standard tread compounds with relatively little oil extenders, such as one having a 23% to 25% styrene co-polymer in high hysteresis styrene butadiene rubber. (See Graph No. 1).



GRAPH NO. 1

Tread rubbers containing a high level of polybutadiene or natural rubber tend to rise in hardness with age at about twice that rate. It is self evident that in order to establish absolute values one needs to have access to the production quality control records of a very substantial number of tyres of many different makes. One must take note of such details as changes in compound composition over the time span investigated, particularly percentage content of the various compound constituents, including oil extenders, particle size and type of carbon black used, sulphur and accelerator used, vulcanisation time and temperature.

We have no access to such company confidential, historical data and have therefore had to confine ourselves to noting typical trends, based on a statistically significant sample of new, part worn and well worn steel belted radial car tyres. We cannot comment in detail on the service and storage history of individual tyres, other than that all had been in regular use on cars just prior to our tests or had been inflated spares. However, we take the pragmatic view that ordinary motorists also have no such information to guide them.

THE EFFECT OF TEMPERATURE ON RUBBER PROPERTIES

It has long been appreciated by the rubber industry, though not by the general public, that heat is the enemy of rubber and that once a normal car tyre has been locally heated to around 100°C or above, even for a relatively short time only, it will lose many of its physical properties without a chance of recovery.

This affects in particular the bond strength of rubber to steel or textile fabric. When such heating does take place, although it may be below the original cure temperature of around 140°C, the desirable polysulphidic cross linking of the rubber polymers tends to break down

and changes to the weaker two or single sulphidic cross linking.

Cooling the tyre, generally, does not have such an irreversible and permanent weakening effect. Whereas it is not uncommon for grossly underinflated tyres to achieve local heat build up in excess of the bond strength of textile fibres embedded in a matter of minutes, i.e., after a relatively short distance run, few situations arise in the UK in which a tyre reaches such a low temperature as to approach the brittle impact fracture phase, where hitting a pothole might shatter it like glass.

All the same as temperatures drop below about 5°C, the resilience drops drastically in some tyres, particularly so in the tread compound, which gets significantly harder. In other rubber mixes this change is not so apparent. The selection of the polymer is critical, for it greatly affects the range of operating conditions at which the tyre will out-perform its competitors.

For over 15 years, or so, the trend in Europe has been to optimise wet grip without sacrificing tread wear. This has generally been achieved by high hysteresis rubbers of the Oil Extended SBR (Styrene Butadiene Co-polymer) type.

Such rubbers have a glass transition temperature, Tg, of around −55°C, at which temperature the rubber changes most rapidly from an elastic to a glassy state. All elastomers have such a transition stage. For the conventional tread rubber compounds the highest hysteresis occurs at about 30°C above the Tg value, falling drastically as rubber bulk temperature drops, and reaches zero at around Tg. As rubber temperature rises above Tg +30°C value, the hysteresis decreases fairly rapidly and then settles to a plateau.

Whereas many of the conventional SBR or OESBR tread compounds for summer tyres will be quite hard at below −12°C ambient conditions, the polybutadiene based ones and some of the natural rubber or polyisoprene type will still be pliable at −30°C, or even lower. It is important to remember that the majority of cars in the UK are left out in the open, rather than kept warm in a lock-up garage.

The average individual trip distance in the UK is under 5 miles. This is insufficient to warm up tyres on the critical first journey of the day to reach the reference tyre temperature of 20°C, or 38°C, which are convenient sets of laboratory conditions. It takes about 17 to 20 miles of normal motoring before radial tyre temperatures stabilise. For crossply tyres it may be nearer half that distance. On average the tyre temperature as measured in the tread grooves is 15°C to 20°C above the ambient air temperature. More aggressive motoring will result in doubling this increment. The extent to which one tyre warms up more than another under identical operating conditions depends on constructional details and selections of materials. The cooler a tyre runs, the lower its rolling resistance and hysteresis.

THE ALL WEATHER TYRE

The ideal of the true all weather car tyre, which can span all the operating and environmental conditions likely to be found in, say Western Europe, has not been achieved to date and probably will not be a commercially profitable venture. For it would be expected to be optimised for hot, dry road, long distance high speed motoring in Spain on the one hand and cold winter conditions in Scandinavia on the other, with a fair sprinkling of rain, snow, slush and water covered icy patches as well. These contradictory requirements would call for very costly rubber compounds to be chosen.

To achieve a reasonable compromise means sacrificing either wear or wet grip, or high speed durability. There are limits to what can be achieved by rubber compounding, carcass design and tread pattern changes. We may well have to accept a set of normal summer tyres suitable for most of the year and a set of winter M+S tyres having more aggressive looking, bolder tread blocks and above all a tread rubber compound which remains resilient even at very low temperatures.

At least this is a sound precaution for those owners who operate in Scotland and Northern England. Over the last 3 winters even the UK, particularly those areas exposed to North Easterly winds, experienced air and ground temperatures sufficiently low for diesel fuel to freeze in the fuel pipe lines and filters. It may be an occurrence which takes place only for a week or two, but it affects many people.

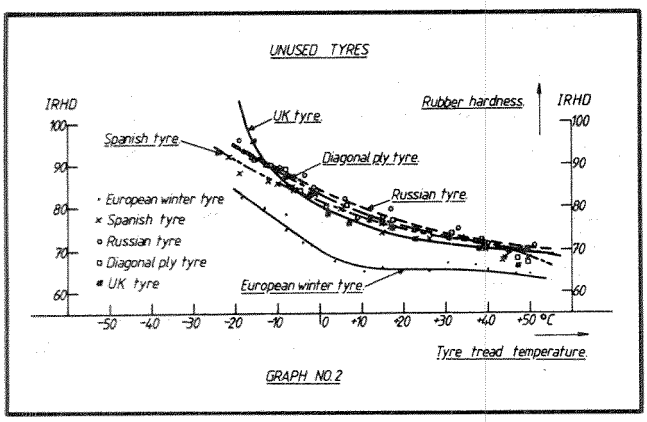
Because it is an infrequent occurrence in the UK—at least the −20°C winds sweeping across exposed major trunk roads—it tends to be ignored by motorists until they find themselves in a situation where progress is hazardous. Unawareness of what tyres can and cannot do in extreme conditions has led to some fatal accidents, which were, however, dismissed as "driver error" or misadventure.

TESTING OF TEMPERATURE EFFECTS ON TREAD RUBBER HARDNESS

When we compared the temperature effects on new, unused tyres with those that had been in service for a number of years, we noticed that there was more to it than could be explained by just considering the remaining depth of tread. Ordinary field service, age and mileage travelled, caused the older tyres to be significantly harder than the new ones when tested in the conditioning chamber (a large industrial oven-freezer at temperatures ranging from +50°C to −25°C. (See Graph No. 2).

For unused tyres we could see two basic patterns:

1. The high butadiene or part natural rubber polymer tread compounds found on several winter tyres of



GRAPH NO.2

different makes, had a basically softer compound, which retains its elasticity of around 65° IRHD (or Shore A) almost unaltered to about +3°C (i.e., from very high ambient down to black ice conditions) and then hardens progressively and fairly steeply with falling temperatures, reaching an IRHD value of 90° at about −25°C.

2. The hard wearing SBR tread summer tyres. These were harder at all temperatures and had a more gradual rise in hardness right from very high ambient conditions onwards. The hardness at about +3°C corresponds to that of the winter tyre compound at about −13°C. As rubber temperatures fall below freezing of water, a gradual divergence occurs, depending on polymer selection for specific markets. One tyre manufacturer's summer tyre compounds hardens to around 90° IRHD at about −12°C. At about −18°C to −20°C it reaches the value of 98°, which is equivalent to virtual total loss of tread compound elasticity, for it is almost the same as that of the steel belt underneath.

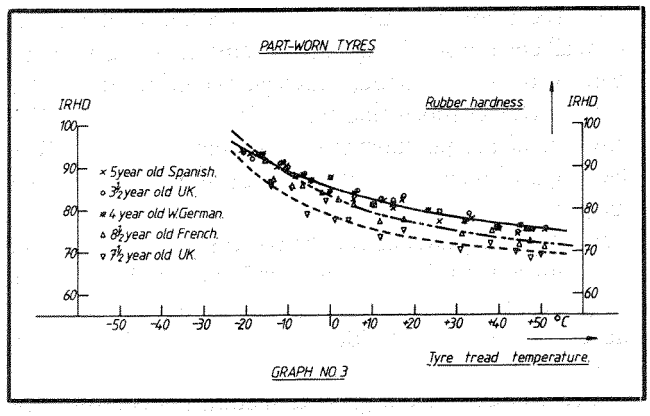
Yet a Spanish built tyre, which has to cater for some snow conditions in parts of Spain, will retain some compound elasticity to below −25°C. At temperatures below about −10°C the difference in hardness can become quite marked between these tyres—and so can their grip.

For comparison we also included a Russian steel belted radial tyre and a UK built crossply tyre. While generally harder they followed the same trend as the Spanish built steel belted tyre.

One of the most difficult areas of tyre grip research is concerned with snow and ice. The density and cohesion of snow can vary greatly and tread patterns suitable for fairly dry snow may tend to get clogged, once the heat from passing truck tyres has partly melted the snow into pronounced tracks or turned it into slush. Whereas really cold zones will have basically dry ice road surfaces, in the UK and many parts of Western Europe passing traffic will abrade and/or melt some of the thin ice covering.

The condition of a thin film of water on top of sheet ice is not easily reproducible in the laboratory. We, therefore, suggest that it is not possible to relate tread hardness values directly to tyre grip for ambient conditions below freezing of water. Other rubber properties become very important under these conditions. All the same, a very hard rubber would not be a desirable feature, nor should there be a great difference between tyre tread harness values on the 4 tyres fitted to a car.

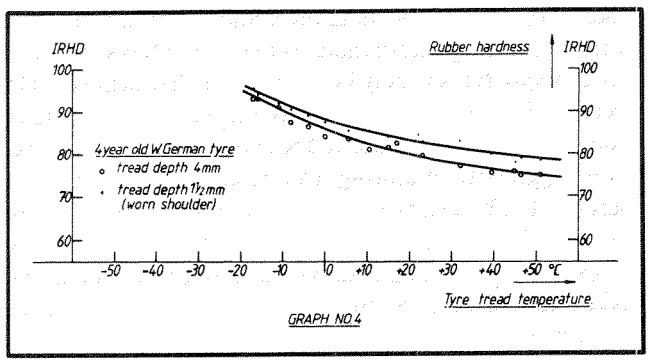
As far as part worn tyres are concerned, (See Graph No. 3), they follow the same general trend of hardening



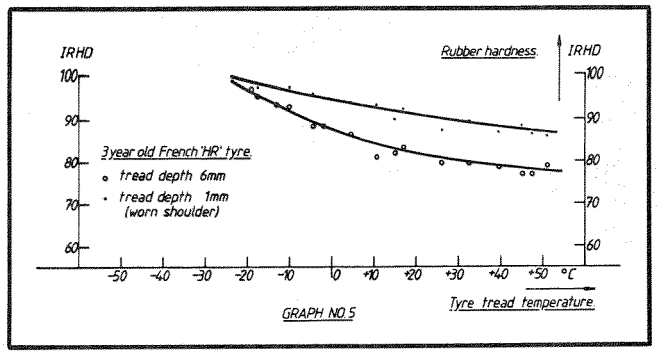
GRAPH NO.3

with a fall in rubber tread temperature. But there are two factors worth noting:

1. Depending on the age of the tyre and its tread rubber composition it may be several points harder at the 20°C reference temperature and maintain that difference over a fairly wide temperature range. At very low temperature the difference in hardness may be much less.
2. Where the shoulder is worn to below about 1½mm tread depth the effective hardness at such zones tends to be higher than that of the rest of the tyre tread, even for high ambient conditions. But as tread rubber temperature falls, the hardness difference between a shallow layer of rubber and a 4mm to 6mm depth of tread decreases, until at very low temperatures there is virtually none. (See Graph Nos. 4 and 5).



GRAPH NO.4



GRAPH NO.5

Regardless of age and rubber compound composition, any tyre which is harder than about 90° IRHD at the ambient conditions in which it has to operate, should be considered no longer suitable for regular use. It is really up to tyre manufacturers to specify what they consider to be the safe hardness number for their products before they are to be phased out. For there is the risk of incautious mixing of old, high hardness tyres with new softer ones.

A FATAL ACCIDENT CAUSED BY IMPROPER SELECTION OF TYRES

A typical case involved a medium sized saloon car, rear wheel drive with 3 different makes of tyres on its 4 wheels. The 25 year old driver decided to fit "knobblies"—old, part worn M+S type tyres to the front to get better steerability on the cold road surfaces in winter conditions of −15°C and, when one of them made rather too abrupt a contact with the kerb and split, fitted the spare wheel with its part worn (just legal) tread.

Cutting in and out, to overtake a line of slow moving vehicles, he reached a section of road which called for a more drastic change of direction, started to slide, braked and lost control altogether, finishing up in a broadside slice into a rigid steel post. The incident contains all the classic elements of an avoidable injury accident. There was a degree of almost reckless driving, over-confidence in the good grip of the winter tyre, a mismatch of tyre makes and types and a staggered junction layout calling for precise handling.

I feel certain that the tyre man who sold part worn winter tyres did not mention that they should always be used in pairs on the same axle and that having one "knobbly" and one almost bald tyre calls for "slow, get you home" motoring, and that in heavy braking one wheel would lock before the other, causing loss of directional stability. The likelihood is that the tyre fitter would not know any of this.

The difference in tread hardness was of the order of 15 points on the Shore A hardness scale at 20°C and at the −10°C operating conditions. A gross mismatch of tyre pressure across the axle (which would have been a clear breach of the traffic laws) would, most likely, not have had such dire consequences as the differences in effective tyre to road grip, for this was of the order of 20% to 25% for the odd mixture of tyres fitted. Yet neither the tyre fitter nor the driver were in breach of the UK Tyre Regulations.

COMBINED AGE AND TEMPERATURE EFFECTS ON RUBBER BONDED SUSPENSION ASSEMBLIES

On a particular range of UK built models, major suspension elements rely on rubber bonded to steel to provide both elastic support, dynamic damping of a wide range of random vibrations excited by the road unevenness, and a degree of axle location. In other words, the units must be capable of dealing with random forces in all 3 directions.

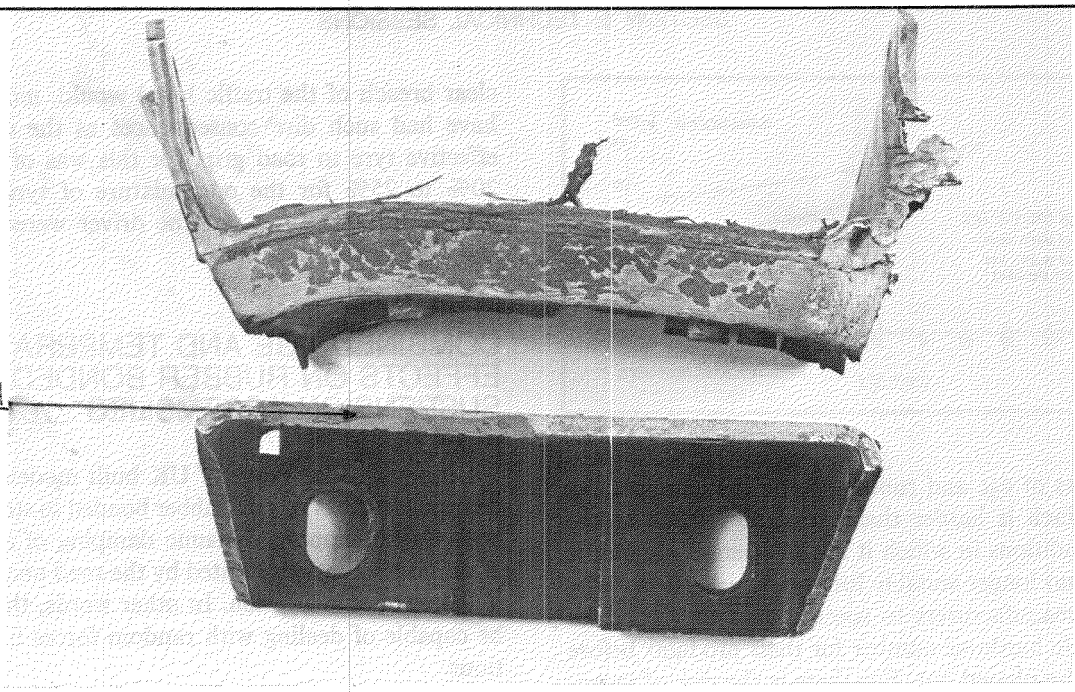
The field experience in countries which have abrupt and often dramatic temperature drops as winter approaches—in addition to very uneven road surfaces, leading to high flex loads—is that a high proportion of these suspension elements suffer from early collapse. In the case of one application it was due to escape of working fluid under high pressure. In another it resulted in a tear-out of rubber bonded mounts. Both types of failure usually occurred within the first winter period, whereas in the UK these elements were known to last for years and sometimes long after they exhibited signs of surface cracking of the rubber or even partial loss of adhesion to the steel component. (See Photograph Nos. 1 and 2).

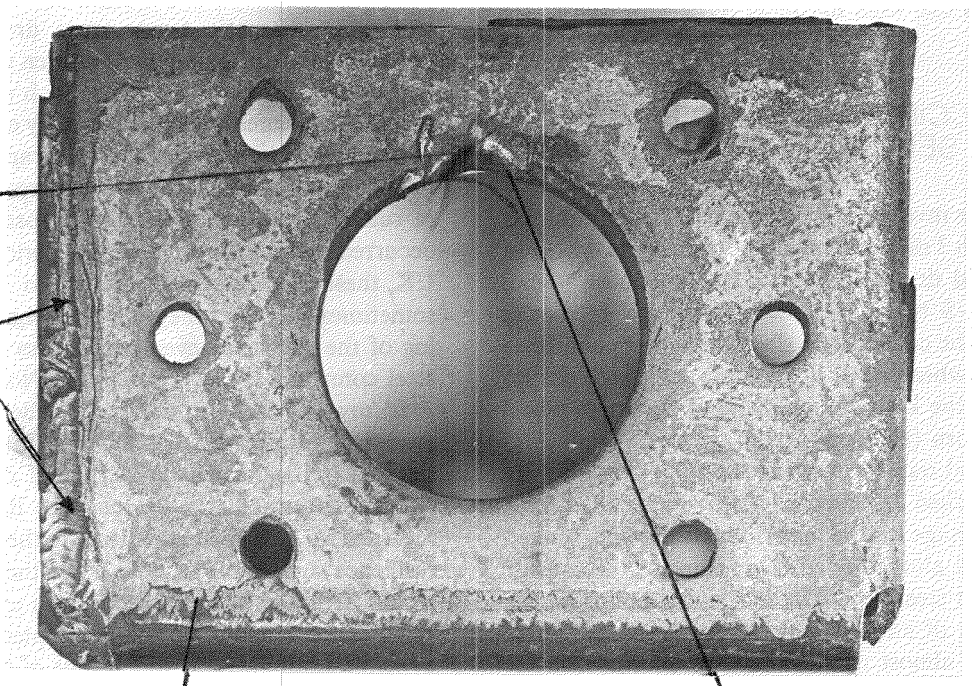
In my opinion, the designers, when selecting certain grades of rubber, did not make adequate allowance for the loss of mechanical properties of rubber at low temperatures, particularly the changes in resilience. When returned to the heated laboratory in the UK, the hardness, resilience and damping values of the companion units would be found adequate and up to specification.

As far as I know, no one attempted to carry out full dynamic testing over a wide range of temperature before the cars went on sale abroad. Apart from any other design changes which would reduce the suspension loading and dynamic deflection of the rubber part, two steps should have been taken:

1. A move toward a rubber compound capable of performing over a wider range of temperatures, including −20°C or even lower, and,
2. Ensuring a better rubber to metal bond than that of applying a chemical bonding cement straight on to the steel parts, for these had not always been meticulously cleaned of surface rust.

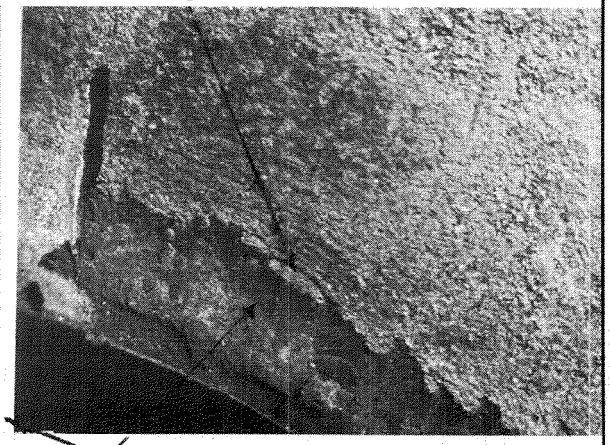
The required changes in material, metal surface preparation and bonding process might have cost a few pence per car, but failure to respond to the environmental pe-

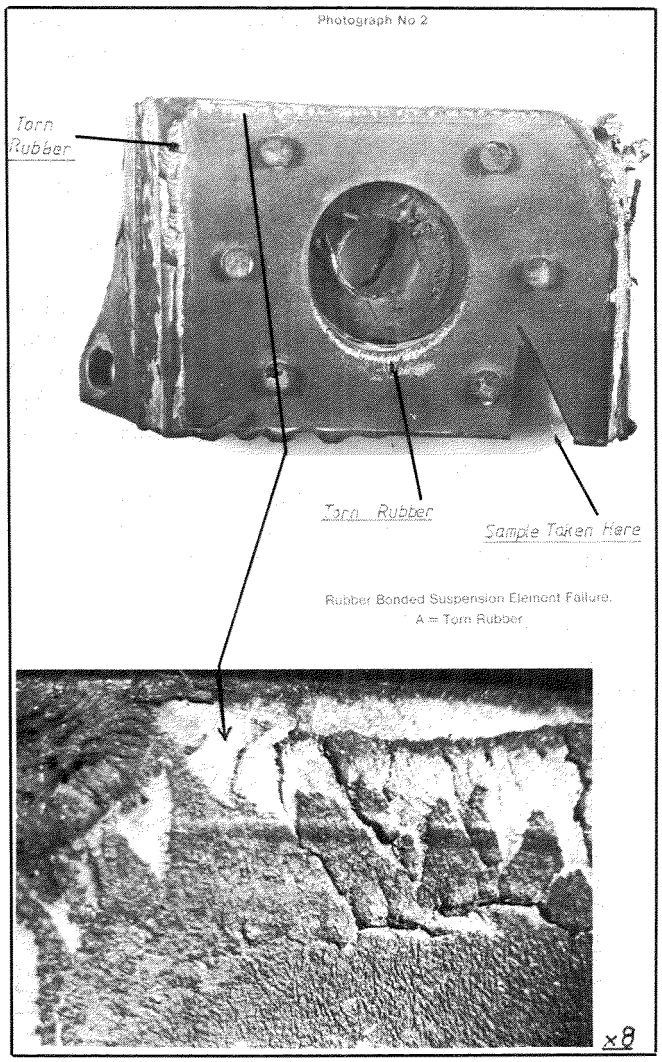




Photograph No 1

Suspension Mount Rubber Bond Failure
A = Metal
B = Impact damage
C = Rubber





culiarities of this and similar export markets have had far more costly consequences—the models have become unsaleable. Fortunately none of the failures which have come to my notice resulted in very serious injury accidents, though collapse of the suspension elements frequently caused loss of vehicle control and wrecked a number of cars and some street furniture.

CAR HANDLING OF OLD NEGLECTED CARS

There is such a wide divergence in car handling characteristics between individual makes and models, when relatively new, that it is perhaps relevant to ask the question: "Are old, badly rusted cars inevitably less safe than new vehicles?" Outward appearances can be quite misleading and, in our experience, whilst the safe handling limit of some cars falls rapidly with age and mileage, this need not be so for all designs. The analysis of 800 vehicle handling tests carried out by the Automobile Association in 1980-81 demonstrate this.

Handling tests were carried out on a well maintained Air Force Base runway, under conditions varying from dry and wind free to driving rain and gusty cross winds. The runway has good rain drainage and a high μ value for both dry and wet road surface conditions.

Whilst differing from ISO handling test procedures and such routine tests as are carried out by vehicle manufacturers, they tend to be more representative of accident avoidance manoeuvres involving sudden lane changes at speed. The relative, subjective rating of handling response and precision follows reasonably closely the pattern of real life narrow misses and collisions, as observed and reported to us.

The purpose of the tests on a representative range of current motor cars, of West and East European as well as North American origin, was to establish:

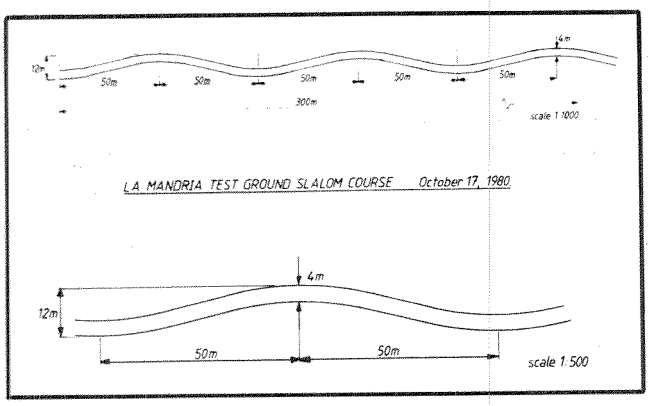
What the subjective limits of handling are, as experienced by different drivers.

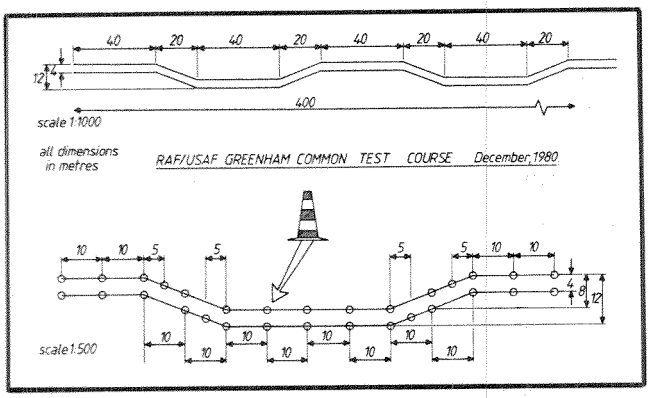
1. The extent to which these limits were related to the dynamic response of the vehicle's suspension, steering and general design characteristics such as weight, weight distribution fore and aft, steering gear, wheelbase to track width ratio, or tyre selection and tyre pressures.
2. Whether they were determined solely by the criterion of tyre to road grip, as determined by "μ" derived from locked wheel braking tests.
3. Whether safe handling at speed was predictable and repeatable in performance.
4. Whether, when the limits of handling were approached or exceeded, the vehicle could still be brought back into line by driver correction or was irretrievably lost.
5. Whether it is possible to compare cars on a "merit of forgiveness" rating.

"MERIT OF FORGIVENESS" RATING OF CARS

A good indication of the relative rating under this heading of one car compared to another is to measure the degree to which a cross section of drivers are able to regain control over the car after approaching, with excessive zeal or high speed, an unexpected road hazard such as sudden switching of traffic from one side of a motorway to the opposite one and back again in a very short distance. This is a more searching test than the Slalom, which many car manufacturers have adopted for car handling evaluation purposes. (See Sketch Nos. 3 and 4 showing the respective test courses.)

Vehicle handling characteristics cannot be adequately determined by one or two selected test parameters, and many papers have been presented to cover individual aspects of car handling (6, 7, 8, 9). This paper suggests another approach to establish transient input response.





The objective of our tests was to establish how vehicles behave under abrupt and severe lane change manoeuvres and how "safe" they were in the hands of a selection of drivers with markedly different driving styles.

Due note was also taken of the subjective comments by driver and front seat passengers and whether the progress was smooth or jerky. We tested 13 popular European and North American cars whose design concepts, size, power and weight span the range of vehicles in everyday use in large numbers in the period 1972-81. Six motorists who differ markedly one from another in driving experience, temperament, driving style, age and occupation, drove these cars. Five of them, at least, could be considered to be better than average, judging by their accident free motoring, ranging from 150,000 to over 1½ million km. The test against the clock (giving the fastest time) is not enough on its own. It clearly established the fact that the professional test driver consistently out-classed other drivers. It was more of a measure of the "merit rating" of the driver rather than that of the car.

With the much sharper change of direction which we employed, the course is made up of a section of short straights, which will induce most drivers to vary vehicle speed by alternately slowing down and accelerating. The smoothest and most experienced driver will vary his speed relatively little, the more ragged driver will tend to brake into corners and accelerate hard into the straight sections. In so doing he may well excite one or more vehicle system transient harmonics, in either suspension, steering, tyres, or even braking system. Whereas most moderately competent drivers can cope with steady state and hence constant conditions, they frequently get caught out by unforeseen, possibly unpredictable, transient behaviour of a car in a severe change of direction manoeuvre, then over-react, and loss of control follows shortly afterwards.

The course was laid out to test the real life combination of the driver and his vehicle in a situation which is not uncommon on multilane highways subject to periodic repair work on bridges or resurfacing.

The rise and fall for the length of the test course was modest, yet there was a difference in the way the road hazard presented itself to the driver. Approaching it on the downhill run, after coming up a gentle rise, he sees a maze of bright red and white cones and has to slow down from a normal high speed approach, to find where he is supposed to position his car, so as to progress quickly through the lane change sections.

Approaching it in the opposite direction, he not only finds the coned off section is almost upon him before he realises that it exists, but then discovers that there are more abrupt changes of direction to come, as he breasts the first slope and dips into the hollow.

In an effort to simplify the presentation of the complex interaction of driver and car, I have devised Table No. 1 on which the following are recorded against each test vehicle:

1. The principal factors which limit the maximum safe speed through the course.
2. The major driver reactions to the car.
3. The overall handling merit rating.

It can clearly be seen from this that in some makes and models severe rusting of the body structure, though not desirable, may *not* be a limiting factor and that, in common with several other models, safe speed through the course was determined by what grip the tyres could exert under the severe sideways loading caused by the rapid changes of direction. All drivers were agreed on this point. In all cases the ultimate handling limit was found to be a function of the initial design. Much to everyone's surprise tyre pressure settings, even deliberate gross mismatching, had less of an effect than the inbuilt basic vehicle handling characteristics. In some test runs there was momentary contact between road wheel rim and the road surface, and in others the tyres were folding under, due to sideways forces, making contact down to about half height of the tyre sidewall in the extreme handling manoeuvres. Screeching tyres and rapid tyre tread wear demonstrated just how severe some testing was. No ordinary driver would normally abuse his vehicle or his tyres to such a degree—he would generally tend to motor no faster than driver No. 6, the slowest of those who took part in the handling tests. In other words the sideways forces would tend to be nearer 0.4 to 0.5 times those generated by the professional test drivers.

Table No. 1.

Vehicle no.	Driver line layout	Optimum speed through lane change manoeuvre limited primarily by	Driver index of performance principal perceived driver reaction to test car						Overall driver performance
			(1)	(2)	(3)	(4)	(5)	(6)	
(1) Reference car	Conv rear engine	Reaching tyre to road adhesion limit	1	1	1+2	2	1+2	2	A
(2)		in-built suspension and steering characteristics. Tendency for rear end breakaway at limit.	2	2	2	2	NA	2	B
(3)	FWD	Reaching general vehicle handling limit. Tendency for front end breakaway at limit.	1+2	1+2	NA	2+5	NA	2	B
(4)	FWD	Reaching tyre adhesion limit and in-built vehicle handling characteristics. Tendency for rear end breakaway at limit.	1	2	1+2		NA	2	A
(5)	FWD		1	1	2	2+5	NA	1	B
(6)	Conv	In-built unwieldiness of handling. Rear end breakaway at limit.	2	2	3	NA	2	2+4	B to C
(7)	FWD	Suspension and steering design. Weak front end. Tendency of breakaway at front followed by rear end breakaway. Narrow wheel rims.	2	2	3+4	2+5	2+4	2+4	C
(8) 8½-year-old badly rusted estate car	Conv	Reaching tyre to road adhesion limit. Acceleration power limited by slightly sluggish power unit. Poor response to opening of throttle.	1	1	2	NA	NA	1	B to A
(9) 8-year-old badly rusted saloon car	Conv		1	1	2	2+5	NA	1	B
(10)	Conv	Reaching tyre to road adhesion limit. In-built unwieldiness of handling. Tendency for front end breakaway at limit.	1+2	1+2	2+4	2+5	2	2+4	C
(11)	Conv	In-built vehicle handling Characteristics and tyre to road adhesion limit. Tendency for rear end breakaway at limit.	NA	NA	NA	2+5	NA	NA	D
(12)	FWD	Serious unwieldiness of handling. Low tyre wall stiffness. Tendency for front end breakaway at limit.	NA	NA	NA	4+5	NA	NA	D
(13)	Conv	In-built vehicle handling characteristics. Steering design slow and heavy. Tendency for front end breakaway at limit due to lack of tyre to road adhesion	2+4	2+4	4	4+5	NA	NA	D Overall handling merit rating of car

Where (1) = No handling problems experienced when motoring briskly, right from start.
(2) = No handling problems experienced after familiarisation with vehicle.
(3) = Individual's best limited by lack of high speed road testing experience.
(4) = Driver generally apprehensive of vehicle characteristics.
(5) = Erratic behaviour.
NA = No tested.

Handling Merit Ratings:
A Above Average
B Average
C Below Average
D Disappointing

Extensive tests by Daimler Benz, VW, Volvo, GM, and others, including those conducted by myself and my staff, have clearly established that the average sideways force acceleration which motorists will accept as tolerable is around 0.3g (about 3m/sec/sec), for moderately fast drivers it is around 0.4g (about 4m/sec/sec), and 0.45g (about 4½m/sec/sec) for the spirited, more sporty drivers.

Similarly acceleration on the flat in excess of 0.15g (about 1½m/sec/sec) is rarely used by the average driver travelling at around 40mph, it can be 0.25g (about 2.5m/sec/sec) for the more sporty one, but it requires a responsive and sports car type power unit to be able to achieve much in excess of 0.3g (about 3m/sec/sec) acceleration.

Deceleration during braking is around 0.2g (about 2m/sec/sec) for check braking, 0.3g (about 3m/sec/sec) for moderate braking, 0.4g (about 4m/sec/sec) to 0.5g (about 5m/sec/sec) for hard braking. By the time the average motorist has pushed the pedal so hard as to achieve full lock braking on all four wheels, he may be about to start sliding out of control, having lost all ability to steer out of harm's way.

Table No. 2 clearly shows that the transient sideways acceleration figures achieved without loss of control were quite high.

In all the many tests we carried out, the heavily rusted 8 year old Italian built cars demonstrated superior accident avoidance performance potential to the US built ones of recent manufacture, regardless of any individual driver's characteristic style of motoring, (as can be seen from Tables Nos. 1 and 2).

RUST DEGRADATION AND ITS EFFECT ON CAR SAFETY

There can be little doubt that corrosion can affect primary safety and the crunch strength of the passenger safety cell. Corrosion is an ever present degradation factor, which ultimately will cause vehicles to be scrapped off. Body corrosion is an almost inevitable fate, though most manufacturers try to delay its onset for a number of years. But, provided the manufacturers ensure that the important sections retain their strength for about 10 years, the effect of corrosion of the structure on both primary and secondary safety may not be as serious as a casual inspection for obvious signs of rust might suggest.

THE MANUFACTURER'S RESPONSIBILITY

It is not impossible to see where, in a particular design and construction, corrosion is likely to arise to a significant degree after five to seven years' normal usage in the UK and many other parts of the world. The UK ranks high amongst the most corrosively aggressive zones and is not far behind the Snow Belt zones of North America. It is significantly worse in that respect than most of Scandinavia, Germany, France, Italy, Eastern Europe and Japan. Whereas the emphasis has for many years been on retaining the skin deep cosmetic appeal, for this is most readily perceived by purchasers in monetary terms, the underbody structure is more deserving of attention.

Designers, stylists and product planning engineers should look more closely at comparable vehicles of their own and competitors' makes after these have been in service for about 5 years in these corrosively aggressive environments, rather than put all their trust in accelerated corrosion test results. For it must not be forgotten that in most accelerated tests the following features are absent: mud, and dirt packing and 'breathing' of joints and assemblies under dynamic loading in everyday motoring.

These allow mud, dirt and dust particles to erode away thin anti-corrosive layers at or close to spot-welds, then leave the steel unprotected against further attack.

Also important are the nature and concentration of those dirt packs. These may contain not only aggressive rock salt but also highly alkaline or acidic dust, the result of road building or abrasive surface wear, as well as chemical spray deposits due to agricultural pesticides, which varies from one part of the country to another. It is these dirt poultices which do the major corrosive weakening, and yet they are largely absent in the standardised accelerated test.

Some of these dirt and mud poultices have been found even inside nominally closed sections of spot-welded sheet steel, such as body sills, underbody stiffener cross members and underbody panel seams. Once established, they are difficult to dislodge.

In general terms, the more parts are spot-welded together to form the major stress bearing sub units, the greater is the risk of corrosion weakening as the car ages. No commercial process used in the mass production of steel bodied cars *fully* protects the immediate zone close to the spot-weld against eventual corrosion attack. Some of the proprietary wax or petroleum materials injected into hollow sections go a long way towards slowing down the degradation process. They do, however, require periodic inspection and re-application.

STRUCTURAL CORROSION

The deterioration of the structure of the car due to rust can play as important a role in the aggravation of accident injuries as, for instance, the deterioration of steering and suspension elements, or poorly maintained brakes, both of which may have been major contributory factors to causing the accident in the first instance.

In order to get a proper appreciation of the effects of corrosion, it is important to compare, as far as possible, like with like, namely similar types of accident, about the

Table 2. Peak lateral acceleration of vehicles achieved by different drivers.

Car no.	Road surface condition	1	2	3	4	5	6
(1)	dry	0.82g	0.73g	0.65g	0.65g	0.63g	0.35g
	wet			0.59g			
(2)	dry	0.82g	0.80g	0.62g	0.75g	—	0.33g
	wet	0.80g	0.72g	0.58g			
(3)	dry	0.82g	0.73g	—	0.70g	—	0.35g
(4)	dry	0.82g	0.81g	0.71g	—	—	0.39g
(5)	wet	0.75g	0.70g	0.62g	0.70g	—	0.31g
(6)	dry	0.75g	0.68g	0.63g	—	0.58g	0.29g
(7)	dry	0.72g	0.65g	0.55g	0.65g	0.55g	
	wet			0.47g			0.33g
(8)	dry	0.72g	0.71g	0.55g	0.70g	—	0.35g
(9)	dry	0.68g	0.67g	0.55g	—	—	—
(10)	dry	0.68g	0.65g	0.52g	0.54g	0.55g	
	wet			0.45g			0.23g
(11)	dry	—	—	—	0.45g	—	—
(12)	dry	—	—	—	0.50g	—	—
(13)	wet	0.63g	0.56g	0.42g	0.55g	—	—

same impacting speeds and relative masses of the vehicles involved. I eliminated high speed collisions of such a severity as would inevitably cause fatal injury, regardless of whether the vehicle was badly corroded or not. For it is neither practicable nor desirable to make cars so strong that they will survive very high speed collisions. The occupants could not survive the sudden deceleration.

Relatively little published information exists about the effect corrosion has on structural safety, the integrity of the car occupant safety cell and the level of injury sustained by occupants (10). Corrosion is an emotive issue and not easily quantifiable. Many accident investigators would quite understandably conclude, after examining a mangled wreck showing several rust affected sheet metal panels, that the corrosion degradation must have increased the peak loading on the seat belt constrained human body and therefore added to the injury severity. This need not be so. To begin with, one must clearly differentiate between frontal and side impacts, rear end shunts and rollovers.

In a collision, the progressive collapse of the body shell under impact dissipates a major proportion of the kinetic energy and the elastic deformation accounts for relatively little. A controlled collapse in a front or rear end impact can often be beneficial to the occupants, for it would tend to lower the numerical peak value and suddenness of the deceleration of the head. In certain structures rust can produce just such a softening of the blow, due to the reduced strength and hence different crunch resistance. But it frequently results in greater intrusion into the passenger space of steering wheel and steering column and possible chest injury.

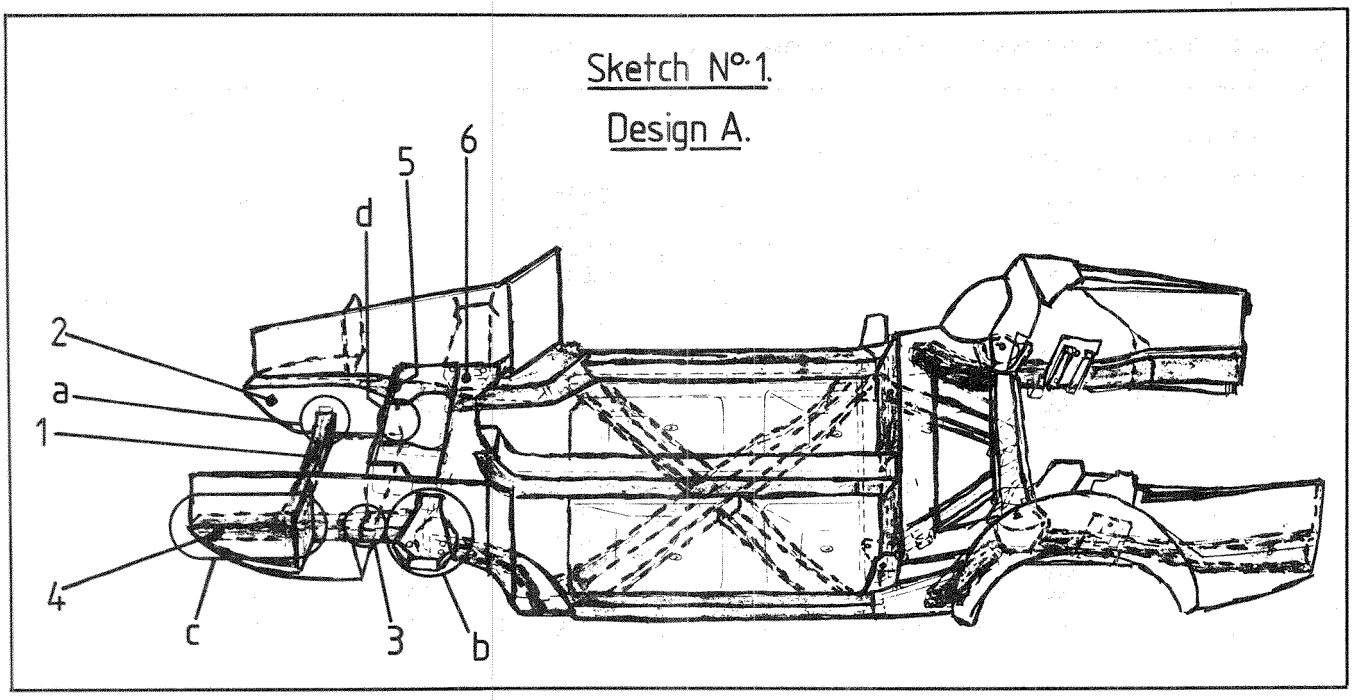
In the case of side impacts, the deep penetration of the impacting vehicle into the survival space may in a large measure be due to corrosion weakening of the body structure. In a rollover, the absence of corrosion at the upper and lower junction of the pillars to floorpan and sill, as well as to the roof and roll over bars, gives the occupants a much better chance of escaping with a low level of injuries.

No proper yardstick exists as yet by which to measure and assess the degree of corrosion degradation. For severe rusting in a front wing may look very serious, but has only a negligible influence on the crunch resistance in a frontal impact. A bitumastic anti-corrosion compound liberally applied to the underside of the floorpan may disguise the fact that the coating has cracked with age and allowed corrosive salts and moisture unsuspectedly to do their worst. In a side impact—particularly one where the impacting vehicle strikes the rust affected car *not* at right angles, but rather at an angle of between 50° to 70° to the longitudinal axis—this may be a very different matter, for it could result in the floorpan tearing apart and offering very little crunch resistance.

FRONTAL COLLISION

The location, relative to the occupants, of the major masses, such as, power unit, transmission, wheels and tyres, fuel tank, spare wheel, are of major significance. In a frontal collision a transversely mounted front-wheel-drive power unit, the engine, transmission, drive shafts, wheels and tyres will tend to be pushed back into the wheel arch/bulkhead zone (where they will jam in tight), more or less as one concentrated mass.

The effect of advanced body and structural corrosion, whilst it may manifest itself in the suspension and power unit attachment points being pulled out, will not generally alter the collapse mode by more than about 10% to 15%



further intrusion into the occupant safety cell. In a number of designs it is much less. Steering columns, however, may not collapse in the mode they demonstrated in the Black Duffy test, which is accepted as the International norm.

Re-arranging the power units into one mounted longitudinally, but still with front-wheel-drive, will alter the mode of failure, for the major mass can then be pushed farther into the front seat survival space, by tearing away the rust weakened bulkhead and underfloor sheet steel sections.

In the conventional layout, power unit mounted in the front and rear-wheel-drive, the degree of intrusion generally tends to be greater than in a transversely mounted front-wheel-drive arrangement. But in modern designs the remaining stiffness and strength of even a badly rusted affected transmission tunnel would tend to prevent intrusion of the propeller shaft. Moreover, in many instances, though the underfloor will buckle upwards and even where seat runners fail under impact, the gearbox, in being pushed back, will also deflect downwards. In every case we have studied, the mode of failure was determined by the *initial* design, rather than subsequent rust weakening.

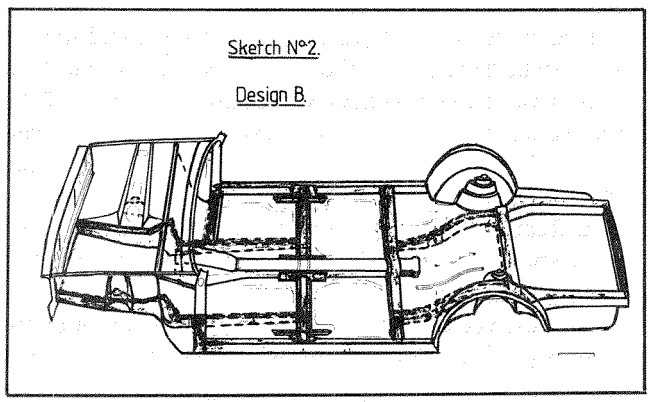
This is a bonus, for it allows one to anticipate, to a great extent, collapse failure modes of age deteriorated, rust affected cars from the measurements of progressive collapse, under hydraulic pressure, in crunch tests of factory new cars and their major body structures.

FLOORPAN CORROSION

As far as frontal, oblique and side impacts are concerned, the effect of floorpan corrosion is most noticeable overall in flat floorpan designs, to which the seat runners are attached by two bolts each.

In a previous analysis (10) the author drew attention to the loss of strength caused by severe underfloor and/or body sill corrosion in small, old cars, and reported on experiments carried out to simulate the type of collision commonly found at road intersections. The seats tended quite readily to tear out of the underfloor and their runners. Where the seat arrangement is such that there is a strong seat support structure, and general underfloor reinforcement, this risk of aggravated injury due to corrosion is small. But the vast majority of European and Japanese car models in daily circulation do not have such an arrangement.

Notable exceptions in the popular and low priced car category are the obsolescent Fiat 124 and their East European derivatives, the Renault 9, several quality cars and, of course, the RSV's of Renault, Peugeot and VW shown at various ESV Conferences from about 1978 on-



wards. But such arrangements add weight and cost. Essentially they constitute a redundant design.

As the primary structural part begins to collapse under overload conditions, the secondary or redundant member progressively takes up this load and acts as a load sharing device. Overload can be due to a sudden shock load or be brought into play by the structural weakening of the part due to corrosion.

CORROSION WEAKENING OF SUSPENSION MOUNTS

Although there have been recent Safety Recalls of actual suspension elements following unexpected failure due to corrosion of welded joints, the real risk is greatest on those attachment points which are difficult to inspect, namely those in the body structure itself.

Since about 1973 we have taken a keen interest in corrosion weakening of suspension mounts and the effect on primary safety, namely the ease of carrying out accident avoidance manoeuvres and predictable and controlled braking.

More than one manufacturer has experienced partial filling of boxed section with moisture, road splash, dirt and corrosive salts. We have on record a number of sudden failures of such closed sections. Where these were the chassis anchorage into which a torsion bar is inserted, it simply meant that the car sat down in the road like an obstinate, overloaded mule. Similarly the collapse of the dome shaped upper spring mount of MacPherson front struts rarely occurred whilst motoring at speed. They were preceded by corrosion. Final failure occurred after the tyre struck a pothole or badly repaired section of road or at roundabouts, when a change of direction put more load on one wheel than its companion.

Adopting a degree of redundancy into the front suspension design reduces the risk of sudden loss of handling control and inability to move the car. It is fairly easy to achieve on double wishbone designs with a strong, stiff cross beam which serves also as engine support and often incorporates a support turret for the telescopic damper. For, although they have been largely superseded by lighter construction, such redundant designs had some advantages. They could still function satisfactorily after partial or total collapse of sections of the redundant structure.

Some manufacturers have adhered to the concept of ladder frame or very strong subframes with suspension and steering attachment brackets welded or brazed on, in contrast to the light weight construction, which favours multi-spotwelds.

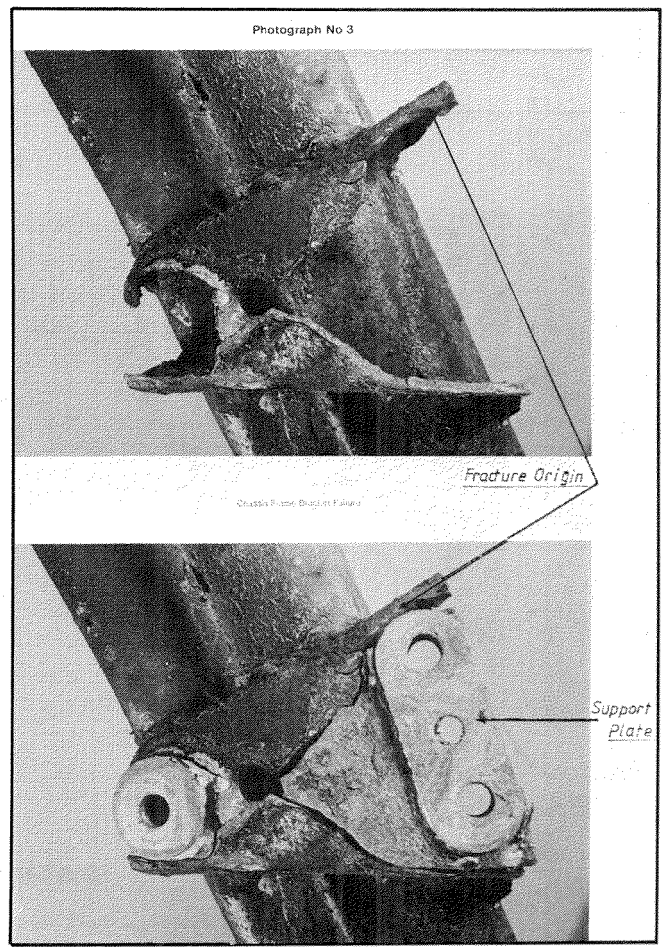
Corrosion of chassis frame members is not uncommon, and where mild steel pressing brackets for suspension or steering attachments are brazed on, there is always the risk of combined corrosion and stress fatigue weakening the joint to the point of sudden failure whilst manoeuvering.

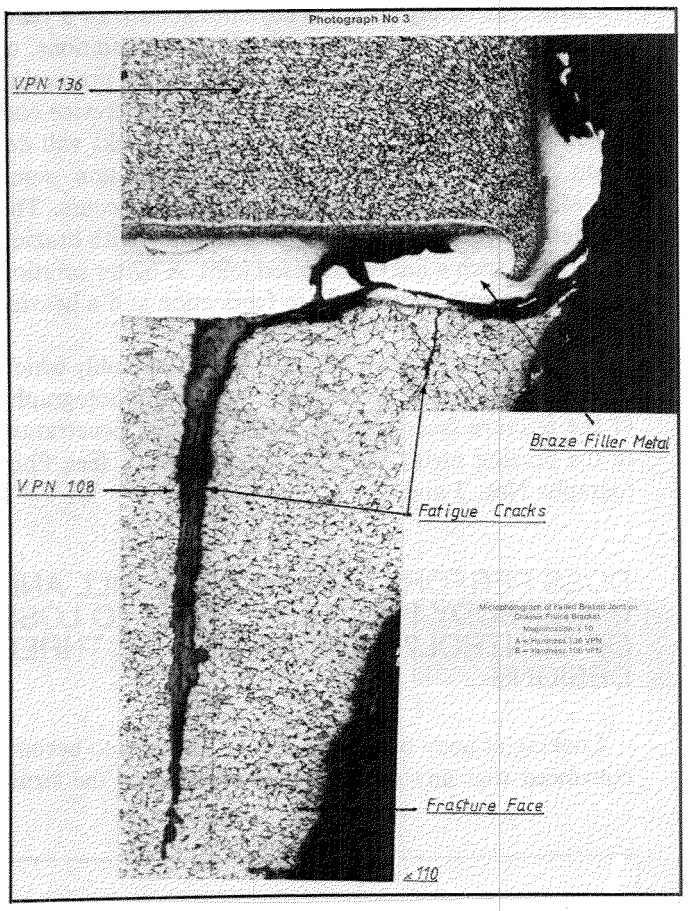
Failures generally do not occur until about 7 or 8 years of normal service. Under severe operating conditions, or in areas where liberal application of corrosion promoting de-icing salts is common, the propagation of crevice corrosion can be more rapid and significant cracks will develop undetected by normal visual inspection some considerable time before a dramatic failure occurs. The problem is aggravated by only partial filling with brazing material of such a heavily stressed joint. A better solution would have been a shielded arc fabrication and a heavier section bracket.

The photographs show a typical brazed assembly which failed after 9 years of gentle motoring. Microphotographs of the fracture faces indicate lack of proper penetration of the brazing metal and long fatigue cracks. (See Photographs Nos. 3 and 4).

DOES PERFORATION OF BODY SILL AND UNDERBODY INEVITABLY LEAD TO LOSS OF CONTROL? COMPARISON OF THREE DESIGNS

Looking at body corrosion, it is all too easy to become convinced that any significant perforation of the struc-

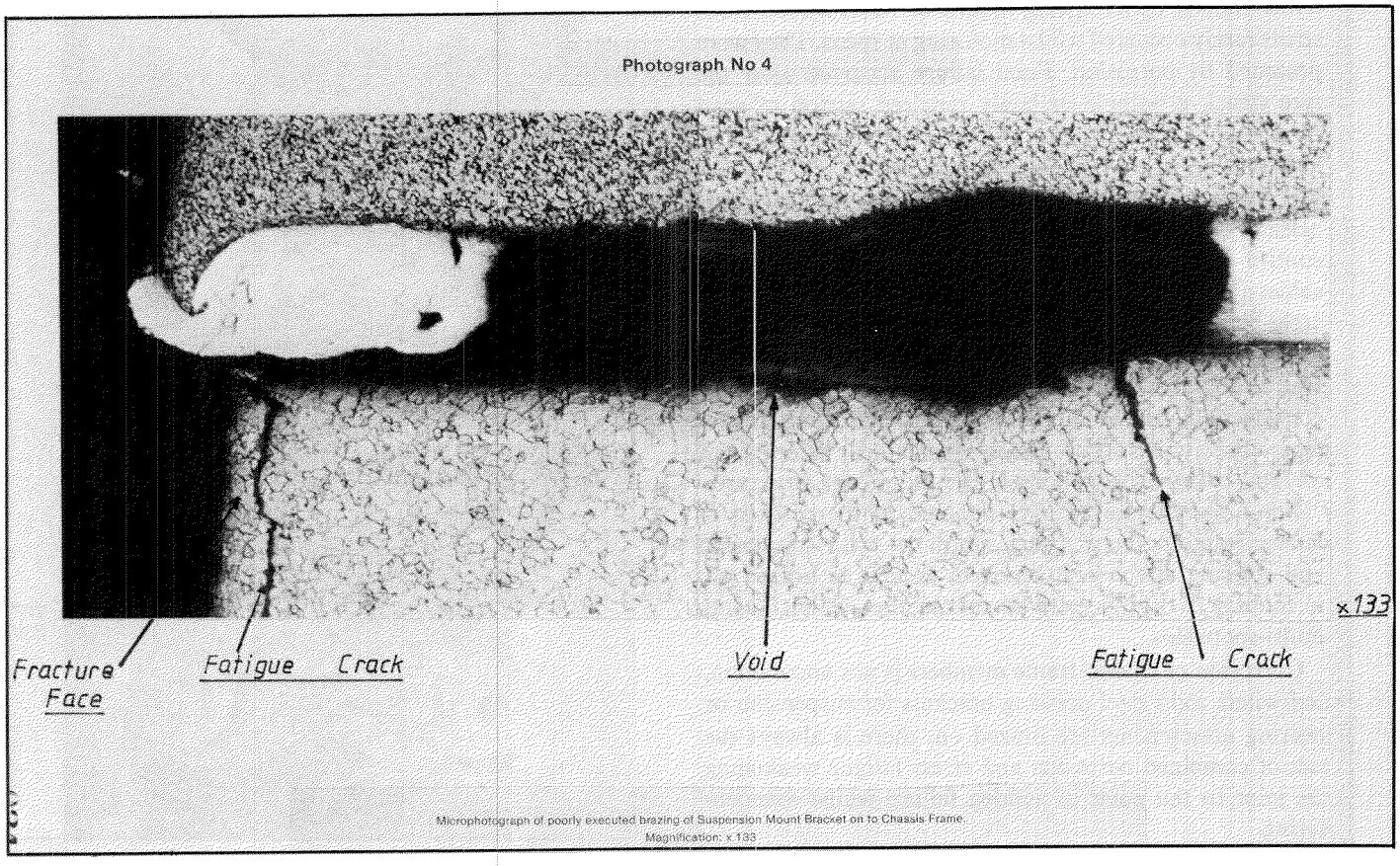




tural components which make up the underbody, particularly those to which the running gear is attached, will inevitably lead to loss of control incidents, aggravated injury levels in accidents, etc.

Yet on a number of makes and models this is patently not true. Perhaps it is easier to demonstrate that on two typical underbody and running gear design concepts: Both are unitary bodies (See Sketches 1 and 2), a construction with reinforcing pressings, added to stiffen and strengthen the under floor and suspension and steering reaction members. In both designs there is a raised floor tunnel to reduce boom and generally stiffen the structure, although the power unit in one design (A) may be mounted in the front or rear and drive could be either through the front or rear wheels. Yet, with this floorpan arrangement, it only requires the closed section welded-in crossmember (1) to become seriously rust affected, holed or detached from the side frame (2) or corrosion weakening at the weld joint (3) of the front extension of the longitudinal frame member (4) for handling control to be irrecoverably lost in a rapid lane change manoeuvre, for there will then be inadequate control of the high transient lateral forces generated. The stiffening section of the bulkhead (5) is too flimsy and offers no proper constraint at the front end of front compartment (6).

Severe corrosion along any one or all of the rust prone zones (a), (b), (c), and (d) will seriously impair handling of the car. If the welds (3) show signs of corrosion or



cracking, very major repairs are called for, the cost of which would often exceed the residual value of the car.

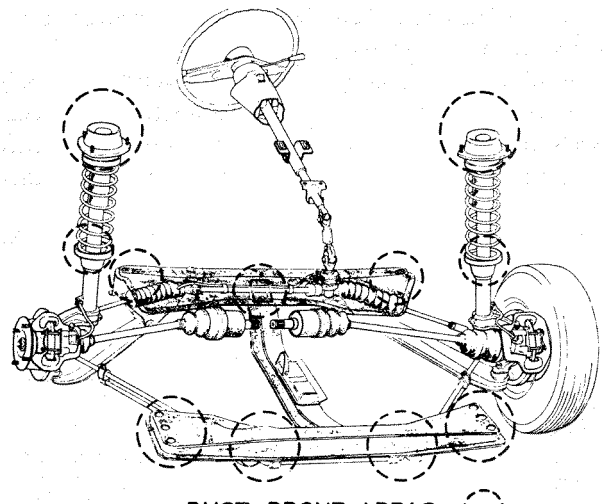
Frontal or oblique frontal impact of such cars in their heavily corroded state will result in a significant increase in steering column rearward intrusion and consequential high loading of the driver's rib cage, for the progressive collapse of the jointed steering column, can only take place as long as there is sufficient strength left in the bulkhead and its attachment to the rest of the front-end structure to act as a reaction member to the force applied on the steering wheel rim. The various floorpan stiffeners even in their heavily corroded state have been found to give a measure of protection against deep intrusion in side impacts. It is certainly an improvement over the basically very flat slightly corrugated floor pan without such reinforcement, which is frequently found in front wheel drive layouts.

The rear compartment, which has well reinforced anchorages for the trailing arm rear suspension and a strong open-channel cross member to tie the longitudinal frame members together, will generally retain its structural strength and cohesion, even though severe rusting has set in.

In design B due to the presence of a strong separate crossmember (not shown in the sketch), to which the double wishbone suspension is attached, one can tolerate a considerable amount of corrosion weakening of the rebound support without it having a marked effect on safe handling. This contrasts markedly with the effect on directional control and safe braking if a MacPherson strut mount in the reinforced inner wing section or its associated dome is badly corroded. In efforts to achieve weight reduction of vehicles several manufacturers may be sacrificing long life durability of vital body structures.

Sketch N°.3.

Design C.



RUST PRONE AREAS:-

Subframe for power unit and suspension.

DESIGN C (See Sketch No. 3)

In cars which incorporate subframe cradles for power unit and suspension and brake elements, the two critical zones are the attachment points to the body shell structure and the closed or semi-closed sections of the subframe itself. Both are liable to corrosion weakening with age, which can be quite serious after 4 to 5 years if anti-rust protection at the manufacturing stage has not been of a sufficiently high standard.

Wholesale safety recalls have had to be agreed on by several manufacturers. In quite a substantial number of cars rust affected in these zones the cost of rectification has been prohibitive, for there is no easy way to strengthen light weight structures once inside-out corrosion has taken place.

FRONTAL CRASH TESTS ON HEAVILY CORRODED CARS

Since the vast majority of injury accidents are frontal collisions, we welcomed the opportunity of submitting some very heavily corroded cars to barrier crash and seat belt anchorage pull out tests. Instrumentation was in accordance with SAE J211b. All tests were carried out at one of Europe's best equipped Auto Safety Centres. Despite their advanced state of corrosion and gross lack of maintenance the 4 cars were fully driveable prior to the destructive tests and had been in regular use in New York State. They performed adequately on the test course, over the Belgian Pave track, on the hill climb sections, including sharp bends, hairpin turns, on both permanent surface and loose gravel.

Two out of the four cars were then submitted to a series of structural tests, which were carried out in strict conformity with the current US Vehicle Safety Regulations—in particular US Standard FMVSS 210 and the 48km/h vehicle frontal crash into a standard concrete block, FMVSS 208.

The mode of failure of the front seat belt attachments under static traction, applied by hydraulic jacks, was pull-out at a level 57% on one and 80% on the other *above* that specified for passing the FMVSS 210 test. This high level was achieved because there was no corrosion degradation of strength of the anchorage points. In several other makes, where the attachment points were located in more corrosion prone areas, tear out occurred well below the stipulated FMVSS 210 level.

Even in its severely rusted state, the 8 year old saloon car gave occupant protection, which compares well with current motor cars of other manufacture, and is superior to many European cars in their factory new state manufactured and tested around 1972/74.

For the 8 year old models were of a strong, robust construction, with a degree of redundancy in design, which gave very good occupant protection, even though some considerable corrosion weakening was present, as indicated in Appendix 'B'. Collapse under frontal impact against the crash barrier at 48km/h gave a better "ride down" to the occupants than those recorded on similar tests carried out on factory new cars 8 years and 6 years earlier. No major model changes had occurred between these 3 tests. They were thus directly comparable one with another. A better "ride down" means less of an abrupt jolt to the occupants, in case of a frontal crash, and manifests itself in different plots of deceleration of the safety cell of the passenger compartment and its occupants versus time.

There are 2 phases of vehicle shortening under impact: An elastic and a plastic one. The elastic one causes the car to rebound after 60 to 90 milliseconds.

The extent of recoil is an indirect measure of how much of the kinetic energy is being dissipated by the physical crunch of the vehicle structure. The dynamic (elastic) shortening is always greater than the plastic one, for the car body acts as a complex mass and spring system, is fully compressed during peak vehicle deceleration after impact, which usually occurs around 50 milliseconds after initial contact, and then slightly expands again to its final crushed shape. For most modern cars of unitary construction the dynamic shortening of the body exceeds the static (permanent plastic) one by about 20%.

In the case of the heavily corroded ones the difference was nearer 12%, indicating that there was little structural resilience left in the corroded sections, particularly the wing and engine compartment.

CONCLUSIONS

There may be a need to revise the long held view that there is little that should be done to check on the mechanical reliability of cars in regular use. For it is argued, based on fairly old injury accident statistics, that mechanical failures play only a minor role in bringing about an accident and that in any case MOT type vehicle safety checks should spot most of these potential vehicle safety risks.

Much of the data on which these Official Views are based have been overtaken by technical developments. This applies in particular to tyres, which tended to have about ½ to ⅓ of the current service life. Old tyres, which still conform to current UK tyre regulations, may be so age affected as to present, under certain driving conditions, a potential hazard to drivers. In the interest of road safety such old tyres should be phased out. In order to be able to spot these, OE and replacement tyres should have open date marking moulded into their sidewalls. All tyres over 6 years old should be carefully inspected for signs of cracking in the roots of tread grooves, severe shoulder wear and carcass distortion, for these may be the first indications of onset of a latent tyre failure risk, particularly the dreaded high speed tread strip. Whether it is due to age-fatiguing causing partial discontinuity of bonding of the steel wires embedded in the peripheral reinforcing belt of modern radial car tyres, or due to unsuspected corrosion of the steel wires following flint cuts, does not really matter, it calls for urgent replacement of the tyres.

More attention should be given to what constitutes sensible, as well as legal tyre fitments, particularly for the relatively short periods of very cold winter weather. For unlike the Alpine countries, which have accepted the need for a change of tyres for winter operation, drivers (and some Government Departments in the UK) tend to dismiss these as fluke conditions hardly worth bothering about.

Nor should one accept, without challenge, that the Automotive Industry has evolved the best method of dealing with such recurring problems as allowing cars to go on sale with incorrect fasteners or improperly tightened ones, when these are associated with such vital safety items as steering, suspension and brakes. There should be better safeguards than the costly procedures incorporated in the Voluntary Recall System.

It is all too easy to jump to the conclusion that a badly corroded car of older design will be inferior to current models, in both accident avoidance capability and, in case of collisions, in providing safety for the car occupants.

Table 3. Measured results on the 8 year old heavily corroded saloon car versus those permitted under U.S. standard FMVSS20.

Head injury criteria		Resultant head acceleration (EEVC recommendation)		Resultant chest acceleration		Femur loading			
HIC must not exceed 1000		For a period greater than 3 milliseconds must not exceed 80g, but can have a shorter duration peak of about twice that.		For a period greater than 3 milliseconds must not exceed 60g, but can have a shorter duration peak of about twice that.		Must not exceed 1020kg			
						Driver		Passenger	
Driver	Passenger	Driver	Passenger	Driver	Passenger	Left	Right	Left	Right
870g	4.23g	137g	43g	40g	28g	147	614	293	84

The actual results obtained on a Hybrid II dummy suggest that, even though the peak value of the driver's head acceleration exceeded the current norm, it occurred for only 12 milliseconds and hence was deemed safe. All other values are well within the specified bio-mechanic safe limits and not very different from those obtained on factory new cars of this make and model.

This is not necessarily so, as demonstrated by physical testing of selected cars. It is recommended to provide a minimum of redundancy into the original design, with a view to load sharing, or fail safe modes, following inevitable deterioration of structural strength with age, corrosion and owner neglect. The principal areas worthy of attention are the seat attachment structure, seat belt anchorage points, suspension attachments and some rubber bonded elements.

It is relatively easy for professional test drivers to get cars through the standard ISO type handling tests, as well as the Slalom test course, which are much favoured by car manufacturers. The repeated sudden lane change manoeuvres proposed here are more effective in grading cars in order of "forgiveness" of driver misjudgment. The more "forgiving" a car, the greater the chance of inexperienced or over-confident drivers to regain control of their car after a temporary loss of control. It is our experience that the need to check for primary safety of cars can be divided into several phases:

In the first few months after sale many owners may experience some annoying handling oddities, which could be due to indifferent quality control at the factory, lack of proper pre-delivery check by the franchised dealer, or "infant mortality" of inadequate components fitted. The majority of owners will tend to go back to the dealers and complain. Some corrective action may follow.

Many drivers tend to treat their cars with less sympathy and consideration for the mechanism than the engineers and test drivers who passed these as fit for mass production. After rectification of early defects there is a progressive deterioration with age and mileage of steering, suspension and brakes. This will generally be rectified just before the car has been in circulation for 3 years.

Structurally significant corrosion and deterioration of properties of rubber and rubber bonded components, from tyres, anti-roll bar and suspension bushes to power unit mounts, will tend to be major deterioration factors in cars over 6 to 7 years old. Selective replacement and reinforcement of sections of the car may still be economically viable. Thereafter the wear-out type of failure will become a predominant feature. The choice of whether to scrap or not will depend on the prevailing economic climate of the country and the purse of the individual.

In the present economic climate there will inevitably be a growth of DIY repairs and neglect, or poorly executed refurbishing of the car, after about the 3rd or 4th year of circulation of the car, or after 50,000 to 80,000km of motoring. Some form of checking whether the repairs have been carried out competently may have to be entrusted to recognised professionals, who have regular access to manufacturer's bulletins and Recall notices issued, to ensure that the vehicles are not allowed on to public roads in a potentially hazardous state.

The aim of the car makers may ultimately be like that of the Watch Industry: "Whilst it works, leave well alone. If it stops replace the driving force. If it fails or becomes erratic, the cheapest and easiest way of repair or servicing is to buy another inexpensive one". But realisation of that dream is still many years away and in the meantime some form of MOT annual vehicle safety checks will still be required.

RAF GREENHAM COMMON—VEHICLE HANDLING TESTS, NOV 1980–FEB 1981 VEHICLE REFERENCE: CAR NO. 1

Country of origin: UK
Engine Capacity: 1593cm^3
Maximum Speed: 148km/h
Nominal Kerbweight: 1055kg
Power/Weight ratio: 14.7kg/bhp
Power Output: 72bhp (DIN) at 5,300rpm
Configuration: Front Engine;
Rear Wheel Drive
F/R Distribution %: (F) 56.5/(R) 43.5
Front Suspension: Independent—unequal length wishbones; concentric coil spring and telescopic hydraulic damper; anti-roll bar.
Chassis: Integral with body; front crossmember
Body Construction: Unitary
Rear Suspension: Live rear axle with 4-link location; telescopic hydraulic damper:anti-roll bar.
Steering: Rack and pinion. Turns lock to lock: 3.7
Tyres: Michelin ZX and XZX steel belted radial 165 SR 13, Made in UK
F/N/S—ZX—186 weeks; tread depth 5mm
F/O/S—XZX—43 weeks; tread depth 6-6½mm
R/N/S—XZX—127 weeks; tread depth 3½mm
R/O/S—ZX—186 weeks; tread depth 2-2½mm
Pressures used: Front—1.8 bar; Rear—2.0 bar.
Wheelbase: 2579mm Track: 1422mm
Wheelbase/Track ratio: 1.81:1
Age of car: 4 years
Recorded Kilometers: 103,800

RAF GREENHAM COMMON—CAR NO. 2

Country of origin: Czechoslovakia
Power/Weight ratio: 15.3 kg/bhp
Engine Capacity: 1174cm^3
Maximum Speed: 148km/h
Nominal Kerbweight: 885kg
Power Output: 58bhp (DIN) at 5,200rpm
Configuration: Rear Engine;
Rear Wheel Drive
F/R Distribution %: (F) 40/(R) 60
Front Suspension: Independent—unequal length wishbones, concentric coil spring and telescopic hydraulic damper from lower

wishbone to turret in reinforced front inner wing; anti-roll bar.
Chassis: Integral with body; rear crossmember
Body Construction: Unitary
Rear Suspension: Independent—swing axle; constant velocity joint at inboard end of drive shaft; radius rod, with large rubber bush at front end. Concentric coil spring and telescopic hydraulic damper from rear of radius rod to reinforced under floor turret.
Steering: Worm and nut.
Turns lock to lock: 2.75
Tyres: Goodyear Grand Prix 'S' steel belted radial—165 SR 13, Made in UK.
F/O/S—70 weeks—tread depth 6mm
F/N/S—67 weeks—tread depth 6mm
R/O/S—70 weeks—tread depth 5mm
R/N/S—54 weeks—tread depth 6½mm
Pressures used: Front 1.5 bar; Rear 1.9 bar
Wheelbase: 2400 Track: F-1310mm; 1290mm R
Average Track = 1300mm
Wheelbase/Track ratio: 1.85:1
Age of car: 1 year
Recorded Kilometers: 13,700

RAF GREENHAM COMMON—CAR NO. 3

Country of origin: France
Engine Capacity: 1647cm³
Maximum Speed: 165km/h
Nominal Kerbweight: 950kg
Power/Weight ratio: 12.0kg/bhp
Power Output: 79bhp (DIN) at 5,500rpm
Configuration: Front Engine—Longitudinal, Front Wheel Drive
F/R Distribution %: (F) 60/(R) 40
Front Suspension: Independent—concentric coil spring and telescopic hydraulic damper; wishbone; anti-roll bar
Chassis: Integral with body
Body Construction: Unitary
Rear Suspension: Trailing beam; side arms with integral anti-roll bar; coil spring/hydraulic damper units; centre top wishbone (A-bracket)
Steering: Rack and pinion,
Turns lock to lock: 3.6
Tyres: Michelin XZX steel belted radial 155 SR 13. Made in France
F/N/S—97 weeks: tread depth 5mm
F/O/S—97 weeks: tread depth 4½mm
R/N/S—97 weeks: tread depth 3½-4mm
R/O/S—97 weeks: tread depth 3½mm
Pressures used: Front 1.7 bar; Rear 2.0 bar
Wheelbase: 2441mm
Track: Front 1420mm Rear 1356mm
Average Track: 1388mm
Wheelbase/Track ratio: 1.76:1
Age of car: 2½ years
Recorded kilometers: 41,840

RAF GREENHAM COMMON—CAR NO. 4

Country of origin: W. Germany
Engine Capacity: 1597cm³
Maximum Speed: 179km/h
Nominal Kerbweight: 895kg
Power/Weight ratio: 9.3kg/bhp
Power Output: 96bhp (DIN) at 6,000rpm
Configuration: Front Engine—Transverse, Front Wheel Drive
F/R Distribution %: (F) 61 (R) 39
Front Suspension: Independent MacPherson Strut; lower wishbone; anti-roll bar.
Chassis: Integral with body
Body Structure: Unitary
Rear Suspension: Independent MacPherson Strut; transverse arms, radius arms.
Steering: Rack and pinion.
Turns lock to lock: 3.7
Tyres: Goodyear NCT steel belted radial 185/60 HR 14. Made in W. Germany
F/N/S—tread depth: 3-4mm
F/O/S—tread depth: 3-4mm
R/N/S—tread depth: 3-4mm
R/O/S—tread depth: 3-4mm
Pressures used: Front 1.8 bar; Rear 1.8 bar
Wheelbase: 2395mm
Track: Front 1384mm; Rear: 1430mm
Average track: 1407mm
Wheelbase/Track ratio: 1.70:1
Age of car: Under 1 year
Recorded kilometers: 13,670

RAF GREENHAM COMMON—CAR NO. 5

Country of origin: UK
Engine Capacity: 1296cm³
Maximum Speed: 156km/h
Nominal Kerbweight: 920kg
Power/Weight ratio: 13.3kg/bhp
Power Output: 69bhp (DIN) at 6,000rpm
Configuration: Front Engine Transverse, Front Wheel Drive
F/R Distribution %: (F) 59 (R) 41
Front Suspension: Independent MacPherson Strut; lower wishbones; anti-roll bar.
Chassis: Integral with body

Body Construction: Unitary
Rear Suspension: Independent MacPherson Strut; transverse arms; radius arms
Steering: Rack and pinion.
Turns lock to lock: 3.7
Tyres: Michelin XZX steel belted radial 155SR13. Made in UK.
F/N/S—10 weeks; tread depth 7½mm
F/O/S—10 weeks; tread depth 7½mm
R/N/S—12 weeks; tread depth 7½mm
R/O/S—12 weeks; tread depth 7½mm
Pressures used: Front 1.8 bar; Rear 1.8 bar
Wheelbase: 2398mm
Track: Front 1385mm, Rear 1430mm
Average track: 1408mm
Wheelbase/Track ratio: 1.70:1
Age of car: 2 months
Recorded kilometers: 3,220

RAF GREENHAM COMMON—CAR NO. 6

Country of origin: W. Germany
Engine Capacity: 1979cm^3
Maximum Speed: 169km/h
Nominal Kerbweight: 1140kg
Power/Weight ratio: 11.4kg/bhp
Power Output: 100bhp (DIN) at 5,200rpm
Configuration: Front Engine; Rear Wheel Drive, Automatic Transmission
F/R Distribution %: (F) 54 (R) 46
Front Suspension: Independent: Unequal length wishbones; concentric coil spring and telescopic hydraulic damper units; anti-roll bar.
Chassis: Integral with body
Body Construction: Unitary
Rear Suspension: Live rear axle; trailing lower radius arms; Panhard rod; upper torque arm; coil springs and telescopic hydraulic damper anti-roll bar
Steering: Recirculating ball. Turns lock to lock: 4.0
Tyres: Pirelli Cinturato steel belted radial 185/70SR14, Made in UK
F/O/S—60 weeks; tread depth 6½mm
F/N/S—62 weeks; tread depth 6½mm
R/O/S—62 weeks; tread depth 6mm
R/N/S—60 weeks; tread depth 6mm
Pressures used: Front 1.9 bar, Rear 2.0 bar
Wheelbase: 2668mm Track: Front 1435mm, Rear 1412mm
Average Track: 1424mm
Wheelbase/Track ratio: 1.87:1
Age of car: 1 year
Recorded kilometers: 12,875

RAF GREENHAM COMMON—CAR NO. 7

Country of origin: UK
Engine Capacity: 1994cm^3
Maximum Speed: 159km/h
Nominal Kerbweight: 1145Kg
Power/Weight ratio: 12.3kg/bhp
Power output: 93bhp(DIN) at 4,900rpm
Configuration: Front Engine
Transverse
Front Wheel Drive
F/R Distribution %: (F) 62 (R) 38
Front Suspension: Independent: unequal length arms and "Hydragas" displacers, hydraulically interconnected front to rear.
Chassis: Integral with body
Body Construction: Unitary
Rear Suspension: Independent: trailing arms and "Hydragas" displacers, hydraulically interconnected front to rear.
Steering: Rack and pinion.
Turns lock to lock: 4.6
Tyres: Michelin ZX steel belted radial 185/70SR14, Made in UK
F/O/S—66 weeks; tread depth 4mm
F/N/S—66 weeks; tread depth 4mm
R/O/S—70 weeks; tread depth 5mm
R/N/S—16 weeks; tread depth 6½mm
Pressures used: Front 1.8 bar, Rear: 1.7 bar
Wheelbase: 2763mm Track: Front 1473mm, Rear 1458mm
Average track: 1466mm
Wheelbase/Track ratio: 1.88:1
Age of car: 3½ years
Recorded kilometers: 67,350

RAF GREENHAM COMMON—CAR NO. 8 (LHD)

Country of origin: Italy
Engine Capacity: 1438cm^3
Maximum speed: 145km/h
Nominal Kerbweight: 930kg
Power/Weight ratio: 13.3kg/bhp
Power Output: 70bhp(DIN) at 5,400rpm
Configuration: Front Engine,
RearWheel Drive
Automatic Transmission
F/R Distribution %: (F) 54 (R) 46
Front Suspension: Independent, unequal length wishbone, concentric coil spring, telescopic hydraulic damper, anti-roll bar
Chassis: Integral with body. Front Crossmember

Body Construction: Unitary, Estate Car
Rear Suspension: Live rear axle, 4 parallel trailing links, Panhard rod, telescopic hydraulic damper, separate coil springs
Steering: Worm and roller
Turns lock to lock: 2.8
Tyres: Front: Pirelli Cinturato P3 steel belted radial 155SR13, Made in Brazil
Rear: Michelin ZX steel belted radial 165SR13
F/O/S—88 weeks; tread depth 6mm
F/N/S—88 weeks; tread depth 5½mm
R/O/S—452 weeks; tread depth 1-1½mm
R/N/S—452 weeks; tread depth 2½mm
Pressures used: Front 1.9 bar, Rear 2.1 bar
Wheelbase: 2420mm Track: Front 1330mm, Rear 1300mm
Average track: 1315mm
Wheelbase/Track ratio: 1.84:1
Age of car: 8½ years
Recorded kilometers: 112,025

RAF GREENHAM COMMON—CAR NO. 9 (LHD)

Country of origin: Italy
Engine Capacity: 1438cm³
Maximum Speed: 145km/h
Nominal Kerbweight: 925kg
Power/Weight ratio: 13.2kg/bhp
Power Output: 70bhp (DIN) at 5,400rpm
Configuration: Front Engine,
Rear Wheel Drive
Automatic Transmission
F/R Distribution %: (F) 54 (R) 46
Front Suspension: Independent unequal length wishbones; concentric coil spring, telescopic hydraulic damper, anti-roll bar.
Chassis: Integral with body, Front Crossmember
Body Construction: Unitary
Rear Suspension: Live rear axle, 4 parallel trailing links, Panhard rod, concentric coil spring, telescopic hydraulic damper into reinforced wheel well turret
Steering: Worm and roller
Turns lock to lock: 2.8
Tyres: Front: Continental TS771 steel belted radial 155SR13. Made in France.
Rear: Continental TS729 M+S steel belted radial 155SR13, Made in Germany
F/O/S—238 weeks; tread depth 6mm
F/N/S—238 weeks; tread depth 3½mm
R/O/S—197 weeks; tread depth 3½mm
R/N/S—197 weeks; tread depth 4½mm
Pressures used: Front 2.0 bar, Rear 2.0 bar.
Wheelbase: 2420mm Track: Front 1330mm
Rear 1300mm
Average track: 1315mm
Wheelbase/Track ratio: 1.84:1
Age of car: 8 years
Recorded kilometers: 122,480

RAF GREENHAM COMMON—CAR NO. 10

Country of origin: USA
Engine Capacity: 4942cm³
Maximum Speed: 161km/h
Nominal Kerbweight: 1556kg
Power/Weight ratio: 12.8kg/bhp
Power Output: 122bhp (DIN) at 3,600rpm
Configuration: Front Engine,
Rear Wheel Drive
Automatic Transmission
F/R Distribution %: (F) 57 (R) 43
Front Suspension: Independent: Upper wishbone, lower transverse link concentric coil spring; hydraulic damper unit from upper wishbone into underbody turret, tailing links. Anti-roll bar.
Chassis: Integral with body
Body Construction: Unitary
Rear Suspension: Live rear axle, 5 leaf semi elliptic spring inclined telescopic hydraulic damper to underbody attachments.
Steering: PAS recirculating ball.
Turns lock to lock: 5.2
Tyres: Pirelli Cinturato P76 radial FR7814. Made in Brazil.
F/N/S—98 weeks; tread depth 7mm
F/O/S—99 weeks; tread depth 7mm
R/N/S—99 weeks; tread depth 7mm
R/O/S—99 weeks; tread depth 7mm
Pressures used: Front 1.8 bar, Rear 2.0 bar.
Wheelbase: 2794mm Track: Front 1499mm
Rear 1466mm
Average track: 1483mm
Wheelbase/Track ratio: 1.88:1
Age of car: 6 months
Recorded kilometers: 5155

RAF GREENHAM COMMON—CAR NO. 11 (LHD)

Country of origin: USA
Engine Capacity: 5736cm³
Maximum Speed: 211km/h
Nominal Kerbweight: 1571kg
Power/Weight ratio: 7.1kg/bhp
Power Output: 220bhp (DIN) at 5,200 rpm

Configuration: Front Engine, Rear Wheel Drive. Automatic Transmission.
F/R Distribution %: (F) 60 (R) 40
Front Suspension: Independent, unequal length wishbones, coil springs, telescopic hydraulic damper, anti-roll bar
Chassis: Ladder frame with crossmembers
Body Construction: Glass Fibre Reinforced Plastic—Tub
Rear Suspension: Independent, Transverse semi-elliptic spring, lower transverse links, semi-elliptic acts as upper arms, trailing radius arms, telescopic hydraulic damper.
Steering: PAS high ratio rack and pinion
Turns lock to lock: 2.5
Tyres: Michelin Wide X steel braced radial GR 70 × 15, Made in USA
F/N/S—103 weeks; tread depth 2½mm
F/O/S—97 weeks; tread depth 2½mm
R/N/S—103 weeks; tread depth 2½mm
R/O/S—97 weeks; tread depth 2½mm
Pressures used: Front 1.8 bar, Rear 1.8 bar
Wheelbase: 2490mm Track: Front 1490mm, Rear 1510mm
Average Track; 1500mm
Wheelbase/Track ratio: 1.66:1
Age of car: 3 years
Recorded kilometers: 117,600

RAF GREENHAM COMMON—CAR NO. 12 (LHD)

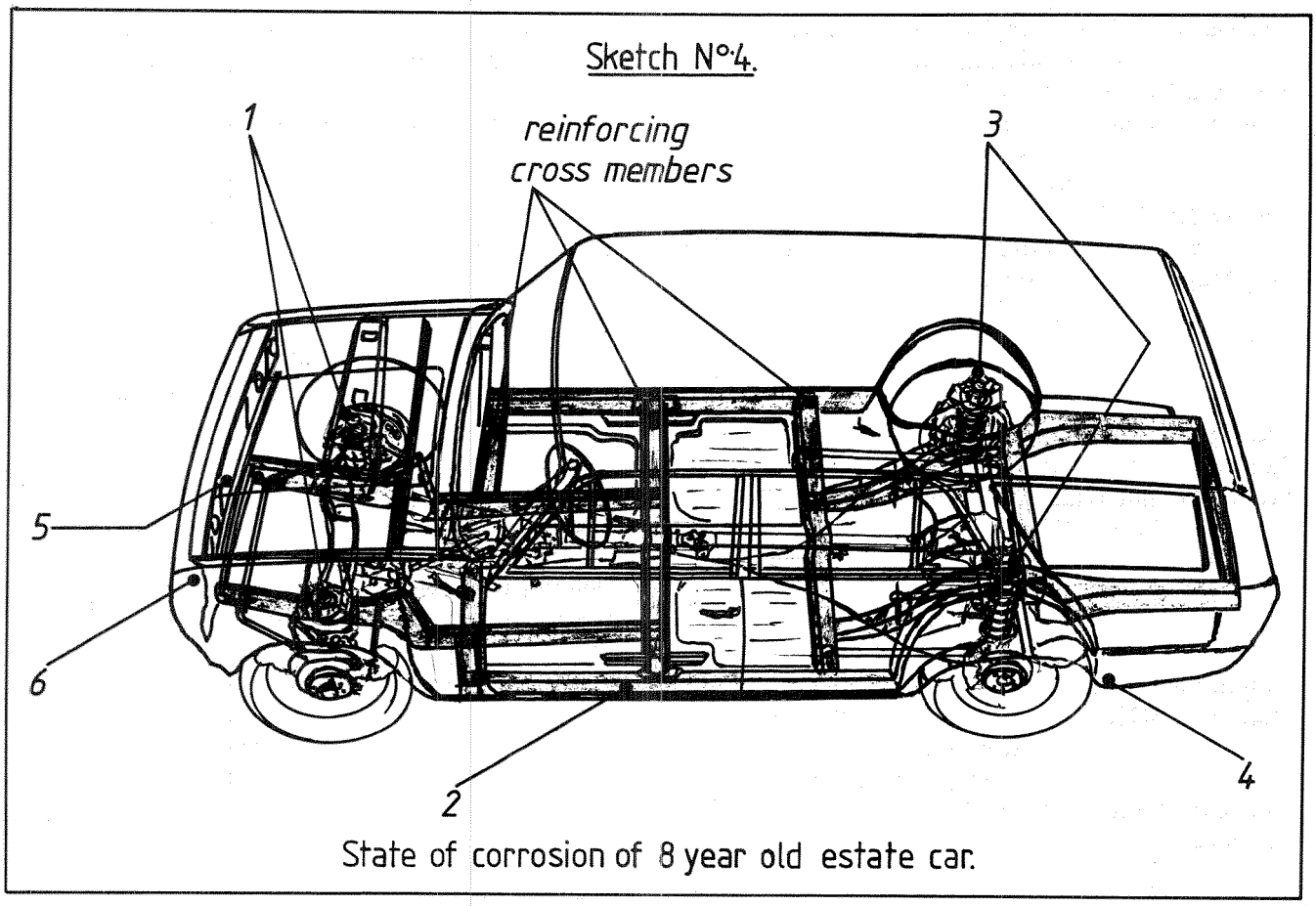
Country of origin: USA
Engine Capacity: 6964cm^3
Maximum Speed: 190km/h
Nominal Kerbweight: 2290kg
Power/Weight ratio: 12.7kg/bhp
Power Output: 180 bhp (DIN) at 4,000rpm
Configuration: Front Engine Longitudinal, Front Drive, Automatic
F/R Distribution %: (F) 65 (R) 35
Front Suspension: Independent unequal length wishbone, longitudinal torsion bars, telescopic hydraulic damper. Anti-roll bar.
Chassis: Ladder frame with crossmembers
Body Structure: Separate steel body shell
Rear Suspension: Rigid tube axle, coil springs, lower trailing arms, upper oblique torque arms, load-levelling pneumatic damper, giving automatic ride height control.
Steering: PAS Recirculating ball, variable ratio.
Turns lock to lock: 3.8
Tyres: Uniroyal steel belted radial LR 78 × 15; 6 ply rating, Made in USA
F/N/S—104 weeks; tread depth 6½mm
F/O/S—104 weeks; tread depth 6½mm
R/N/S—108 weeks; tread depth 6½mm
R/O/S—108 weeks; tread depth 6½mm
Pressures used: Front, 1.9 bar, Rear 1.9 bar
Wheelbase: 3210mm Track Front: 1620mm
Rear 1610mm
Average track: 1615mm
Wheelbase/Track ratio: 1.99:1
Age of car: 2 years
Recorded kilometers: 6435

RAF GREENHAM COMMON—CAR NO. 13 (LHD)

Country of origin: USA
Engine Capacity: 3802cm^3
Maximum Speed: 137km/h
Nominal Kerbweight: 1375kg
Power/Weight ratio: 15.3kg/bhp
Power Output: 90bhp (DIN) at 3,400
Configuration: Front Engine, Rear Wheel drive. Automatic Transmission
F/R Distribution %: (F) 56 (R) 44
Front Suspension: Independent, unequal length wishbones, coil springs, telescopic hydraulic damper, anti-roll bar.
Chassis: Integral with body, front crossmember
Body Construction: Unitary
Rear Suspension: Live rear axle, semi elliptic multi leaf springs, torque tube, telescopic hydraulic damper.
Steering: Recirculating ball.
Turns lock to lock: 6.0
Tyres: Goodyear: steel belted radial DR 78 × 14, Made in USA
F/N/S—143 weeks; tread depth 2½mm
F/O/S—143 weeks; tread depth 2½mm
R/N/S—143 weeks; tread depth 2½mm
R/O/S—143 weeks; tread depth 2½mm
Pressures used: Front 2.1 bar, Rear 1.9 bar
Wheelbase: 2740mm Track: Front 1470mm, Rear 1450mm
Average track: 1460mm
Wheelbase/Track ratio: 1.88:1
Age of car: 3 years
Recorded kilometers: 46,670

STATE OF CORROSION OF 8 YEAR OLD TEST CAR
TYPE OF CAR: ESTATE
FRONT ENGINE—REAR WHEEL DRIVE

1. Right and left front suspension domes badly rust affected.

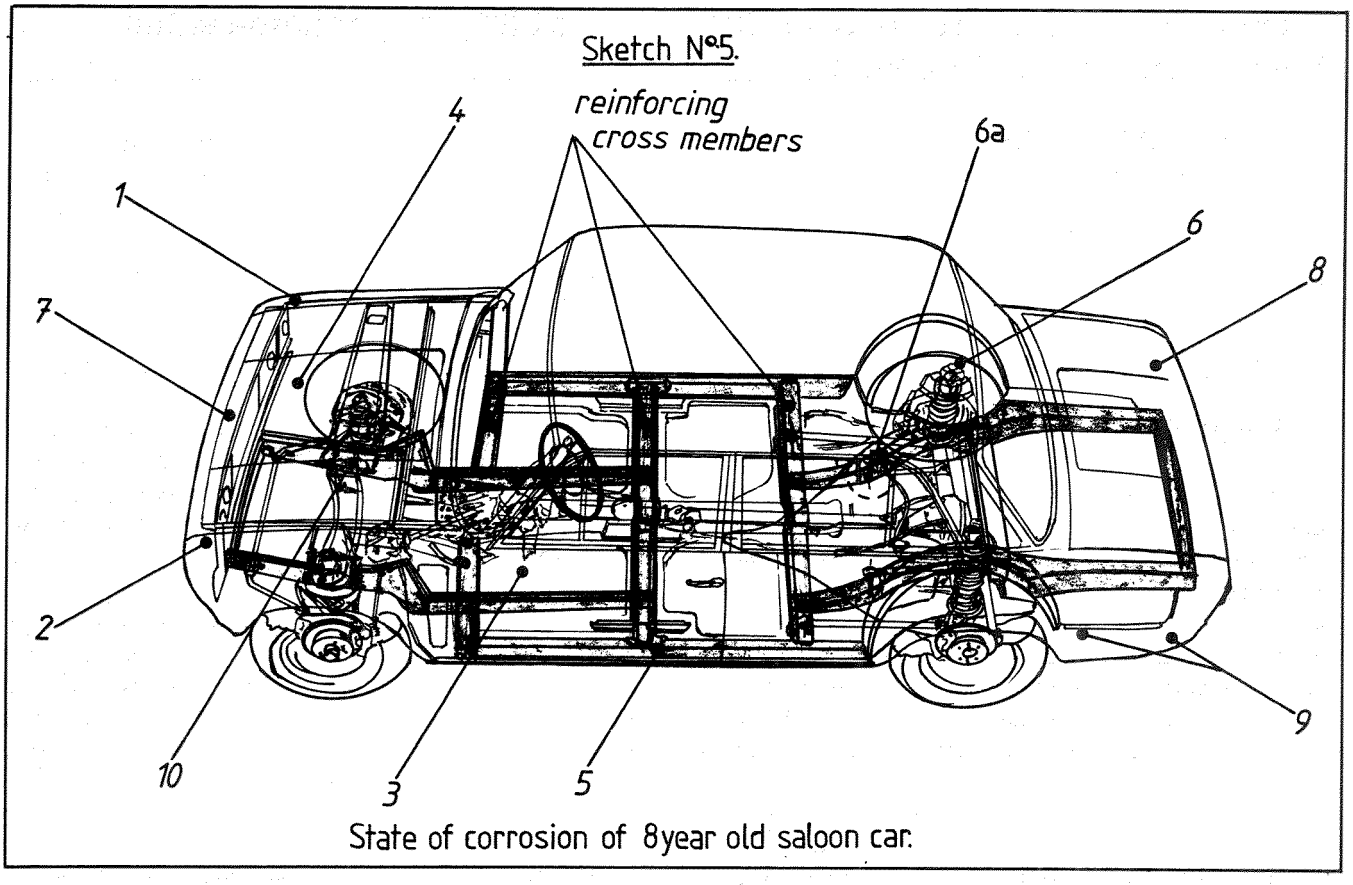


State of corrosion of 8 year old estate car.

2. Right and left sill very rusty, with many holes in the box section under the doors.
3. Rear suspension struts—alarming corrosion at attachment to floor support.
4. Bad rust both on right and left sides.
5. Front panel rusted away in parts.
6. Front left external panel completely detached from engine compartment; floor is severely corroded and is completely detached from the sill box sections; floor reinforcement cross members badly rusted.

STATE OF CORROSION OF 8 YEAR OLD TEST CAR
TYPE OF CAR: SALOON
FRONT ENGINE—REAR WHEEL DRIVE

1, 2. Front right and left external panels completely detached from engine compartment, curled back as far as halfway along the wheel.
3. Door, driver side, inside out corrosion in lower section.
4. Bonnet cannot be fastened properly.
5. Right and left hand sills badly corroded, with large holes in the box section under the doors.
6. Rear suspension struts—in good condition, but in the RH floor reinforcement, where control bar is attached, there is a crack.
7. The whole of the front secetion is almost completely detached and held together with electrician's sticky tape. Each time the bonnet is opened the entire front section tends to become detached (various pieces of panel are missing, as they have rusted and come off).
8. Spare wheel carrier severely corroded.
9. Fuel tank attachment reinforcements have rusted completely away, allowing the tank to drop and move about on rough roads. All the floorpan is badly corroded, in the areas where the driver and passengers rest their feet, which is almost completely missing.
10. The front forecarriage is still reasonably functional—hydraulic dampers are passably functional—driveability is good. New reinforcement cross members have been welded into the floorpan, but the floor panels welded in above them show signs of cracks.



State of corrosion of 8year old saloon car.

REFERENCES

1. Car Accident Insurance Claims 1979, 1980 and 1981. Unpublished Confidential Reports.
2. Measurement of Skidding Resistance, Parts I to IV, by J. R. Hosking and G. C. Woodford. Transport and Road Research Laboratory, Crowthorne, Berks, England. Reports Nos. 737, 738, 739 and Supplementary Report No. 346, 1978.
3. Vehicle Safety: Car Handling and Braking: Legislation Cannot Cover Everything, by M. A. Jacobson, 7th ESV Conference, Paris 1979.
4. The Influence of Tread Wear Irregularity On Wet Friction Performance of Tyres, by A. R. Williams and M. S. Evans, Tyre Technical Division, Dunlop Ltd., Birmingham, England, 1982.
5. The Effect of Tire Ageing on Force and Moment Properties of Radial Tires, by M. G. Pottinger and K. D. Marshall, of B. F. Goodrich Co., SAE Paper No. 810066, 1981.
6. Dynamik der Kraftfahrzeuge, by M. Mitschke, Springer Verlag, 1972.
7. Safe Car Handling Factors, by M. A. Jacobson, I.Mech.E., London, December 1974.
8. Possibilities for Improving Safety within the Driver-Vehicle-Environment Control Loop, by Dr. K. Enke, Daimler Benz AG, 7th ESV Conference, Paris 1979.
9. Vehicle Characteristics: Describing the Steering Control Quality of Cars, by F. O. Jaksch, Volvo Car Corporation, 7th ESV Conference, Paris 1979.
10. Corrosion of Motor Vehicles: Safety and Environmental Factors: The User's View, by M. A. Jacobson, I.Mech.E. London, Conference 1974.

ACKNOWLEDGEMENTS

The author wishes to thank the Committee and Directors of the Automobile Association for general encouragement to undertake the work reported here and permission to publish the results of several years of detailed investigations.

The views expressed and conclusions drawn are however entirely his own, and do not necessarily represent in every respect those of the Automobile Association.

He is grateful for the enthusiastic support given by his staff and the various volunteer drivers who drove the test cars.

Evaluation and Improvement of Indirect Visibility in Circumferential Area of Commercial Vehicle

HIROSHI SATOH, AKIRA YAMANAKA, TSUTOMU KONDOH
Mitsubishi Motors Corporation

MAKOTO YAMASHITA, MIKIO MATSUZAKI, KUNIO AKIZUKI
Ichikoh Industries, Ltd.

ABSTRACT

Indirect visibility of mirrors has conventionally been measured according to an area of vision and there have been no appropriate methods to evaluate a degree of visual cognizance. This paper deals with a concrete evaluation of the visibility of the mirror based on the changeability of basic area and a rate of image distortion.

An evaluation better than the third level in the five ranks of evaluation scale can hardly be hoped for with the present outside-cross-view-mirror on current heavy-duty trucks in Japan.

To improve such situation, we have developed a periscope mirror system and succeeded in decreasing a number on the left side of confirming mirrors (from 3 to 2) and achieved the best evaluation (5th level).

INTRODUCTION

In recognition that study of the driving field-of-view is the most important for promoting driving safety, Mitsubishi Motors Corp. has, since 1960, been working on expanding the direct field-of-view of vehicles and its static evaluation (1), (2), (3).

In 1960's, our traffic environment in Japan, including pedestrian crossings, was poorly equipped, leading to an increasing number of pedestrian victims who attempted to cross immediately before oncoming vehicles. In attempts to prevent such accidents and to determine the optimum driving field-of-view , we built vehicles specially for experimenting with the field-of-view, namely buses with their fronts fully glazed (4). The results indicated that an eye angular velocity over 2 rad/s was undesirable as it imposed considerable burden and stress on the driver (5).

At the 4th ESV International Conference held in Kyoto, in 1973, Dr. Franchini (FIAT) suggested that aggressiveness and compatibility should be important themes for commercial vehicles and this conference marked a turning point for us commercial vehicle designers.

In order to achieve compatibility in the driving field-of-view with passenger vehicles, investigation and study were made on the influence of spray on a following passenger car, from a road's surface caused by a commercial vehicle. It was found that an appropriate distance between the two vehicles is the most important (6).

Recently, accidents caused by heavy vehicles when turning left have increased to such an extent that they have become a social problem. To cope with this, building of prototype low-driving-seat heavy cargo trucks and many other studies have been undertaken.

Since it has been established in previous works (4), (5) that a direct field-of-view larger than necessary is detrimental in terms of human engineering, passenger protection, vehicle body strength, cost and other factors, we have placed emphasis on improvement of the indirect field-of-view.

Ichikoh Industries Ltd. started research on the field-of-view and perspective of convex mirrors in 1960 and then engaged in the development of periscope system as a measure against the FMVSS revision in the U.S.A. and also the development of the "Back-Eye Television System" as a means for immediate rear view for heavy vehicles. In 1975, the company participated in the project "Improvement of Safety Through Reduction of Burden on the driver" (7) of the Traffic Safety Commission of Japan Automobile Manufacturers' Association, and in 1977, it started research on the improvement of the indirect field-of-view of heavy vehicles for greater safety when turning left.

The two companies, with the history just described, jointly developed the method for evaluation of the indirect field-of-view around a vehicle. In addition, a new periscope system was developed that was designed to prevent and reduce accidents caused when vehicles are turning left.

This research was funded by a research subsidy granted by the Ministry of Transport for fiscal year 1979.

HISTORY OF INDIRECT FIELD-OF-VIEW EVALUATION

Early recognition by the driver of danger information, within the driving field-of-view, to enable him to take adequate evasive action is essential for reducing the chance of accidents. In this respect, the quality of visual information provided as the indirect field-of-view is very important.

Recently, in the U.S.A., FMVSS No. 111 was put into effect which makes it obligatory to install outside-cross-view-mirrors on school buses to enable observation of immediately forward of the vehicle and in the vicinity of the bumper. In Japan, from March 1979, it was made obligatory to install a left-side-view-mirror on heavy

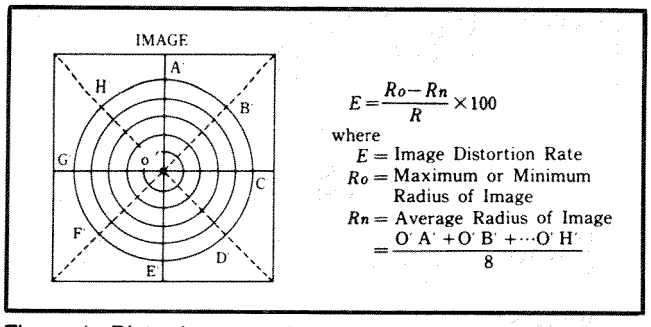


Figure 1. Distortion rate of mirror image (JIS).

trucks in addition to conventional cross-view-mirrors for wider field-of-view on the left side. As reflected in these examples, works have been undertaken by many researchers on the improvement of the driving field-of-view, both direct and indirect, in view of the importance of such visual information. The works on the evaluation of the indirect field-of-view, however, have mainly focused on the extension of the field-of-view, with only a few of them covering the quality of visual information, namely, visibility, practicability, etc.

As for rear-view-mirrors, works (8) (9) have been published on sense of distance, image distortion and visibility of images of persons and vehicles behind the vehicle as viewed through rear-view mirrors of varying radius of curvature and size. As for overseas regulation, FMVSS specifies image magnification and reflection factor, while Japanese Industrial Standard D5705 specifies the image distortion factor calculation method as shown in Figure 1 for checking a mirror's surface accuracy.

However, a cross-view-mirror for observing the surrounding environment of a vehicle is convex mirror with a relatively small radius of curvature. This means that when viewing them directly, the change in visual angle θ is large in the upper and lower sections as shown in Figure 2, resulting in larger image distortion where visual angle θ is small. Even if the radius of curvature of a cross-view-mirror is increased, for example, from 100R to 190R, image distortion remains substantially the same as shown

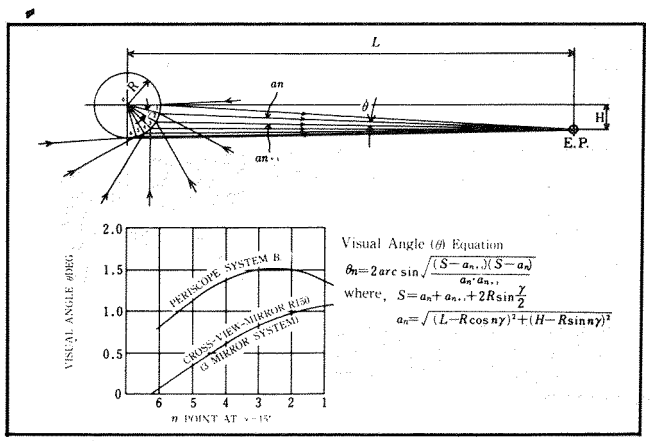


Figure 2. Visual angle comparison by mirror positions.

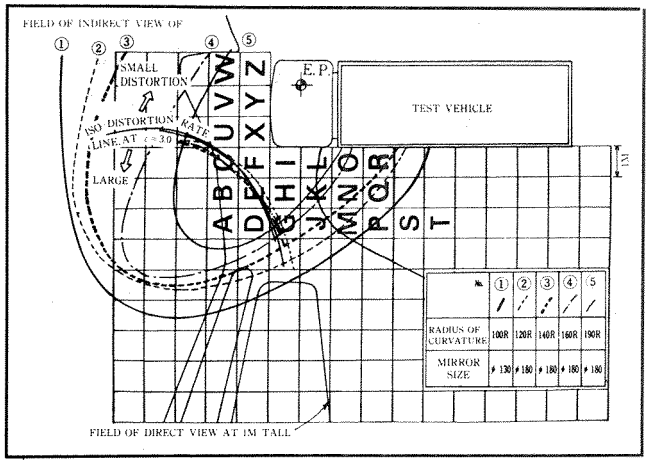


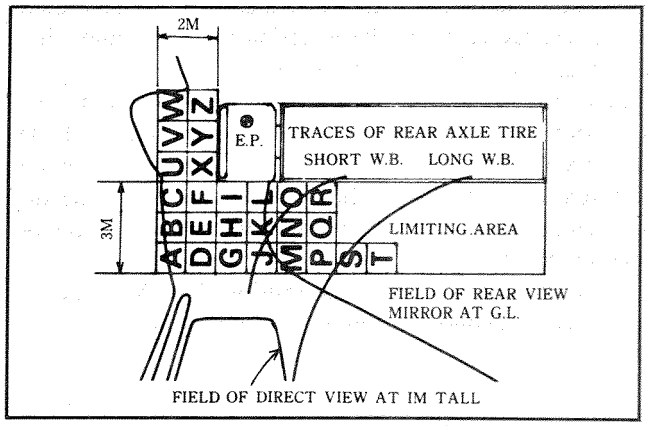
Figure 3. Iso-distortion rate line and field of indirect view by outside-cross-view-mirror.

in Figure 3, although the field-of-view and image size change. In order to analyze the visibility of these cross-view-mirrors, conventional evaluation methods are not adequate and the data that will provide the basis for judgment, such as what portion of the image must be improved and to what extent, are necessary. We started, therefore, the development of a new evaluation method that gives evaluation in new terms.

PURPOSE OF PRESENT STUDY

Establishment of Evaluation Method of Indirect Field-of-View of Vehicle Surroundings

The first objective of the present study was to establish a method to quantify image distortion and image size, and to analyze and evaluate them, while at the same time, grasping the positional relationship between the images of fields directly forward and to the left of the vehicle



Note. Limiting area is ruled by Japanese Road Vehicle Safety Standards Article 44

Figure 4. The limiting area of view and character boards arrangement.

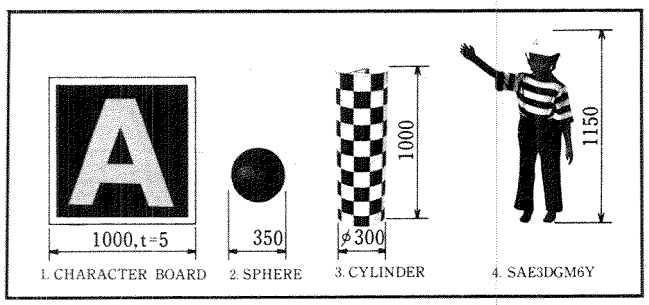


Figure 5. Four types of signs.

provided by the cross-view-mirrors and left-side-view-mirrors.

Development of Indirect View Equipment for Higher Visibility

The second objective was to establish a course and target of visibility improvement utilizing the evaluation method, and to develop new indirect view equipment. Since significant improvement cannot be expected in distortion of the left forward images with cross-view-mirrors, a new concept of a periscope system was adopted. Three basic types A, B and C, of the periscope system, were combined with various mirrors and a total of 20 systems were subjected to research and development.

CONCRETE METHODS

Selection and Arrangement of Signs

1. *Character Boards:* 26 alphabetical character boards (1 m × 1 m, t = 5 mm) were arranged as shown in Figure 4 for use as signs to determine visibility and relative position to the vehicle.

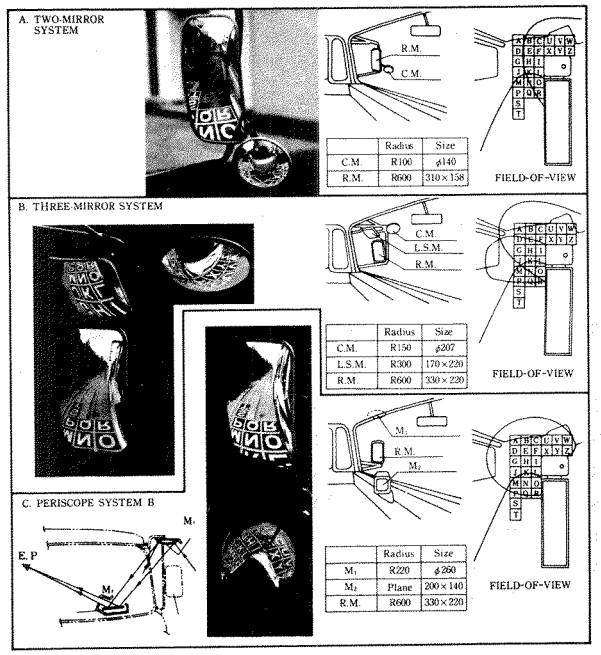
2. *Spheres:* A spherical sign was positioned at the center of each character board since a sphere was identified as a circle regardless of the direction viewed, minimizing the measurement error and facilitating analysis.

3. *Cylinders:* In order to comply with the field-of-view measurement standards of the Japanese Road Vehicle Safety Standards Article 44, that assumes that 5-year-old children are one meter tall, a cylinder of the same dimensions was positioned at upper left corner center of each character board.

4. *Dummy:* A dummy was positioned at the same location as the cylinder to compare visibility of a child and the cylinder.

Measuring Method

In the field-of-view limiting area, shown in Figure 4, four types of signs as shown in Figure 5 were installed, and these targets were photographed at the vehicle eye-point (E.P.), through three types of indirect view equipment, as shown in Figure 6. From the photos obtained, the single eye field-of-view, image distortion and image size were analyzed. The calculation equations used to determine image distortion and size are shown in Figures 7, 8 and 9.



Notes. 1. Photos taken from Eyepoint of driver
2. Simplified C.M. = Cross-View-Mirror L.S.M. = Left-Side-View-Mirror
R.M. = Rear-View-Mirror

Figure 6. Comparison with three systems—construction, specification and field-of-view.

Evaluation Method

Image distortion and image size as a function of relative location to the vehicle were quantified and divided into five levels for comparative evaluation of various types of equipment.

Equipment Tested

Two-Mirror System: Indirect viewing equipment consisting of a rear-view mirror to view rearward and a cross-view-mirror for viewing vehicle surroundings.

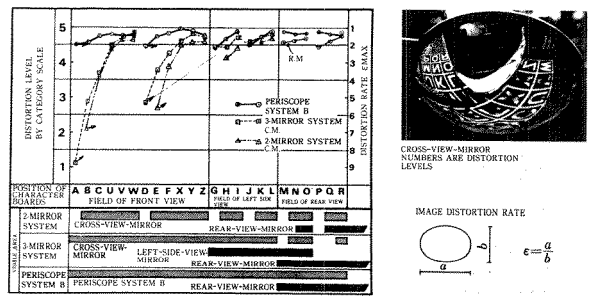
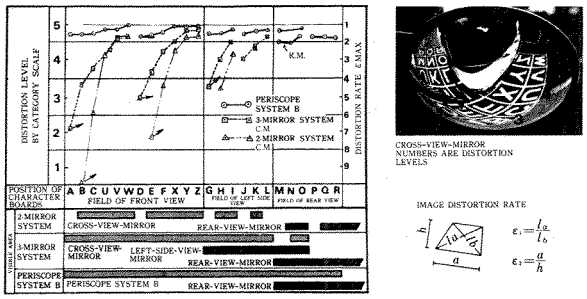


Figure 7. Image distortion of spherical signs.



CROSS-VIEW-MIRROR NUMBERS ARE DISTORTION LEVELS

IMAGE DISTORTION RATE

Figure 8. Image distortion of character boards.

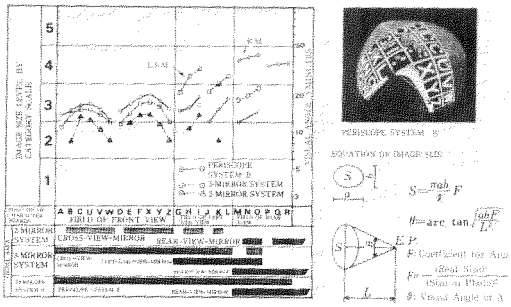


Figure 9. Image size of spherical signs.

Three-Mirror System: Indirect viewing equipment consisting of a 2-mirror system and a left-side-view mirror.

Periscope System B: Indirect viewing system consisting of a rear-view mirror and a periscope B for viewing vehicle surroundings.

Vehicles Tested

Mitsubishi Fuso Heavy Truck FT117S.

RESULTS OF ANALYSIS

The results of analysis are shown in Figure 6–11.

DISCUSSION

Way Targets Are Observed

The image distortion of the spherical sign and the character board sign exhibited nearly the same trend as shown in Figures 7 and 8. The images obtained of cylinders and dummies (SAE 3 DGM 6Y) resembled each other.

As for the image size, those of spheres and character boards showed nearly the same trend as shown in Figures 9 and 10, although the visual angle θ differed between the two.

Evaluation Method

Image Distortion

a. By the use of character boards, visibility by sense could be evaluated based on the image distortion and character identification for various relative positions to the vehicle.

Table 1. Evaluation level by psychological category scale.

Level	Degree of Image Form	Degree of Image Distortion
5	Excellent	No image distortion
4	Good	Visible,but no problem.
3	Fair	Visible, but possible to judge.
2	Poor	Large and to obstruct the judgement
1	Very Poor	Impossible to judge

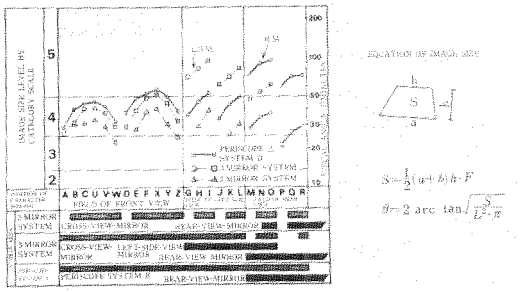
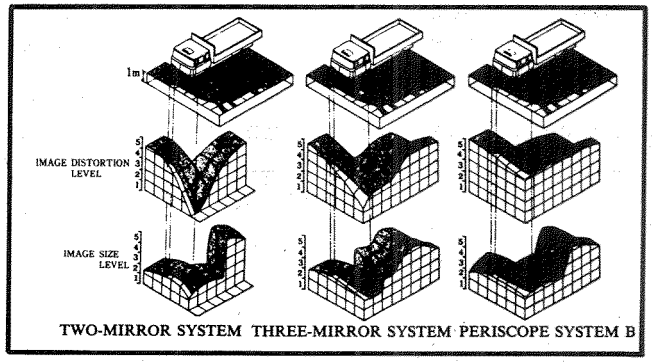


Figure 10. Image size of character boards.

b. Quantifying the image distortion into five levels provided comparative evaluation of each piece of equipment, making it possible to establish numerically the target for improvement, which greatly helped research and development activities.

c. The degree of image distortion was tabulated (Table 1) based on a psychological category scale evaluation (10). To verify correspondence between this table and the five levels of evaluation, sense evaluation on 23 subjects was conducted using actual vehicles, although this category scale evaluation technique is given here for information only.

d. From these evaluations, image distortion of level 2 and lower, in Figures 7 and 8, is considered to



Note. Hatching area is blind field of direct view at 1 m tall.

Figure 11. Comparison of image distortion and size by category scale between three systems.

require improvement. This is in agreement with the opinions of many others concerned.

Image Size

a. By clarifying the relative position to the vehicle through the use of character boards, quantifying image size with reference to spherical signs and grading by five levels, setting of a numerical target for comparative evaluation and improvement of each piece of equipment was simplified.
b. There are many factors involved in the relationship between image size and visibility, and we adopted as a standard the following criteria established in past works: (11) "In the observation of a complicated target, human eyes can identify any alphabetical character of the target so long as the visual angle is 5 minutes or more and in the observation of patterned target, accurate identification is possible if the visual angle to maximum dimension of that pattern is 12 minutes or more."
c. In actual cases, cylinders approximated children more closely than spheres. As shown in Table 2, cylinders gave images two to three times larger than spheres and were easier to identify. However, in order to take into account the driver's eyesight and variations of the external environment (available light, weather, etc.), the use of the image size given by a less favorable target (spheres) in the evaluation will be more practical.

Comparison of Indirect Viewing Equipment

Two-Mirror System: As for image arrangement, this is easier to use because of its close location to the rear-view-mirror and cross-view-mirror, but the effective field-of-view range is restricted due to large image distortion in the left forward direction.

Three-Mirror System: With the addition of a left-side-view-mirror and use of larger sized mirrors, this system gives a wider effective field-of-view, and improved image size and distortion. As for image arrangement, however, it has one additional mirror requiring observation.

Periscope System B:

a. Mirrors requiring observation during driving are two

Table 2
Comparison of Size(area) between Cylindrical/Spherical Signs.

	E′	F′	X′	Y′	Z′	F″
3-Mirror System	3.2	3.0	2.7	3.3	2.9	2.2
Periscope System B	3.4	3.7	3.0	3.4	3.7	1.9

Notes. 1. E′ means the sign on front left corner of character board E
2. F″ means the sign on front right corner character board F

As compared to the three mirrors required by the 3-mirror system, this system uses two mirrors, i.e., the periscope mirror and rear-view-mirror.

b. Alignment with sight line when turning left

When observing obstacles in the direct field-of-view to the forward left for turning left, the periscope mirror is positioned near the sight line, allowing natural identification of obstacles in the indirect field-of-view.

c. Normal image obtained, the same as direct field-of-view

The periscope mirror system is designed to cover the forward, left forward and left side field-of-views, and therefore the images produced should preferably be, for physiological reasons, normal such as those obtained through direct view. In particular, this is important as continuity with the left forward direct view is ensured when turning left. This system meets this requirement.

d. Smaller image distortion

As compared to the cross-view-mirror and left-side-view-mirror of the 3-mirror system, this system has smaller image distortion in the left forward zones A through E, allowing easy identification of object shape.

e. Generally uniform image size

Thanks to smaller distortion, the image size obtained through the periscope mirror is relatively uniform, providing evaluation of relative distance to the obstacles.

f. Greater time available for target observation and smaller image flow angular velocity

This system gives greater time available for observation of a target on the mirror, and image flow velocity is smaller, which means easier identification of obstacles. When turning left, the vehicle is usually running at a low speed and what differs from the static condition is the low speed V and the fact that the driver must obtain information through the indirect view equipment in a very short time while driving. Figures 12 and 13 show the results of analysis of image flow velocity on the mirror's surface and the time available for observation. As can be seen, the periscope mirror system gave the best performance in all cases. At 30 kg/h, for example, the eye angular velocity ω

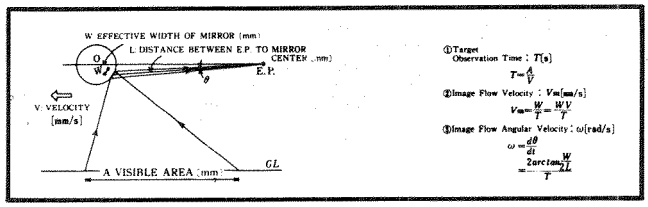


Figure 12. Image flow on mirror surface.

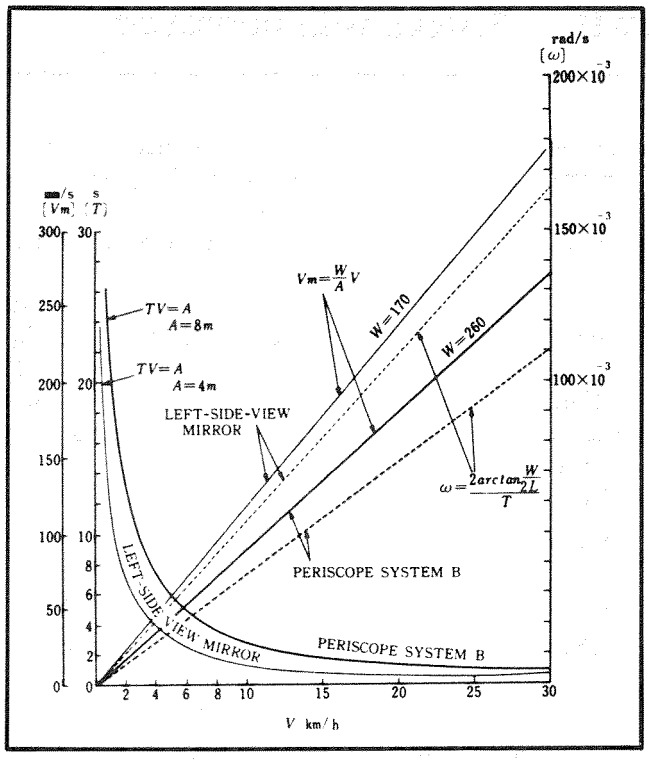


Figure 13. Running velocity and image flow on mirror surface.

is 0.11 rad/s for the periscope mirror system, while it is 0.16 rad/s for the 3-mirror system. Thus, this system is believed to provide better visibility and hence safer driving.

g. View area equivalent or wider than 3-mirror system

The periscope mirror system provides a view area equivalent or wider than that of the combination of the cross-view-mirror and left-side-view-mirror of the 3-mirror system.

CONCLUSION

As described earlier, the purpose of this study was to contribute to the reduction of accidents when vehicles are turning left through evaluation and improvement of the indirect field-of-view around heavy vehicles. In addition to the view area, the study quantified image distortion and size to establish a method to evaluate image quality. Furthermore, periscope system B was developed which has potential for significant improvement in quality over conventional 2-mirror and 3-mirror systems. This system is also effective in avoiding trouble caused by extension of the direct field-of-view.

ACKNOWLEDGEMENT

In this research, many prototypes could be tested within a short period thanks to the joint help by the chassis manufacturer and parts manufacturer. The research was conducted with the unlimited help of both manufacturers, while not limiting themselves just to their own fields, and with best available chassis and parts in use. The final system developed was periscope system B featuring minimal requirement for vehicle body modification, the minimum number of parts and simplified construction, all reflecting the merits of the joint study.

The grant by the Ministry of Transport for this research enabled us to install new facilities for its purpose. We also are greatly indebted to the officials of the ministry who gave us valuable advice and help in many ways in the course of this study.

Finally, we hope that this new system developed through the joint efforts of both the private and official sectors will contribute to prevention of traffic accidents caused when the vehicles are turning left and around vehicles, in the world traffic environment.

REFERENCES

1. Shomura M.: On the Visibility of Trucks. Journal of the Society of Automotive Engineers of Japan, Vol. 17, No. 2, (1963).
2. Yamanaka A.: Visibility Test on Mitsubishi-Fuso Heavy-Duty Trucks, Mitsubishi Nippon Juko Technical Report, Vol. 4, No. 1, (1963).
3. Yamanaka A.: Visibility of Motor Vehicles. 730th Japan Society of Mechanical Engineers Seminar Proceedings.
4. Kobayashi M., et al.: Dynamic Visibility of Automobiles. Autumn Seminar Proceedings of the Society of Automotive Engineers of Japan, (1965).
5. Yamanaka A. and Kobayashi M.: Dynamic Visibility of Motor Vehicles. 13th FISITA and 1970 SAE Transaction SAE Paper 700993.
6. Yamanaka A. and Nagaike N.: Measurement and Control of Truck Spray on Wet Roads, 16th FISITA Proceedings (1976).
7. Tamura, et al.: Remote Watching Mirror for Automobiles. Proceedings of Japan Ergonomics Research Society Kanto-branch Meeting in 1979.
8. Morgen, C. T., et al.: Human Engineering Guide to Equipment Design—Japanese translation by Kondo T. et al., Published by Corona Publishing Co., LTD.—.
9. Hiwatari: Vision and Television. Association of Japan Broadcasting Publication.
10. Rouland, George E., et al.: A Comparison of Plane and Convex Rear View Mirrors for Passenger Automobiles, PB 197748.
11. Traffic Safety Commission of Japan Automobile Manufacturers' Association. Improvement of Safety Through Reduction on Burden on the Driver—2nd Year Report—(1977).

Performance of the Experimental Heavy Duty Trucks with Improved Field of View

HIDEHIRO DAIGO, KIYOKAZU YOKOI and HIDEICHI NAKANO
Japan Automobile Research Instiute, Inc.
Traffic Safety and Nuisance Research Institute, Ministry of Transport

ABSTRACT

The dead angle range of a heavy duty truck driver at crossroads has been found to be one of the factors in traffic accidents, especially when turning left in Japan.

Therefore, the Ministry of Transport of Japan requested five heavy duty truck manufacturers to manufacture experimental heavy duty trucks with an improved field of view. Each of them produced two types of modified trucks in September, 1979. One is called a visibility-improved vehicle of which field of view has been improved mainly by adopting supplementary windows, while the other is a low-floored vehicle of which the field of view has been improved mainly by lowering the height of the eye point.

This paper presents the results of experiment which comprises of (1) static visibility test, (2) dynamic visibility test, and (3) subjective evaluation test by professional drivers, conducted on such vehicles.

As a result, it was proved that the experimental vehicles surpass current model vehicles in visibility.

In the case of the low-floored vehicles, however, many problems still remain to be solved. On the other hand, it seems to be possible to commercialize the visibility-improved vehicles without any drastic modification of the current design concept though they don't necessarily have a sufficient field of direct view.

INTRODUCTION

The dead angle range of a heavy duty truck driver at crossroads has been found to be one of the factors in the cause of traffic accidents, especially when turning left in Japan.

The Ministry of Transport (MOT) of Japan requested five heavy duty truck manufacturers to manufacture experimental heavy duty trucks with an improved field of view as a step of the program for prevention of traffic accidents. In response to the request, they studied a system to improve the field of view of current model trucks, and produced two types of modified trucks in September, 1979.

One is a vehicle of which the field of view is improved mainly by means of adopting supplementary windows, and the other is a vehicle of which the field of view is improved mainly by means of lowering the height of the eye point.

The former is called a visibility-improved vehicle and the latter a low-floored vehicle.

To evaluate the performances of these experimental heavy duty trucks, the Committee for Evaluation of Experimental Heavy Duty Trucks are organized by MOT.

The authors made the experiments on the performances of these vehicles according to the program prepared by the committee.

The experiments are as follows.

(1) static visibility test
(2) dynamic visibility test
(3) subjective evaluation test by professional drivers

The paper presents the outlines of the experimental heavy duty trucks and the test results.

OUTLINES OF THE EXPERIMENTAL HEAVY DUTY TRUCKS

Table 1 shows the experimental heavy duty trucks with improved field of view, manufactured by five heavy duty truck manufacturers in compliance with the request of MOT.

Hereinafter, each of the experimental heavy duty trucks shall be denoted by the symbols shown in Figure 1.

The appearances of these vehicles are shown in Figures 2 to 6. Furthermore, their principal dimensions are shown

Table 1. List of experimental vehicles with improved field of view.

Manufacturer	Vehicle	Quantity (unit)
ISUZU MOTORS LTD.	Visibility-improved vehicle (right- and left-hand drive dump truck)	2
	Low-floored vehicle (right- and left-hand drive dump truck)	2
TOYOTA MOTOR CO., LTD.	Visibility-improved vehicle (right-hand drive medium-sized truck)	1
	Low-floored vehicle (right- and left-hand drive medium-sized truck)	2
NISSAN DIESEL MOTOR CO., LTD.	Visibility-improved vehicle (right- and left-hand drive tractor)	2
	Low-floored vehicle (right- and left-hand drive tractor)	2
HINO MOTORS LTD.	Visibility-improved vehicle (right- and left-hand drive truck)	2
	Low-floored vehicle (right- and left-hand drive truck)	2
MITSUBISHI MOTOR CORP.	Visibility-improved vehicle (right- and left-hand drive truck)	2
	Low-floored vehicle (right- and left-hand drive truck)	2
Total		19

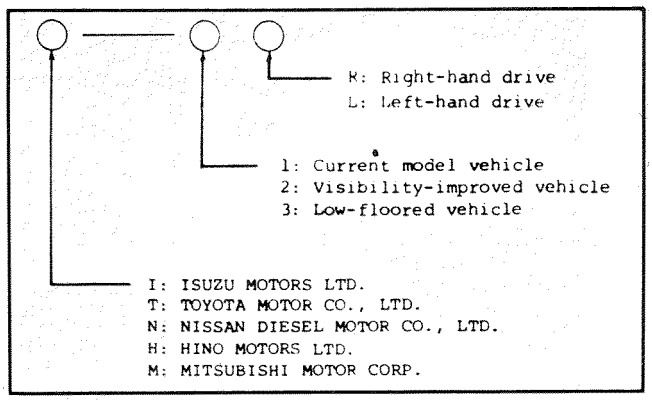


Figure 1. Symbols representing test vehicles.

in Tables 2 to 6. These tables also show the original specifications of these vehicles.

The outlines of individual experimental vehicles are as follows.

(1) Isuzu Dump Trucks

(a) I-2R: This vehicle has been made on the basis of the current model dump truck. The vehicle is provided with a supplementary window in the lower-left part below the windshield to improve the front-left field of direct view. Moreover, the left-hand door has been remodeled into a full-sized glass door in order to improve the left side field of direct view, and the assistant seat position has been shifted backward to make it more effective (Fig. 2-b).

(b) I-2L: This vehicle is a left-hand drive vehicle based on the current model dump truck. The vehicle is provided with a supplementary window in the lower-right part below the windshield and the right-hand door is made of a full-sized glass in order to keep the forward-right field of direct view as well as the right side field of direct view.

(c) I-3R: This vehicle has been experimentally designed to lower the height of driver's seat above the ground. Both the front axle and the engine have been moved backward to make the height of the driver's eye point

Table 2. Principal dimensions of Isuzu vehicles.

Item		Current model vehicle	Visibility-improved vehicle (right- and left-hand drive)	Low-floored vehicle (right- and left-hand drive)
Overall length	mm	7,675	〃	〃
Overall width	mm	2,485	〃	〃
Wheelbase	mm	4,500	〃	4,470
Curb weight	kg	9,185	8,285/9,315 (left)	9,440/9,490 (left)
Maximum loading capacity	kg	10,500	〃	10,250
Front overhang	mm	1,430	〃	2,000
Driver's eye location (height above the ground)	mm	2,505	〃	1,950

(a) Current model vehicle

(b) Visibility-improved vehicle (right-hand drive)

(c) Low-floored vehicle (left-hand drive)

Figure 2. Isuzu vehicles.

lower than that of the current model vehicle by 555 mm. Furthermore, the vehicle is provided with a supplementary window in the lower-left part below the windshield, and the left-hand door is made of a full-sized glass. The assistant seat position has also been shifted backward.

(a) Current model vehicle

(b) Visibility-improved vehicle (right-hand drive)

(c) Low-floored vehicle (left-hand drive)

Figure 3. Toyota vehicles.

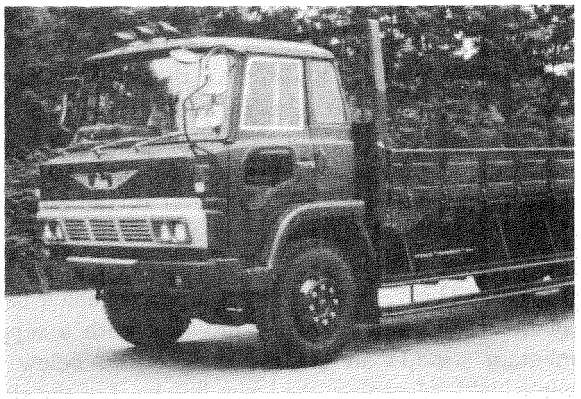
(a) Current model vehicle

(b) Visibility-improved vehicle (right-hand drive)

(c) Low-floored vehicle (left-hand drive)

Figure 4. Nissan diesel vehicles.

(a) Current model vehicle



(b) Visibility-improved vehicle (right-hand drive)

(c) Low-floored vehicle (left-hand drive)

Figure 5. Hino vehicles.

(a) Current model vehicle

(b) Visibility-improved vehicle (right-hand drive)

(c) Low-floored vehicle (left-hand drive)

Figure 6. Mitsubishi vehicles.

Table 3. Principal dimensions of Toyoto vehicles.

Item		Current model vehicle	Visibility-improved vehicle (right-hand drive)	Low-floored vehicle (right- and left-hand drive)
Overall length	mm	7,850	←	8,350
Overall width	mm	2,385	←	←
Wheelbase	mm	4,300	←	←
Curb weight	kg	4,740	←	4,860
Maximum loading capacity	kg	6,000	←	←
Front overhang	mm	1,370	←	1,870
Driver's eye location (height above the ground)	mm	2,050	←	1,820

Table 4. Principal dimensions of Nissan diesel vehicles.

Item		Current model vehicle	Visibility-improved vehicle (right- and left-hand drive)	Low-floored vehicle (right- and left-hand drive)
Overall length	mm	5,295	←	5,955
Overall width	mm	2,485	←	←
Wheelbase	mm	3,150	←	←
Curb weight	kg	6,000	←	6,185
Maximum loading capacity	kg	9,000	←	←
Front overhang	mm	1,240	←	1,900
Driver's eye location (height above the ground)	mm	2,355	←	1,880

Table 5. Principal dimensions of Hino vehicles.

Item		Current model vehicle	Visibility-improved vehicle (right- and left-hand drive)	Low-floored vehicle (right- and left-hand drive)
Overall length	mm	11,990	←	←
Overall width	mm	2,490	←	←
Wheelbase	mm	5,875+1,270 =7,145	←	←
Curb weight	kg	8,875	Right:8,875 Left :8,845	8,820
Maximum loading capacity	kg	10,750	←	←
Front overhang	mm	1,350	←	2,050
Driver's eye location (height above the ground)	mm	2,370	←	1,990

Table 6. Principal dimensions of Mitsubishi vehicles.

Item		Current model vehicle	Visibility-improved vehicle (right- and left-hand drive)	Low-floored vehicle (right- and left-hand drive)
Overall length	mm	11,215	←	11,750
Overall width	mm	2,490	←	←
Wheelbase	mm	5,250+1,300 =6,550	5,300+1,300 =6,600	←
Curb weight	kg	8,540	8,680	8,835
Maximum loading capacity	kg	11,000	←	10,750
Front overhang	mm	1,400	1,350	1,885
Driver's eye location (height above the ground)	mm	nearly 2,305	nearly 2,335	nearly 1,975

(d) I-3L: This vehicle is a left-hand drive vehicle based on the I-3R. Also, the vehicle is provided with a supplementary window in the lower-right part below the windshield and the right-hand door is made of a full-sized glass (Fig. 2-c).

(2) Toyota Trucks

(a) T-2R: This vehicle has been made on the basis of the current medium-sized truck. The vehicle is provided with a supplementary window in the lower-left part below the windshield to improve the front-left field of direct view. Moreover, the left-hand door has been remodeled into a door with a supplementary window in its lower part in order to improve the left-side field of direct view, and the waist line of the door is lower than that of the original vehicle by 210 mm (Fig. 3-b).
(b) T-3R: This vehicle has been experimentally designed to lower the height of driver's seat above the ground. The cab has been moved forward and downward beyond the front wheels so that the height of the driver's eye point is lower than that of the current model vehicle by 230 mm. In addition, in the same manner as T-2R, the vehicle is provided with a supplementary window in the lower-left part below the windshield, and the waist line level of the left-hand door window is lower than that of the current model vehicle by 210 mm.
(c) T-3L: This vehicle is a left-hand drive vehicle based on the T-3R. The vehicle is provided with a supplementary window in the lower-right part below the windshield. Moreover, the waist line level of the right-hand door window is lower than that of the current model vehicle by 210 mm (Fig. 3-c).

(3) Nissan Diesel Tractor

(a) N-2R: This vehicle has been made based on the current model tractor. The vehicle is provided with a supplementary window in the lower-left part of the front panel of the cab to improve the front-left field of direct view. Further, the left-hand door has been remodeled into a door with a supplementary window in its lower part, of which the waist line is lower than that of the current model tractor in order to improve the left side field of direct view (Fig. 4-b).
(b) N-2L: This is a left-hand drive vehicle based on the current model tractor. The right-hand door has been remodeled to have a supplementary window in its lower part and the waist line lower than that of the current model vehicle. Furthermore, the vehicle is provided with a supplementary window in the lower-right part of the front panel of the cab.
(c) N-3R: In the case of this vehicle, an attempt has been made to lower the driver's seat level down. The cab has been moved forward and downward beyond the front wheels so that the height of the driver's eye

point is lower than that of the current model tractor by 475 mm. Besides, in the same manner as the N-2R, the vehicle is provided with a supplementary window in the lower-left part of the front panel of the cab. The left-hand door has been remodeled into a door with a supplementary window in its lower part and with the waist line lower than that of the current model vehicle.
(d) N-3L: This is a left-hand drive vehicle based on the N-3R. The vehicle is provided with a supplementary window in the lower-right part of the front panel of the cab. Further, the right-hand door has been remodeled to have a supplementary window in its lower part and the waist line lower than that of the current model vehicle (Fig. 4-c).

(4) Hino Trucks

(a) H-2R: This vehicle has been made based on the current model of a general heavy duty truck. The vehicle has a windshield which has a waist line lower than that of the current model vehicle by 90 mm. The left-hand door is provided with a supplementary window in its lower part, and its waist line is lower than that of the current model vehicle by 90 mm (Fig. 5-b).
(b) H-2L: This is a left-hand drive vehicle based on the current model truck. This vehicle is also provided with a windshield of which waist line is lower than that of the current model vehicle by 90 mm. Moreover, the right-hand door is provided with a supplementary window in its lower parts, and its waist line is lower than that of the current model vehicle by 90 mm.
(c) H-3R: This vehicle has been experimentally designed to lower the height of driver's seat down. The cab has been moved forward and downward beyond the front wheels so that the height of driver's eye point is lower than that of the current model vehicle by 380 mm. In addition, the vehicle is provided with a supplementary window in the lower-left part of the front panel of the cab. Another supplementary window is also provided in the lower part of the left-hand door.
(d) H-3L: This is a left-hand drive vehicle based on the H-3R. The vehicle also has a supplementary window in the lower-right part of the front panel of the cab. Another supplementary window is also provided in the lower part of the right-hand door (Fig. 5-c).

(5) Mitsubishi Trucks

(a) M-2R: This vehicle has been made on the basis of the current model of a general heavy duty truck. The vehicle is provided with a windshield which has a waist line lower than that of the current model vehicle by 105 mm to improve the forward field of direct view. In order to improve the left-side field of direct view, the left-hand door has been remodeled to have a supplementary window in its lower part and a waist line lower than that of the current model vehicle by 85 mm.

Moreover, to improve the left-side field of indirect view in vehicle's vicinity, the vehicle is provided with a view mirror system of periscope type (Fig. 6-b).
(b) M-2L: This is a left-hand drive vehicle based on the current model truck. In the same manner as the M-2R, the vehicle is provided with a windshield of which the waist line is lower than that of the current model vehicle by 105 mm.

And, in order to keep the right side field of direct view, the right-hand door has also been remodeled to have a supplementary window in its lower part and a waist line lower than that of the current model vehicle by 85 mm.
(c) M-3R: This vehicle has been experimentally designed to lower the height of driver's seat down. The cab has been moved forward and downward beyond the front wheels so that the height of driver's eye point is lower than that of the current model vehicle by 330 mm. Furthermore, the vehicle is provided with a windshield of which the waist line is lower than that of the current model vehicle by 105 mm. The left-hand door is provided with a supplementary window in its lower part and its waist line is lower than that of the current model vehicle by 85 mm.
(d) M-3L: This is a left-hand drive vehicle based on the M-3R. Consequently, the waist line of the windshield is 105 mm lower than that of the current model vehicle. Also, the right-hand door has been remodeled to have a supplementary window in its lower part and a waist line lower than that of the current model vehicle by 85 mm (Fig. 6-c).

STATIC VISIBILITY TEST

Test Procedures

(1) Fields of Direct View

A test vehicle (unladen, except for a spare tire, standard tools, a jack and so on) is set stationary on a horizontal plane, with wheels in straight forward position. An observer is seated on the driver's seat in the test vehicle cab, and his binocular location is set with reference to the eye point specified for the test vehicle (design value). Under these conditions, the fields of direct view are measured on the road surface and on the horizontal plane 1 m above the road. For the field of direct view on the road surface, the vision area is determined by the limit within which the observer can recognize the lower end of a pole of 1 m in length held perpendicular to the road surface.

For the field of direct view on the plane 1 m above road, the vision area is defined by the limit within which the observer can recognize the upper end of the pole.

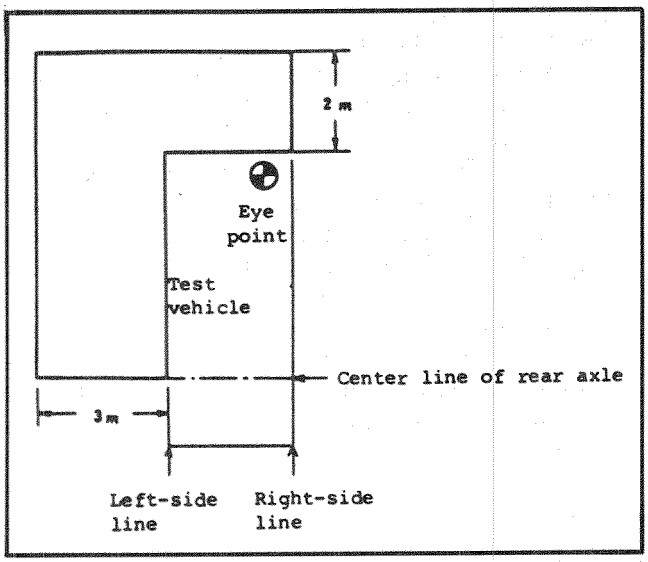


Figure 7. Reference area for comparison of vision areas.

(2) Fields of Indirect View

For each test vehicle, the rear-view mirror, the under-view mirror and so on are installed at the designated standard positions, and their angles are adjusted in accordance with the standard adjustment manuals.

The fields of indirect view through the view mirror systems are measured on the road surface and on the horizontal plane 1 m above the road in the same manner as those mentioned above.

Test Results

According to the Safety Regulations for Road Vehicles, the reference area is defined as the area surrounded by the transverse line located 2 m ahead of the frontmost end, the longitudinal line 3 m outboard on the left side, the line extended along the right side and the transverse line extended through the line of rear axle (the forward rear axle in the case of tandem axles) for each test vehicle as shown in Figure 7.

For each test vehicle, the vision area is determined within the reference area. The test results obtained are shown in Tables 7 to 11.

In these tables, the fields of view are compared between the current model vehicles and the experimental vehicles.

Moreover, the fields of direct view on the road surface are shown in Figure 8.

In comparison of the test results, the general features by which each type of the test vehicles is distinguished from each other are described as follows.

(1) Fields of Direct View

There are almost no vision areas at ground level for the current model vehicles within the reference area, al-

Table 7. Comparison of vision areas of Isuzu vehicles.

(Unit: m^2)

Field of view \ Vehicle type		I-1	I-2R	I-2L	I-3R	I-3L
Direct	Ground	0.23 (1.0)	1.69 (7.3)	3.91 (17)	4.33 (19)	6.11 (27)
	Plane 1m above the ground	1.86 (1.0)	6.51 (3.5)	7.75 (4.2)	11.6 (6.2)	13.0 (7.0)
Indirect	Ground	24.7 (1.0)	24.6 (1.0)	24.7 (1.0)	25.5 (1.0)	24.0 (1.0)
	Plane 1m above the ground	19.9 (1.0)	19.9 (1.0)	21.0 (1.1)	19.5 (1.0)	17.1 (0.9)

Note 1. Vision area is specified with the reference area shown in Figure 7 (which also applies to Tables 8 to 11 and Figure 8).
2. Figure in parentheses shows a ratio to the current model vehicle (which also applies to Tables 8 to 11).

Table 8. Comparison of vision areas of Toyota vehicles.

(Unit: m^2)

Field of view \ Vehicle type		T-1	T-2R	T-3R	T-3L
Direct	Ground	0 (-)	1.90 (-)	1.02 (-)	6.09 (-)
	Plane 1m above the ground	4.25 (1.0)	7.69 (1.8)	8.47 (2.0)	13.4 (3.2)
Indirect	Ground	27.5 (1.0)	27.3 (1.0)	28.9 (1.1)	24.3 (0.9)
	Plane 1m above the ground	20.6 (1.0)	18.9 (0.9)	16.6 (0.8)	17.6 (0.9)

Table 9. Comparison of vision areas of Nissan diesel vehicles.

(Unit: m^2)

Field of view \ Vehicle type		N-1	N-2R	N-2L	N-3R	N-3L
Direct	Ground	0 (-)	0.89 (-)	5.93 (-)	1.37 (-)	8.50 (-)
	Plane 1m above the ground	3.19 (1.0)	4.25 (1.3)	10.0 (3.1)	10.8 (3.4)	14.2 (4.5)
Indirect	Ground	22.3 (1.0)	22.9 (1.0)	19.7 (0.9)	23.5 (1.1)	14.7 (0.7)
	Plane 1m above the ground	18.9 (1.0)	19.0 (1.0)	17.2 (0.9)	17.0 (0.9)	12.1 (0.6)

Table 10. Comparison of vision areas of Hino vehicles.

(Unit: m^2)

Field of view \ Vehicle type		H-1	H-2R	H-2L	H-3R	H-3L
Direct	Ground	0 (-)	0.27 (-)	6.36 (-)	0.78 (-)	6.50 (-)
	Plane 1m above the ground	1.95 (1.0)	4.94 (2.5)	10.8 (5.5)	8.33 (4.3)	14.2 (7.3)
Indirect	Ground	32.5 (1.0)	31.5 (1.0)	32.8 (1.0)	34.1 (1.0)	33.1 (1.0)
	Plane 1m above the ground	30.9 (1.0)	30.9 (1.0)	26.4 (0.9)	30.8 (1.0)	26.3 (0.9)

Table 11. Comparison of vision areas of Mitsubishi vehicles.

(Unit: m^2)

Field of view \ Vehicle type		M-1	M-2R	M-2L	M-3R	M-3L
Direct	Ground	0 (-)	1.10 (-)	4.56 (-)	0.73 (-)	6.73 (-)
	Plane 1m above the ground	2.05 (1.0)	5.32 (2.6)	10.1 (4.9)	9.27 (4.5)	13.6 (6.6)
Indirect	Ground	30.5 (1.0)	29.6 (1.0)	30.3 (1.0)	32.2 (1.1)	30.6 (1.0)
	Plane 1m above the ground	30.1 (1.0)	30.3 (1.0)	23.0 (0.8)	27.9 (0.9)	20.3 (0.7)

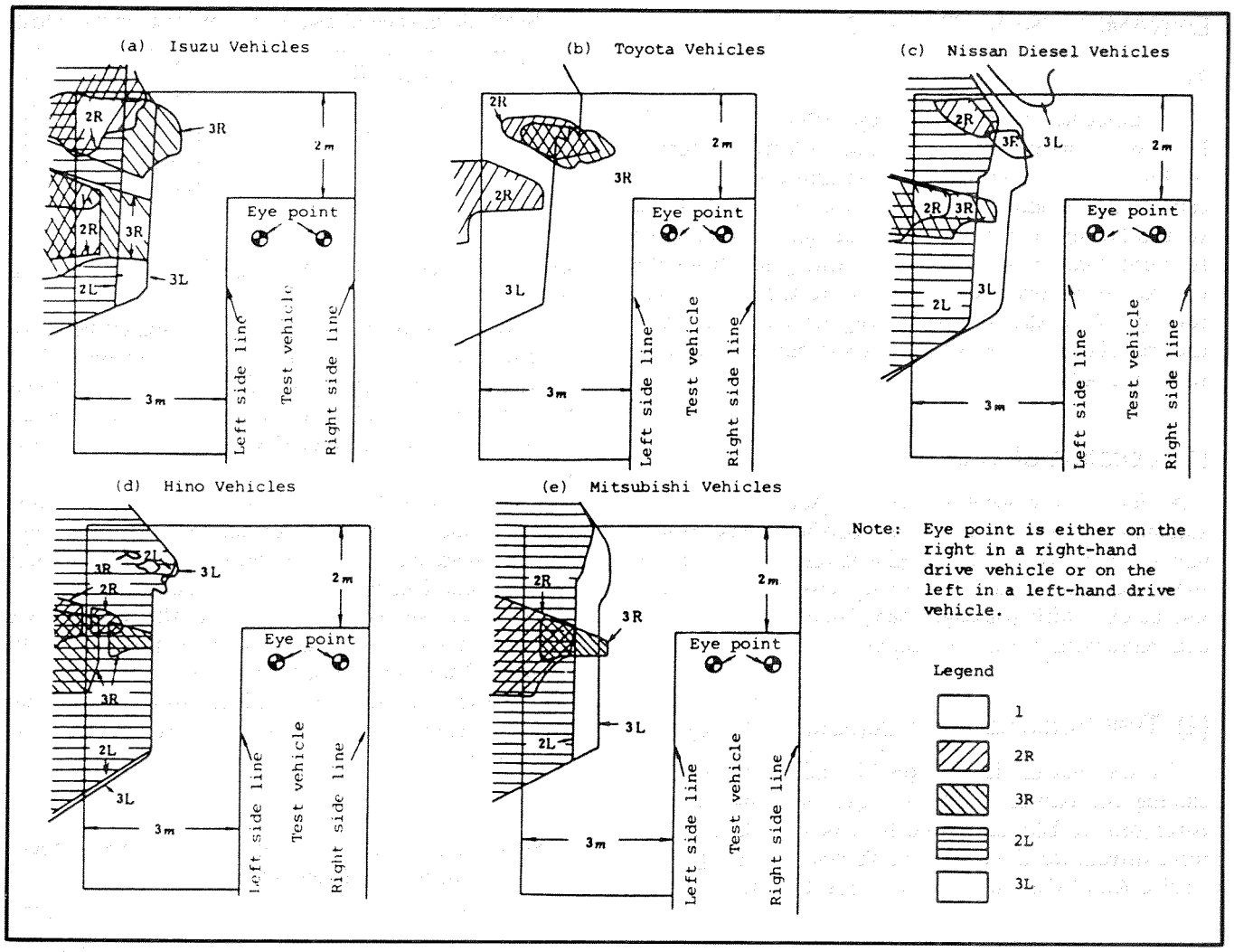


Figure 8. Comparison of fields of direct view on the road surface within the reference area.

though there are some for the experimental right-hand drive vehicles and more for the experimental left-hand drive vehicles. Comparing the visibility-improved vehicles with the low-floored vehicles, the vision areas are almost the same for all right-hand drive vehicles except the dump trucks. In the case of the right-hand drive dump trucks, the vision area of the low-floored vehicle is larger than that of the visibility-improved vehicle.

For the left-hand drive vehicles, the vision areas of the low-floored vehicles are slightly larger than those of the visibility-improved vehicles.

For all test vehicles, the location of the fields of direct view is in the forward-left of each of them and in the left sideward of it as shown in Figure 8.

The observer has a vision area of some degree on the plane 1 m above the ground for the current model vehicles.

The vision area on the plane 1 m above the ground is the largest for the left-hand drive vehicles with a low floor (3L) among the experimental vehicles, the second largest for the left-hand drive vehicles with improved visibility (2L) and the right-hand drive vehicles with a low floor (3R) followed by the right-hand drive vehicles with improved visibility (2R).

In the case of the vision area on the plane 1 m above the ground, the vision areas exist also in the forward of the vehicles in addition to the forward-left of them and the left sideward of them.

For the low-floored vehicles, especially, the forward part in the vision area accounts for a comparatively large proportion of the whole vision area.

(2) Fields of Indirect View

The difference in the vision areas in fields of indirect view is comparatively small between the current model vehicles and the experimental vehicles.

The vision area on the ground is larger than that on the plane 1 m above the ground.

The vision areas of some experimental left-hand drive vehicles are smaller than those of the current model vehicles on the plane 1 m above the ground in particular.

DYNAMIC VISIBILITY TEST

Test Procedures

A subject has an eye camera on. While a test vehicle he drives turns left at a crossroads with traffic signals, his line of sight is recorded on a 16 mm film by the eye camera. The windows and view mirror systems of the test vehicle he turned his eyes upon are surveyed with the recorded film in the process of turning left from the entrance of a crossroads (stop line) to the point where turning left finishes (corresponding to the point where the test vehicle gets ready for going straight ahead passing the crossroads).

(1) Location of Test

As for the test location, we used the courses in an automobile driver's school and a driving license examination center. The traffic conditions on the public roads were simulated in and around the crossroads on these test courses with passenger cars, motorcycles, bicycles and pedestrians passing at random.

(2) Test Vehicles and Subjects (Drivers)

The test was carried out on 10 vehicles in total, including the current model vehicles, manufactured by Isuzu Motors Ltd. and Hino Motors Ltd. Subjects are three drivers for the dump trucks and four for general trucks. All of them were professional drivers.

(3) Frequency of Test Runs

The test runs for the dynamic visibility test were repeated 139 times in total. The frequencies of test runs are shown in Table 12.

Table 12. Frequency of test runs in dynamic visibility test.

Kind of vehicle \ Vehicle type	Current model vehicle	Visibility-improved vehicle (right-hand drive)	Visibility-improved vehicle (left-hand drive)	Low-floored vehicle (right-hand drive)	Low-floored vehicle (left-hand drive)
Dump truck	21	17	11	11	11
General truck	18	15	11	15	9

Results of Dynamic Visibility Test

(1) Utilization of View Mirror Systems and Window Openings by the Drivers on Isuzu Dump Trucks in Turning Left

It is shown in Table 13 how each of the mirrors and window openings was utilized by the drivers on each test vehicle in turning left on every test run.

For I-1, a driver can utilize the rear-view mirror, the side-and-under-view-mirror, the under-view mirror and the supplementary window in the lower part of the left-hand door for the purpose of confirming the traffic condition in turning left.

In the case of this vehicle, both the rear-view mirror and the side-and-under-view mirror were utilized in almost all test runs, and the supplementary window was sometimes used in spite of the small vision area through it.

In the case of I-2R, the tendency to utilize the mirror systems and window openings is similar to that of I-1, and the newly-adopted supplementary window was used fairly often. For I-2L, the left-hand door window was utilized, and the fact remarkably distinguishes it from I-1.

When I-2L goes ahead in the oblique left direction following the beginning of turning left, the driver on it can get a field of direct view in the same direction through the left-hand door window. In I-3R, the driver is able to recognize the oblique left-forward zone through the lower left part of the windshield. Therefore, this part of the windshield was utilized in turning left.

In the case of I-3L, the tendency to utilize the view mirror systems and window openings is similar to that of the I-2L.

Table 13. Utilization of view mirror systems and window openings of Isuzu vehicles in turning left.

Test vehicle	Test run	Left-hand rear-view mirror	Side-and-under-view mirror	Under-view mirror	Left-hand door window	Supplementary window in the left-hand door	Supplementary window in the front panel	Lower left part in the windshield
I-1	1	o	x	x	x	x	-	-
	2	o	x	x	x	x	-	-
	3	o	o	x	x	x	-	-
	4	o	o	x	x	x	-	-
	5	o	o	x	x	x	-	-
	6	o	o	x	x	x	-	-
	7	o	o	x	x	x	-	-
	8	o	o	x	x	o	-	-
	9	o	o	x	x	o	-	-
	10	o	o	x	x	o	-	-
	11	o	o	x	x	o	-	-
	12	o	o	x	x	x	-	-
	13	o	o	x	x	x	-	-
	14	o	o	x	x	x	-	-
	15	o	o	x	x	x	-	-
	16	o	o	x	x	x	-	-
	17	o	o	x	x	x	-	-
	18	o	o	x	x	x	-	-
	19	o	o	x	x	x	-	-
	20	o	o	x	x	x	-	-
	21	o	o	x	x	x	-	-
I-2R	1	o	o	x	x	x	-	-
	2	o	o	x	x	x	-	-
	3	o	o	x	x	x	-	-
	4	o	o	x	x	x	-	-
	5	o	o	x	x	x	-	-
	6	o	o	x	x	x	-	-
	7	o	o	x	x	x	-	-
	8	o	o	x	x	x	-	-
	9	o	o	x	x	x	-	-
	10	o	o	x	x	x	-	-
	11	o	o	x	x	x	-	-
	12	o	o	x	x	x	-	-
	13	o	o	x	x	x	-	-
	14	o	o	x	x	x	-	-
	15	o	o	x	x	x	-	-
	16	o	o	x	x	x	-	-
	17	o	o	x	x	o	-	-
I-2L	1	o	o	x	o	-	-	-
	2	o	o	x	o	-	-	-
	3	o	o	x	o	-	-	-
	4	o	o	x	o	-	-	-
	5	o	o	x	o	-	-	-
	6	o	o	x	o	-	-	-
	7	o	o	x	o	-	-	-
	8	o	o	x	o	-	-	-
	9	o	o	x	o	-	-	-
	10	o	o	x	o	-	-	-
	11	o	o	x	o	-	-	-
I-3R	1	o	o	x	x	x	x	o
	2	o	o	x	x	x	x	o
	3	o	o	x	x	x	x	o
	4	o	o	x	x	x	x	o
	5	o	o	x	x	x	x	o
	6	o	o	x	x	x	x	o
	7	o	o	x	x	x	x	o
	8	o	o	x	x	x	x	o
	9	o	o	x	x	x	x	o
	10	o	o	x	x	x	x	o
	11	o	o	x	x	x	x	o
I-3L	1	o	o	x	x	-	-	-
	2	o	o	x	x	-	-	-
	3	o	o	x	x	-	-	-
	4	o	o	x	x	-	-	-
	5	o	o	x	x	-	-	-
	6	o	o	x	x	-	-	-
	7	o	o	x	x	-	-	-
	8	o	o	x	x	-	-	-
	9	o	o	x	x	-	-	-
	10	o	o	x	x	-	-	-
	11	o	o	x	x	-	-	-

o : Used
x : Not used
- : Not applicable

(2) Utilization of View Mirror Systems and Window Openings by the Drivers on Hino Trucks in Turning Left

It is shown in Table 14 how mirrors and window openings were utilized by the drivers on each test vehicle on every test run.

For H-1, the rear-view mirror, the side-and-under-view mirror and the under-view mirror are available for confirming safety. In practice, the under-view mirror was not used at all and the side-and-under-view mirror was used in about half the number of test runs.

Each experimental vehicle by Hino Motors Ltd. is similar to the corresponding vehicle by Isuzu Motors Ltd. in the tendency to utilize the view mirror systems and window openings. However, the frequency of using the view mirror systems and the window openings is rather less for the former than the latter.

(3) Arrangement

The rear-view mirrors were always used in turning left by the drivers driving each of the test vehicles. The side-and-under-view mirror was often utilized for I-1, I-2R, I-2L, H-1 and H-2R, sometimes for 3L, and not at all for the rest of the test vehicles (I-3R, H-2L, H-3R and H-3L).

The under-view mirror was occasionally used for I-2R, but not at all for all of the test vehicles other than I-2R.

Table 14. Utilization of view mirror systems and window openings of Hino vehicles in turning left.

Test vehicle	Test run	Mirror and window	Left-hand rear-view mirror	Side-and-under-view mirror	Under-view mirror	Left-hand door window	Supplementary window in the left-hand door	Supplementary window in the front panel	Lower left part in the windshield
H-1	1		o	o	x	x	-	-	-
	2		o	o	x	x	-	-	-
	3		o	o	x	x	-	-	-
	4		o	o	x	x	-	-	-
	5		o	x	x	x	-	-	-
	6		o	x	x	x	-	-	-
	7		o	x	x	x	-	-	-
	8		o	x	x	o	-	-	-
	9		o	x	x	x	-	-	-
	10		o	x	x	x	-	-	-
	11		o	o	x	x	-	-	-
	12		o	o	x	x	-	-	-
	13		o	o	x	x	-	-	-
	14		o	x	x	x	-	-	-
	15		o	o	x	x	-	-	-
	16		o	o	x	x	-	-	-
	17		o	o	x	x	-	-	-
	18		o	x	x	x	-	-	-
H-2R	1		o	o	x	x	x	-	-
	2		o	o	x	x	x	-	-
	3		o	o	x	x	x	-	-
	4		o	o	x	x	x	-	-
	5		o	o	x	x	x	-	-
	6		o	o	x	x	x	-	-
	7		o	o	x	x	x	-	-
	8		o	o	x	x	x	-	-
	9		o	x	x	x	x	-	-
	10		o	x	x	o	x	-	-
	11		o	o	x	x	x	-	-
	12		o	o	x	x	x	-	-
	13		o	x	x	x	x	-	-
	14		o	x	x	x	o	-	-
	15		o	o	x	x	x	-	-

Test vehicle	Test run	Mirror and window	Left-hand rear-view mirror	Side-and-under-view mirror	Under-view mirror	Left-hand door window	Supplementary window in the left-hand door	Supplementary window in the front panel	Lower left part in the windshield
H-2L	1		o	x	x	o	-	-	-
	2		o	x	x	o	-	-	-
	3		o	x	x	o	-	-	-
	4		o	x	x	o	-	-	-
	5		o	x	x	o	-	-	-
	6		o	x	x	o	-	-	-
	7		o	x	x	o	-	-	-
	8		o	x	x	o	-	-	-
	9		o	x	x	o	-	-	-
	10		o	x	x	o	-	-	-
	11		o	x	x	o	-	-	-
H-3R	1		o	x	x	x	o	x	o
	2		o	x	x	x	o	x	x
	3		o	x	x	x	o	x	x
	4		o	x	x	x	o	x	x
	5		o	x	x	x	o	x	x
	6		o	x	x	o	x	x	x
	7		o	x	x	x	x	x	x
	8		o	x	x	x	x	x	x
	9		o	x	x	x	x	x	x
	10		o	x	x	x	x	x	x
	11		o	x	x	x	o	x	x
	12		o	x	x	x	o	x	x
	13		o	x	x	x	x	x	x
	14		o	x	x	x	x	x	o
	15		o	x	x	x	x	x	x
H-3L	1		o	x	x	o	-	-	-
	2		o	x	x	o	-	-	-
	3		o	x	x	o	-	-	-
	4		o	x	x	o	-	-	-
	5		o	x	x	o	-	-	-
	6		o	x	x	o	-	-	-
	7		o	x	x	o	-	-	-
	8		o	x	x	o	-	-	-
	9		o	x	x	o	-	-	-

o : Used
x : Not used
- : Not applicable

Comparing the usage of the window openings, the left-hand door windows were frequently used for the purpose of confirming safety in turning left in the left-hand drive vehicles, and the lower parts of the windshields were used in the right-hand drive vehicles with a low-floor. However, the newly-adopted supplementary windows were used only several times.

SUBJECTIVE EVALUATION TEST BY PROFESSIONAL DRIVERS

Test Procedures

To evaluate the visibility of the experimental vehicles, the five-points scale comparative test was carried out by using the current model vehicles as the standard. The test was carried out on the nine major items which include the various performances such as visibility, habitability, maneuverability, control and so on.

Evaluated items on visibility are shown in Table 15. The subjective evaluation test was performed by professional heavy duty truck drivers. They operated each test vehicle in place of the daily-used vehicles for a definite period (2 or 3 days) either on the regular routes or in their daily operating areas. Through the process of operating the test vehicle, they rated the performances of these vehicles by their feeling.

(1) Test Vehicles and Subjects (Drivers)

The test was performed on 24 trucks in total which comprise the experimental vehicles and the current model vehicles by five manufacturers shown in Table 1.

Subjects were classified into five groups according to the manufacturer of the vehicle which each of them operated daily.

Each group was composed of ten subjects.

Each of them performed the subjective evaluation test on the test vehicles in reference to the current model vehicle he operated daily.

(2) Location of Test

Using the truck terminals, where the subjects worked, as the bases, every test vehicle was used for routine transportation on public roads and highways around the terminals or on regular routes.

Table 15. Evaluated items on visibility in subjective evaluation test.

Major item	Minor item	Sub item
Visibility	1. Static visibility	(1) Field of direct view (2) Field of indirect view (3) Visibility by headlamp
	2. Dynamic Visibility	(1) Line of sight (2) Confirmability (3) Anti-dazzling, ghost

Table 16. Total travelling distance during subjective evaluation test.

(Unit: km)

Test vehicle \ Group		1st group	2nd group	Total
Isuzu	I-1	4,733	2,365	7,098
	I-2R	5,531	3,135	8,666
	I-2L	4,397	616	5,013
	I-3R	4,449	1,803	6,252
	I-3L	4,108	1,960	6,068
Toyota	T-1	1.930	6,785	8,715
	T-2R	1,572	5,924	7,496
	T-3R	2,328	7,197	9,525
	T-3L	2,165	6,329	8,494
Nissan Diesel	N-1	3,465	4,836	8,301
	N-2R	3,605	5,710	9,315
	N-2L	3,019	4,954	7,973
	N-3R	3,495	7,222	10,717
	N-3L	3,678	5,283	8,961
Hino	H-1	4,459	3,857	8,316
	H-2R	4,130	4,196	8,326
	H-2L	1,296	1,548	2,844
	H-3R	3,167	1,590	4,757
	H-3L	2,707	1,206	3,913
Mitsubishi	M-1	633	5,906	6,539
	M-2R	757	6,146	6,903
	M-2L	372	6,060	6,432
	M-3R	505	6,097	6,602
	M-3L	507	6,000	6,507
Total		67,008	106,725	173,733

Test Results

For each test vehicle, the total distance of travelling during the subjective evaluation test is shown in Table 16. The test results on the main evaluated items are shown in Table 17.

These results were obtained by statistically analyzing the results of the five-points scale comparative test on the performances of the experimental vehicles.

Visibility

(1) Static Visibility

For each of the experimental vehicles, the field of direct view was improved as shown in Table 17. However, the field of indirect view of every experimental vehicle was not remarkably improved in comparison with that of the current model vehicle corresponding to it. This coincides with the result of the static visibility test mentioned previously.

(2) Dynamic Visibility

Every experimental vehicle was evaluated superior to the current model vehicle in the ability for the driver to grasp the traffic condition in stopping, just before starting and in turning left at a crossroads among the items on visibility.

Consequently, it can be said that the original purpose in making experimental vehicle was attained.

However, some of the experimental vehicles were evaluated inferior to the current model vehicles in some of the items on visibility. For example, the 2L vehicles were evaluated inferior to the current model vehicles in the ability to allow drivers to confirm the traffic condition in turning right at a crossroads, the 3L vehicles in the ability to allow drivers to confirm the traffic condition in going straight ahead, and both of the 2L and 3L vehicles in the ability to allow drivers to confirm the traffic condition in their front and rear in passing.

Habitability, Maneuverability and Control

(1) Habitability

In terms of habitability, that of experimental vehicles was evaluated approximately the same as that of current model vehicles. However, the 3R and 3L vehicles were evaluated inferior to the current model vehicles in the performance of heat isolation.

(2) Maneuverability

The experimental vehicles other than the 2R vehicles were evaluated inferior to the current model vehicles in maneuverability.

(3) Control and Ease of Getting On and Off the Cab

In terms of control, the 2R vehicles were evaluated the same as the current model vehicles. However, the 2L and 3L vehicles were evaluated inferior to the current model vehicles in this point.

The 3R vehicles were evaluated superior to the current model vehicles in the ease of getting on and off.

CONCLUSIONS

As a step of the program for preventing traffic accidents caused by heavy duty trucks when turning left, five heavy duty truck manufacturers made experimental vehicles with improved field of view to examine the effect of the visibility improvement in traffic accident prevention at the request of MOT.

As the test results on these experimental vehicles, the conclusions are obtained as follows.

(1) It is confirmed from the static visibility test that each

Table 17. Result of subjective evaluation test.

o : Better x : Worse
- : Not changed Δ : Scattered

Major item	Minor item	Sub item	Detail	2R	2L	3R	3L
a. Visibility	(1) Static visibility	1) Field of direct view	o Forward and lower field of view through windows	o	o	o	o
			o Left sideward field of view through windows	o	o	o	o
		2) Field of indirect view	o Field of view through rear-view mirror	-	-	-	-
	(2) Dynamic visibility	1) Confirmability	o Confirmation of the circumstance around the vehicle itself in stopping, just starting	o	o	o	o
			o Integrated rating on confirmation of the circumstance in and around crossroad in turning left	o	o	o	o
			o Confirmation of the circumstance in and around crossroad in turning right	o	x	o	Δ
			o Confirmation of the traffic condition in going straight ahead	o	Δ	Δ	x
			o Confirmation of the traffic condition forward and rearward of the vehicle itself in passing	-	x	-	x
			o Confirmation of pedestrians, motorcycles and other vehicles around the vehicle itself in reversing	o	Δ	Δ	Δ
		(at rain)	o Visibility under the condition of mud splashing	-	-	x	x
		2) Anti-dazzling, ghost	o Glare due to the headlamp of opposing vehicle	-	Δ	x	Δ
b. Habitability	(1) Riding space	1) Around seat 2) Around bed	o Integrated rating on the ride space	-	-	Δ	Δ
	(2) Vibration and ride comfort		o Integrated rating on vibration and ride comfort	-	-	Δ	Δ
	(3) Air conditioning	Ventilation, air conditioning	o Integrated rating on comfort owing to ventilation and air conditioning	-	-	-	-
	(4) Isolation from heat		o Integrated rating on the ability to isolate from heat	-	-	x	x
c. Maneuverability	(1) Maneuverability on general road (Handling)	1) Lane change	o Integrated rating on stability and controllability in lane changing	-	-	-	x
		2) Obstacle avoidance maneuverability	o Integrated rating on stability and controllability in turning	-	Δ	Δ	x
	(2) Maneuverability on off-road		o Integrated rating on maneuverability on off-road	-	-	x	x
	(3) Ease of driving	1) Urban area	o Integrated rating on ease of driving in urban area	-	x	Δ	x
		2) Highway	o Confirmation of the traffic condition in following the next vehicle ahead	-	x	x	x
		3) Mountainous region	o Integrated rating on ease of driving in moutainous region	-	x	x	x
		4) Reversing, moving aside	o Maneuverability in reversing and moving aside	-	x	-	x
d. Control and getting on and off	(1) Control		o Integrated rating on control	-	x	-	x
	(2) Getting on and off		o Integrated rating on getting on and off	-	x	o	Δ

of the vision area directly recognized by a driver in an experimental vehicle is larger than that of the current model vehicle. The experimental vehicles, however, are comparable to the current model vehicles as to the vision area through the view mirror systems. In the subjective evaluation test, the evaluation leading to these facts was obtained.

In particular, the fields of direct view of the left-hand drive vehicles with a low floor are the largest among those of the test vehicles.

However, on the contrary, the fields of indirect view of some left-hand drive vehicles with a low floor are rather smaller than those of the current model vehicles.

(2) As a result of the dynamic visibility test on the utilization of the view mirror systems and window openings, it is found that the rear-view mirrors are always used in stopping, starting and turning left at a crossroads for all vehicles, and that the improvement of the field of direct view by means of lowered height of the eye point, enlarged window openings and newly-adopted supplementary windows more or less serves to confirm safety. This is supported by the result of the test on the visibility at turning left which is one of the items evaluated in the subjective evaluation test. Consequently, it should be said that the original purpose to make an experimental vehicle with improved field of view was attained.

(3) The left-hand drive vehicles with improved visibility and the low-floored vehicles (both right-hand and left-hand drive vehicles) were evaluated inferior to the current model vehicles in some of the evaluated items on the visibility in the subjective evaluation test such as the ability to confirm safety in going straight ahead or in passing.

(4) The experimental vehicles were evaluated to be approximately the same as the current model vehicles, except for some exceptions, as to the evaluated items on the habitability in the subjective evaluation test.

(5) Each of the experimental vehicles was generally evaluated inferior to the current model vehicles in the evaluated items on the maneuverability, such as that on off-roads, in the subjective evaluation test.

(6) The right-hand drive vehicles with improved visibility were evaluated the same as the current model vehicles in the evaluated items on the control and ease of getting on and off the cab in the subjective evaluation test.

However, the left-hand drive vehicles (both the visibility-improved and the low-floored vehicles) were evaluated inferior to the current model vehicles in these points.

The summarized conclusion is as follows.

It was proved that both of the visibility-improved vehicles and the low-floored vehicles surpass the current model vehicles in the ability to allow drivers to confirm the safety in stopping, turning left and reversing, and that the enlargement of window openings and the adoption of the supplementary windows are effective.

The visibility-improved vehicles, particularly the right-hand drive vehicles, seem possible to be commercialized without any drastic modification of the current design concept. However, these don't necessarily have sufficient fields of direct view at present.

For the low-floored vehicles, many problems still remain to be solved.

ACKNOWLEDGEMENT

This work was programed by the Committee for Evaluation of Experimental Heavy Duty Trucks (chairman: professor K. Higuchi). The authors wish to acknowledge the kind guidance and earnest discussion given by the members of the committee.

They also wish to express their gratitude to their colleagues who assisted them in the experiments and many people who contributed to various phases of this work.

The Volvo Electronic Traction Control (ETC) System—A Concept for Safe Driving

LARS LIND
Volvo Car Corporation
Gothenburg, Sweden

ABSTRACT

When driving on low-friction road surfaces or on roads with changing friction conditions, it is easy to lose control of the car, especially when stepping too hard on the accelerator pedal. The problem is increasing with more powerful engines such as high-performance, turbo-charged engines. Especially at overtaking, it is easy to lose driving wheel lateral stability by a too high wheel spin rate, causing dangerous skidding.

The Volvo ETC system is developed to avoid such situations. It is designed to optimize traction and lateral stability by controlling engine torque in response to the actual road conditions.

This paper describes the theoretical background, the components and the functions of the Volvo ETC system.

INTRODUCTION

From the point of view of road safety, the concept of vehicle speed is always relative. It has to be judged with respect to the actual road conditions—for instance the friction of the road surface. For example, a slow ride in a low-powered car in very slippery road conditions may be almost as dangerous as far as the risk of skidding is concerned as driving at 200 km/h in a high-powered performance car in very good friction conditions.

The friction between the wheels and the road surface is especially important if you want to change the vehicle speed rapidly. If you brake hard on a low friction road surface it is easy to lock the wheels and lose any possibility of steering away from a dangerous traffic situation. This may be counteracted by an anti-skid braking system, which has been documented before, and I will therefore not go into details here. Equally well, if you want to accelerate rapidly to overtake safely or want to adjust to a higher speed when driving on to a motorway, it is easy to spin the driving wheels, thereby losing traction and losing control of the front or rear end of the car, depending on where the driving wheels are.

Regardless what type of engine—high or low powered—we put into a vehicle it would be quite an achievement to be able to control and regulate the engine output to the actual road friction. When the road is slippery and sudden acceleration is required, the engine should provide only the amount of output which the grip between the wheels and the road surface will permit. This is basically the main idea of the Electronic Traction Control (ETC) system, a system developed by the Volvo Car Corporation. It controls the engine to provide optimum use of existing road grip for acceleration and lateral stability, including adaptation to variations in road friction, such as, for example, when icy conditions have to be negotiated.

THEORETICAL BACKGROUND

It is a fact that the wheels of the car seldom run with the same speed as the car itself. This may sound odd, but just think of the situation when you brake so hard that your wheels lock—the wheels have zero rolling speed but the car still moves. The opposite occurs when, on a slippery road, you try to accelerate quickly from zero speed—the driving wheels spin at a high speed but the car remains stationary.

Even between these extreme conditions, there is always a difference in speed between the wheels and the car—the wheel speed is lower than the car speed if you brake even very carefully, (known as "slip") and higher if you accelerate even very slowly, (known as "spin"). This is due to the elasticity of the rubber in the tread surface and the deformations caused by the acceleration or braking forces on the wheel. Only when the wheel is absolutely free-rolling—with no engine or braking power applied—is the spin or slip equal to zero.

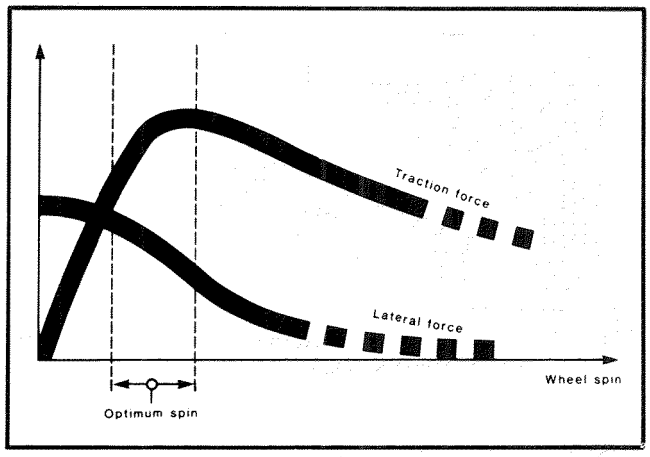


Figure 1. Relationship between traction force, lateral force and wheel spin rate.

The relative difference in speed between a driving wheel and a free-rolling wheel is called spin, S. There is a certain relationship between the rate of wheel spin, the traction force and the lateral force that can be adopted by a certain combination of tyre and road surface. The relationship can be seen in Figure 1. The traction force curve forms are similar for different combinations but the slope of the curve and the maximum level differ due to type of tyres and friction conditions of the road. The higher the friction, the higher the maximum level.

When a wheel is free-rolling (spin rate = 0) there is zero traction force transferred from the wheel to the road surface—no acceleration. At the same time there is maximum lateral force, which means that the risk of lateral skidding is minimum.

As engine torque is applied and increased, the wheel spin rate increases slightly, due to the deformation in the tyre tread. The traction force increases in proportion to the spin rate in this area, enabling the car to accelerate. The lateral force decreases, but not significantly, which means that you still have a reasonable margin for skidding. However, if the engine torque becomes higher than the maximum friction possible between wheel and road surface the wheel spin rate increases very rapidly, causing a dramatic decrease *both* in lateral stability and traction force. The car accelerates less efficiently and, more importantly, the lateral force approaches zero very quickly. This is when the car starts skidding, causing dangerous situations which are difficult to handle even by an experienced driver.

The aim for the Volvo ETC-system is to maintain an optimum spin rate for the driving wheels to allow maximum acceleration, and, at the same time, to maintain a high lateral force to ensure a good margin for skidding.

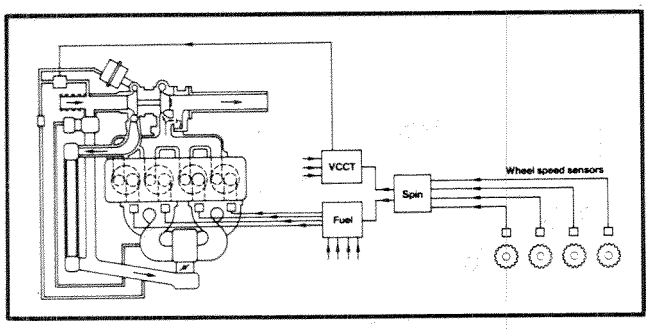


Figure 2. Simplified block diagram showing ETC, VCCT and fuel injection systems.

SYSTEM COMPONENTS

The ETC-system, Figure 2, consists of four wheel-speed sensors, one in each wheel, and an electronic control unit for signal conditioning of the wheel speed signals, with interface to an existing electronic fuel injection system and turbo charge control system, if present.

The VCCT in the figure stands for Volvo Computer Control Turbo, and is a turbo charge control system also developed by the Volvo Car Corporation. It should be underlined, however, that the ETC-system is not linked or limited to turbo-charged engines. It also performs a sound function with less powerful engines.

In each wheel is installed a toothed ring and a magnetic sensor for independent sensing of each wheel-speed, Figure 3.

The toothed ring rotates close to the sensor, inducing changes in magnetic flux. The sensor output signal is an alternating voltage with a frequency proportional to the speed of each wheel.

The electronic control unit, Figure 4, contains circuits to detect the four wheel speeds, to make comparisons between them and to decide whether to decrease or increase engine torque by action upon the fuel injection and turbo charge control system.

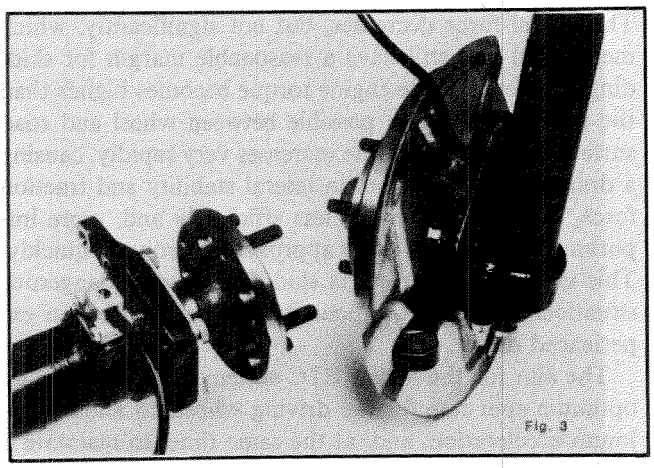


Figure 3. Installation of wheel speed sensors.

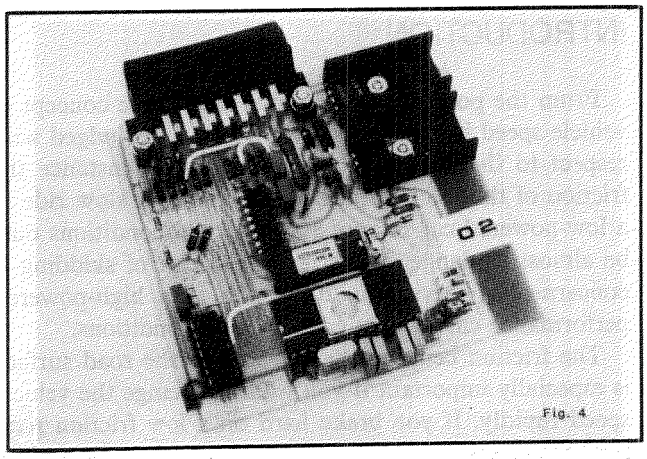


Figure 4. Prototype electronic control unit.

The electronic circuits may be contained in a separate box but may also be integrated in the VCCT microprocessor control unit. This prototype is based on a 1-chip microcomputer with an EPROM memory of 3,5 k bytes for development purposes.

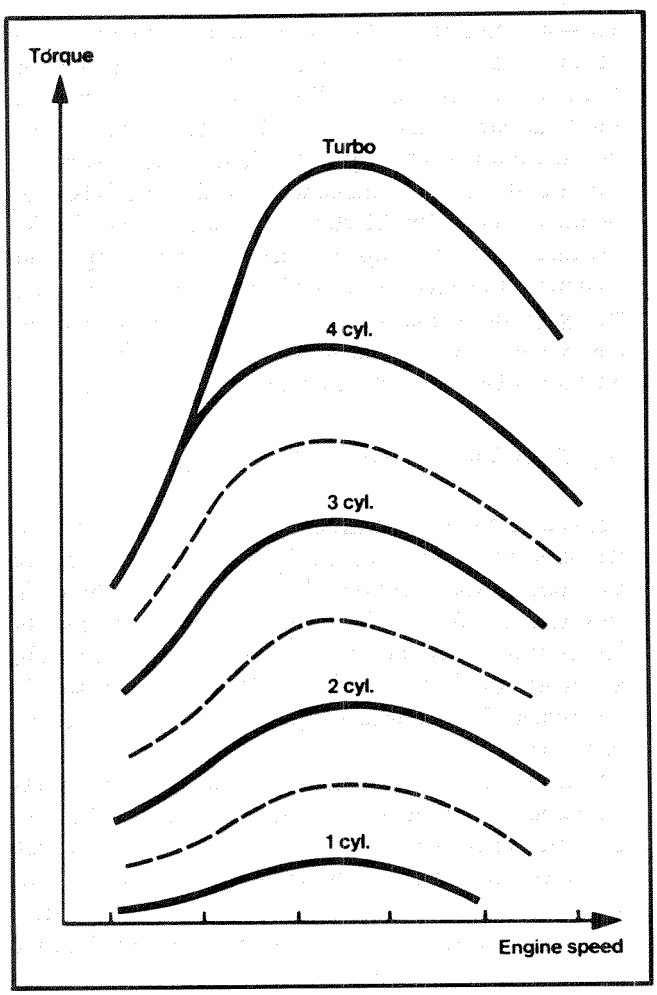


Figure 5. Reduction of engine torque in stages.

SYSTEM FUNCTION

In order to determine the spin rate of a given driving wheel, the speed signal from that wheel is compared with that from the free rolling wheel on the same side of the car. The same pair comparison is made on the other side. If any of these comparisons show that one driving wheel speed is (for instance) 5% higher than the corresponding free rolling wheel, spin is detected. This will cause the turbo charge to switch off, Figure 5.

If the spin rate continues to increase, the ETC-system will switch into the electronic fuel injection system and cut off the fuel supply to one or more cylinders, in stages and in proportion to wheel spin. The number of stages may vary, but in the prototype the fuel supply is cut by ½ cylinder per stage by cutting out half the number of fuel injection pulses.

This means that the engine torque is reduced in stages of ½ cylinders until the spin rate starts to decrease. The fuel supply is then switched on again in stages according to the actual spin. This will cause the spin rate to oscillate around the optimum value for traction force and lateral force. The cycling frequency is typically 1-5 times per seconds. The lowest engine torque occurs at a spin rate above approximately 20% where only one cylinder is active.

SUMMARY

The Volvo Electronic Traction Control System has been designed to optimize traction and lateral stability by controlling engine torque in response to the actual road conditions. It has been developed to further increase safe driving, particularly handling and stability when driving and overtaking on slippery roads.

Special Technical Session

The Legal System of Japan on Motor Vehicles*

KAZUHIKO MORISAKI
KUNIO TAKAHASHI
Engineering Division, Motor Vehicles Department, Road Transport Bureau, Ministry of Transport

Part 1: Outline of Legal System on Motor Vehicles

Introduction

In Japan, the recent progress of motorization has been remarkable, and today we cannot talk about social activities without including motor vehicles. In this series entitled "Legal System of Japan on Motor Vehicles", we will explain in seven installments the contents of various systems mainly on structures of vehicles in the environments surrounding motor vehicles.

As the first installment of the series, we explain in the present issue the outline of the legal system relating to motor vehicles centering around the Road Vehicles Act so as to provide a general picture of how the laws and acts relating to motor vehicles have been legislated in Japan. We hope this series will be of help to those concerned with motor vehicles in foreign countries in understanding the various measures in Japan governing motor vehicles from the side of hardware.

Outline of This Series

Before embarking on the main subject, we will explain the outline of contents of the respective installments.

1st Installment: Outline of Legal System on Motor Vehicles

Explanation will be made on various systems under the Road Vehicles Act and at the same time the outline of the Road Traffic Law, the Air Pollution Control Law, etc.

2nd Installment: Safety Regulations for Motor Vehicles

Furthermore, as to the Safety Regulations for Road Vehicles, explanation will be made on the environment surrounding motor vehicles such as the number of motor vehicles, the number of traffic accidents, etc. and also on the system of safety regulations under the Road Vehicles Act and circumstances leading up to the main amendment. On the other hand, contents of recommendations by the Council for Transport Technics which is preparing a plan to strengthen and expand the safety regulations will be explained.

3rd Installment: Motor Vehicle Pollution Control Measures and Energy-Saving Measures

As to the regulations of exhaust emissions for motor vehicles and the regulations of noise, explanation will be made on the outline and circumstances of regulations and at the same time on the environmental standards laid down by the Basic Law for Environmental Pollution Control and the present pollution situation, etc.

In addition, regarding the energy-saving measures of motor vehicles, the Rationalization of Energy Consumption Act and the standards such as a goal for improving fuel consumption, etc. based on the said Act will be explained.

4th Installment: Motor Vehicle Type Approval System

As the type approval systems for the purpose of examining whether motor vehicles meet safety and pollution control regulations, there are two systems, the Type Designation System and the Type Notification System, which will be explained in this installment.

In applying such systems, for a concrete application of safety and pollution control regulations, technical requirements, standards for type approval testing and test procedures are determined, an outline of which will be provided.

In addition, reference will be made to the recall system, which will be applied in case the structure and devices of a motor vehicle have any defect which may cause a problem affecting the safety or pollution control.

5th Installment: Motor Vehicle Inspection and Registration System

Explanation will be made not only on the vehicle inspection system whereby the Government itself inspects motor vehicles at its Land Transport Office to determine whether they meet the safety regulations, but also on the actual inspection procedures, facilities, personnel, etc.

Further, the registration system for motor vehicles which have passed the inspection will also be explained.

* Received 10th July, 1980

6th Installment: Motor Vehicle Accident Preventive Measures and Research System of the Government

Explanation will be made on various measures for preventing motor vehicle accidents and also on measures for prevention of accidents from the sides of operational management and vehicle maintenance of motor vehicle transportation businesses.

Further, explanation will be made on the safety measures for the transportation of dangerous materials such as gasoline, liquefied petroleum gas, high-pressure gas, etc. In addition, we will explain the test and research system conducted by the Government relating to the safety, pollution and energy-saving of motor vehicles.

7th Installment: Maintenance and Repair of Motor Vehicles

Explanation will be made on the periodical inspection and maintenance system for the prevention of motor vehicle accidents and at the same time reference will be made to the actual procedures of maintenance and repair and the conditions of application.

Further explanation will be made on the approval system aiming at a sound development of motor vehicle maintenance and repair business and the designated motor vehicle repair business system whereby the motor vehicle inspection conducted at the Land Transport Office can be substituted by repair and inspection at designated maintenance and repair shops.

Explanation will also be made on the authorization system of motor vehicle maintenance and repair mechanics aiming at improving their skills in maintaining and repairing motor vehicles.

Outline of Legal System on Motor Vehicles

The total number of motor vehicles in use in Japan was only 140,000 in 1945, but in recent years there has been a remarkable increase in the number of motor vehicles in use. The number doubled to 5 million in 1963, 10 million in 1967 and 20 million in 1971 and reached 37 million at the end of March, 1980, a jump of about 7% over each previous year, and the number of persons who have driver's licenses now exceeds 40 million (Table 1: Number of motor vehicles in use and number of persons who have driver's licenses). During the above period, the performance of motor vehicles also improved greatly, and with the improvement of roads, enlargement of economic scale, etc. the diffusion of motor vehicles increased outstandingly, with the result that they have considerable influence on Japan's economic and social life.

Incidental to such spread and popularization of motor vehicles, the legal system has been improved and completed gradually. The following chart outlines the main laws and acts relating to motor vehicles:

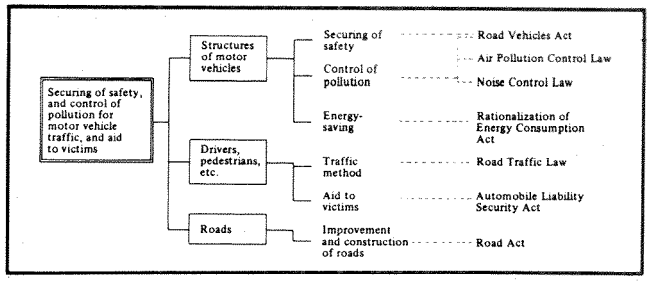


Chart of legal system relating to motor vehicles.

The outline of these main Acts and Laws is as follows:

The Road Vehicles Act, or 1951-Law No. 185, was enacted on June 1, 1951 and has been the changing conditions.

This Act sets out requirements for structures and systems of motor vehicles for the purpose of ensuring the safety and pollution control of motor vehicles and at the same time establishes a system for inspection and registration of motor vehicles, aiming at their appropriate use. Further, the Act also obliges proper maintenance and repair of motor vehicles in order to ensure the safe performance, etc. of structures and systems of motor vehicles and provides for the maintenance and repair business.

Since the Act is the fundamental law to regulate motor vehicle structure, further explanation will be made on the outline of the main items:

Safety regulations for road vehicles:

In order to secure the safety of motor vehicles and control pollution on the structures and systems of motor vehicles, the minimum technical requirements for safety are determined. Therefore, motor vehicles must be manufactured so as to meet such requirements.

Further, regulations must be met in conducting maintenance and inspection of motor vehicles which are presently used. The respective technical requirements are determined in the "Safety Regulations for Road Vehicles" as the Ministry of Transport Ordinance (Ministry of Transport Ordinance No. 67 of July 28, 1951) under the provisions of the Act.

Registration system of motor vehicles:

In order to certify officially the ownership of motor vehicles, all motor vehicles (excluding motorcycles and motor vehicles with special structures) must be registered and must bear motor vehicle registration number plates. No unregistered motor vehicle is permitted to run on the roads.

Table 1. Number of motor vehicles in use and number of persons who have driver's licenses.

Year	Number of motor vehicles (1)											Number of persons who have driver's licenses	Index
	Buses, passenger cars, trucks								Others (4)	Grand total	Index		
	Buses	Index	Passenger Cars (2)	Index	Trucks (3)	Index	Total	Index					
1954	34,187	18	138,518	2	234,598	4	407,303	3	343,952	751,255	4	2,788,888	10
'55	34,187	18	153,325	2	250,005	5	437,517	4	520,656	958,173	5	3,780,241	13
'56	38,050	20	181,074	3	294,213	6	513,337	4	537,873	1,051,210	6	4,299,688	15
'57	42,724	23	218,524	3	372,442	7	633,690	5	606,783	1,240,473	7	5,009,417	17
'58	46,957	25	259,631	4	454,617	9	761,205	6	673,372	1,434,577	8	6,025,653	21
'59	51,030	27	318,758	5	574,481	11	944,269	8	812,646	1,756,915	10	7,654,152	27
'60	56,179	30	419,921	6	738,001	14	1,214,101	10	1,118,577	2,332,678	13	10,723,136	37
'61	63,450	34	569,469	9	971,306	18	1,604,225	13	1,544,814	3,149,039	18	11,871,634	41
'62	72,029	38	742,918	11	1,245,543	24	2,060,490	17	2,029,971	4,090,461	23	13,919,536	48
'63	81,414	43	1,009,868	15	1,608,535	30	2,699,817	22	1,949,477	4,649,294	26	16,211,847	56
'64	93,011	49	1,370,591	21	2,042,629	39	3,506,231	29	2,284,532	5,790,763	32	18,989,959	66
'65	102,695	55	1,787,501	27	2,469,322	47	4,359,518	36	2,632,737	6,992,255	39	21,103,820	73
'66	114,289	59	2,337,606	36	3,019,827	57	5,471,722	48	3,033,858	8,505,580	48	22,856,547	79
'67	129,217	69	3,095,070	47	3,699,541	70	6,923,828	58	3,589,340	10,513,168	59	24,697,215	86
'68	148,286	79	4,067,173	62	4,358,308	82	8,573,767	71	4,312,304	12,886,071	72	26,343,152	92
'69	170,137	91	5,296,090	81	4,934,128	93	10,400,355	87	5,062,958	15,463,313	87	24,782,107	100
'70	187,980	100	6,534,558	100	5,299,821	100	12,022,359	100	5,826,497	17,848,856	100	26,449,229	92
'71	194,360	104	7,871,277	120	5,639,560	106	13,705,197	114	6,381,642	20,086,839	117	28,000,367	97
'72	202,819	108	9,531,576	146	6,078,692	115	15,813,087	132	6,790,727	22,603,814	127	29,474,643	102
'73	212,622	113	11,429,191	175	6,617,875	114	18,259,688	154	6,909,085	25,168,773	141	30,778,778	107
'74	222,430	118	12,927,078	183	6,950,769	131	20,100,277	167	6,839,366	26,939,643	151	32,143,688	112
'75	226,284	120	14,625,196	224	7,298,479	138	22,149,959	184	6,028,405	28,178,364	158	33,482,514	116
'76	222,796	119	15,667,959	240	7,656,609	144	23,547,364	196	6,162,736	29,710,100	166	35,148,742	122
'77	224,648	120	17,112,567	262	8,054,405	152	25,391,620	211	6,696,783	32,088,403	190	37,022,922	129
'78	226,970	121	18,976,620	290	8,365,869	158	27,569,459	229	6,628,987	34,198,457	192	39,174,099	136
'79	229,039	122	20,447,090	313	8,670,578	164	29,346,707	244	6,961,074	36,307,781	203	41,042,876	166

(1) Excluding small-sized special motor vehicles and two-wheel motor vehicles
(2) Excluding light motor vehicles
(3) Excluding light motor vehicles
(4) Large-sized special vehicles, vehicles for special uses, light passenger and cargo carrying vehicles

Table 2. Actual length of roads.

(Unit: km)
(Paving rate: %)

Year	Actual extension	Index	Paving rate	Index	Extension of sidewalks	Index
1956	943,430	92	2.1	12	–	–
'57	952,932	93	2.3	13	–	–
'58	959,950	94	2.5	14	–	–
'59	961,914	94	2.8	15	–	–
'60	972,949	95	3.1	17	–	–
'61	968,441	95	3.5	19	–	–
'62	971,522	95	4.1	23	–	–
'63	967,534	95	5.1	28	–	–
'64	984,753	96	6.2	34	–	–
'65	988,774	97	7.4	41	–	–
'66	996,630	97	9.0	49	–	–
'67	994,926	97	10.8	59	–	–
'68	1,004,315	98	12.6	69	–	–
'69	1,013,951	99	14.9	82	–	–
'70	1,022,936	100	18.2	100	17,004.7	100
'71	1,036,895	101	21.7	119	21,438.9	126
'72	1,048,496	103	25.1	138	26,288.1	155
'73	1,057,648	103	28.6	157	29,539.5	174
'74	1,066,028	104	31.6	174	33,750.0	199
'75	1,077,320	105	34.4	189	38,920.5	229
'76	1,086,230	106	37.1	204	42,959.8	253
'77	1,095,053	107	40.0	220	47,394.6	279
'78	1,103,731	108	42.8	235	52,032.1	306

Note: Statistical data of the Ministry of Construction (excl. national expressway)

Table 3. Running distance of motor vehicles.

(Unit: km)
(Paving rate: %)

Year	Total running kilometers	Index	Buses	Index	Passenger cars	Index	Trucks	Index
1956	13,859,887	6	1,398,674	26	4,852,452	4	7,608,761	8
'57	16,695,533	7	1,575,229	29	6,774,381	6	9,345,923	9
'58	19,207,242	9	1,748,883	32	6,641,197	6	10,817,162	11
'59	21,492,342	10	1,932,814	36	7,433,941	6	12,125,587	12
'60	28,163,992	13	1,994,286	37	8,724,773	7	17,444,933	17
'61	35,545,397	16	2,206,014	41	11,866,980	10	21,472,403	22
'62	42,963,344	19	2,448,188	45	15,388,572	13	25,126,584	25
'63	56,282,902	25	2,775,045	51	20,934,617	17	32,573,240	33
'64	70,329,156	31	3,326,712	62	25,913,310	22	41,089,134	41
'65	82,155,224	36	3,589,909	67	34,002,311	28	44,563,004	45
'66	104,746,513	46	3,898,335	72	43,489,704	36	57,358,474	57
'67	132,213,728	59	4,278,356	83	58,100,265	48	69,835,107	70
'68	163,421,042	72	4,707,369	87	76,207,835	63	82,505,838	83
'69	193,602,944	86	5,013,385	93	96,572,290	80	92,017,269	92
'70	226,016,858	100	5,394,083	100	120,582,367	100	100,040,408	100
'71	243,478,952	108	5,378,047	100	137,399,672	114	100,701,233	101
'72	259,593,276	115	5,666,980	105	146,272,038	121	107,654,258	108
'73	276,194,188	122	5,473,747	102	164,010,339	136	106,710,102	107
'74	266,484,708	118	5,318,404	99	161,009,634	134	100,156,670	100
'75	286,345,148	127	5,450,669	101	176,035,354	146	104,859,155	105
'76	309,698,312	137	5,469,302	101	186,082,581	154	118,146,429	118
'77	342,325,595	151	5,722,674	106	205,366,844	170	131,236,077	131
'78	361,261,270	160	5,896,439	109	220,362,502	183	135,002,329	135

Note: Statistical data of the Ministry of Transport

On the other hand, for the identification of motor vehicles, the number and type must be embossed on the chassis and engine.

Motor vehicle inspection system:

In order to ensure the safety of motor vehicles and control pollution by motor vehicles, a motor vehicle inspection system is provided and all motor vehicles which run on the roads must have received such inspection and obtained a valid motor vehicle inspection certificate. In case of a new motor vehicle which has not yet obtained the inspection certificate, the vehicle must be inspected by the Government (initial inspection) to obtain the inspection certificate. In the certificate, the effective period of two years in case of a passenger carrying motor vehicle and one year each in case of bus and truck is entered, respectively.

In case such a motor vehicle is to be used continuously after the effective period, the motor vehicle must be inspected by the Government or a maintenance and repair shop designated by the Government (continuation inspection) and the effective period may be extended. The result of inspection will be judged on the basis of whether the motor vehicle meets the Safety Regulations for Road Vehicles and the related circular notices or not.

Table 4. Changes in volume of traffic by transportation means.

1. Cargo:

	Tonnage of domestic cargo transported (Unit: 1 million tons)							Ton-kilometers of domestic cargo transported (Unit: 100 million ton-kilometers)							Transportation share (%)							
			Railways							Railways					Tonnage					Ton-kilometers			
Year	Total	Motor vehicles	Total	Japan National Railways	Private railways	Coastal vessels	Domestic airways	Total	Motor vehicles	Total	Japan National Railways	Private railways	Coastal vessels	Domestic airways	Motor vehicles	Rail-ways	Coastal vessels	Air-ways	Motor vehicles	Rail-ways	Coastal vessels	Air-ways
1950	523	309	165	136	29	49	–	647	54	338	333	5	255	–	59	31	9	–	8	52	39	–
'55	831	569	193	160	33	69	–	818	95	433	426	7	290	–	69	23	8	–	12	53	35	–
'59	1,394	1,062	220	181	39	112	–	1,198	183	505	497	8	510	–	76	16	8	–	15	42	43	–
'60	1,533	1,156	238	195	43	139	0.009	1,389	208	545	536	9	636	0.06	75	16	9	0	15	39	46	0
'61	1,841	1,437	251	206	45	153	0.015	1,562	266	584	575	9	712	0.10	78	14	8	0	17	37	46	0
'62	2,012	1,602	248	202	46	162	0.018	1,615	324	572	563	9	719	0.12	80	12	8	0	20	35	45	0
'63	2,378	1,948	253	206	47	177	0.024	1,810	420	602	592	10	788	0.15	82	11	7	0	23	33	44	0
'64	2,634	2,210	259	207	52	165	0.031	1,842	472	599	589	10	771	0.20	84	10	6	0	26	32	42	0
'65	2,626	2,193	253	200	53	180	0.033	1,864	484	574	564	9	806	0.21	83	10	7	0	26	31	43	0
'66	3,106	2,654	250	196	54	202	0.051	2,095	649	559	550	9	887	0.32	85	8	7	0	31	27	42	0
'67	3,744	3,272	259	203	56	213	0.070	2,442	811	595	585	10	1,036	0.43	87	7	6	0	33	24	43	0
'68	4,330	3,813	254	199	55	263	0.082	2,704	1,015	600	590	10	1,088	0.52	88	6	6	0	38	22	40	0
'69	4,741	4,165	253	197	56	323	0.104	3,152	1,199	612	602	10	1,340	0.65	88	5	7	0	38	19	43	0
'70	5,259	4,626	256	199	57	377	0.116	3,506	1,359	634	624	10	1,512	0.74	88	5	7	0	39	18	43	0
'71	5,434	4,796	251	193	58	387	0.127	3,621	1,427	623	613	10	1,570	0.81	88	5	7	0	39	17	44	0
'72	5,876	5,203	239	182	57	434	0.167	3,892	1,536	596	586	10	1,759	1.16	88	4	8	0	39	15	46	0
'73	5,716	4,912	229	176	53	575	0.204	4,072	1,410	583	574	9	2,077	1.50	86	4	10	0	35	14	51	0
'74	5,084	4,377	206	158	48	501	0.185	3,758	1,308	525	516	9	1,924	1.40	86	4	10	0	35	14	51	0
'75	5,030	4,393	185	142	43	452	0.190	3,609	1,297	474	466	8	1,836	1.52	87	4	9	0	36	13	51	0
'76	5,000	4,356	186	141	45	458	0.200	3,734	1,326	463	455	8	1,943	1.60	87	4	9	0	36	12	52	0
'77	5,101	4,456	175	132	43	470	0.226	3,869	1,431	413	406	7	2,023	1.83	88	3	9	0	37	11	52	0
'78	5,541	4,860	178	133	45	503	0.265	4,095	1,561	412	404	8	2,120	2.24	88	3	9	0	38	10	52	0

2. Passengers:

	Number of passengers transported (Unit: 1 million persons)							Person-kilometers of passengers transported (Unit: 100 million person-kilometers)							Transportation share (%)			
		Motor vehicles		Railways					Motor vehicles		Railways				Passengers		Person-kilometers	
Year	Total	Buses	Passenger cars	Japan National Railways	Private railways	Coastal vessels	Domestic airways	Total	Buses	Passenger cars	Japan National Railways	Private railways	Coastal vessels	Domestic airways	Motor vehicles	Rail-ways	Motor vehicles	Rail-ways
1950	9,813	1,393	122	3,001	5,297	–	–	1,146	83	7	691	365	–	–	15	85	8	92
'55	14,116	3,556	706	3,849	5,932	74	0.00	1,658	233	42	912	449	20	2	30	70	17	83
'59	18,985	5,937	1,281	4,813	6,856	96	0.83	2,213	392	88	1,142	561	26	4	38	62	22	78
'60	20,291	6,291	1,610	5,124	7,166	99	1.22	2,433	440	115	1,240	604	27	7	39	61	23	77
'61	22,379	7,144	2,150	5,284	7,691	108	2.01	2,663	492	160	1,318	653	29	11	42	58	25	75
'62	24,190	7,873	2,564	5,610	8,029	111	2.99	2,898	544	196	1,412	698	30	18	43	57	26	74
'63	26,177	8,411	3,152	6,040	8,458	112	4.05	3,222	629	265	1,527	747	30	24	44	56	28	72
'64	29,384	10,324	3,695	6,410	8,831	119	4.80	3,556	760	319	1,642	777	31	27	48	52	31	69
'65	30,792	10,557	4,306	6,722	9,076	126	5.19	3,821	801	406	1,740	814	31	29	48	52	32	68
'66	32,088	10,794	5,236	6,842	9,081	130	4.89	4,033	839	546	1,758	830	31	29	50	50	35	65
'67	34,189	11,232	6,663	7,048	9,246	145	6.46	4,422	905	741	1,843	861	33	39	52	48	37	63
'68	36,107	11,529	8,214	6,868	9,336	152	8.44	4,812	953	1,036	1,848	889	35	51	55	45	42	58
'69	37,993	11,674	10,111	6,541	9,493	163	10.83	5,281	1,002	1,419	1,815	938	37	70	57	42	47	53
'70	40,606	11,812	12,221	6,534	9,850	174	15.43	5,872	1,029	1,813	1,897	991	48	94	59	41	50	50
'71	42,010	11,634	13,687	6,659	9,836	178	16.42	6,177	1,008	2,116	1,903	997	50	103	60	39	52	48
'72	43,275	11,711	14,572	6,724	10,061	188	18.86	6,482	1,082	2,203	1,978	1,025	67	127	61	39	52	48
'73	44,563	11,390	15,922	6,871	10,185	171	23.54	6,737	1,117	2,257	2,081	1,048	74	160	62	38	52	48
'74	45,080	11,206	16,105	7,113	10,476	155	25.26	6,934	1,158	2,284	2,156	1,085	75	176	61	39	52	48
'75	46,176	10,731	17,681	7,048	10,540	151	25.44	7,104	1,101	2,508	2,153	1,085	66	191	62	38	53	47
'76	46,667	10,231	18,679	7,180	10,402	147	28.25	7,093	987	2,645	2,107	1,088	65	201	62	38	53	47
'77	47,548	10,189	19,416	7,068	10,699	143	32.89	7,108	1,046	2,640	1,997	1,126	63	236	62	37	52	44
'78	49,351	9,964	21,446	6,997	10,763	144	37.10	7,472	1,070	2,960	1,958	1,153	62	269	64	36	54	42

Type designation system:

The type designation of motor vehicles is established for motor vehicles manufactured in large quantity uniformly. Manufacturers or importers of motor vehicles can apply for type designation of motor vehicles to the Minister for Transport by presenting necessary documents and the motor vehicles.

The type designation will be made by determining whether the subject motor vehicle meets the Safety Regulations and whether motor vehicles identical to the motor vehicle for which application is being submitted can be manufactured.

The person who has obtained the type designation must, if he intends to manufacture and sell the type-designated motor vehicles, inspect the motor vehicles to determine whether they meet the Safety Regulations and that their uniformity is secured (completion inspection) and issue the termination certificate of completion inspection.

If, at the time of initial inspection, this termination certificate of completion inspection is presented, the Government will omit the enforcement of initial inspection and issue a motor vehicle inspection certificate.

Maintenance and repair system and maintenance and repair business system:

In order to ensure constant compliance with the Safety Regulations and prevent any decline in safety and use efficiency of motor vehicles, an operator of a motor vehicle is obliged to conduct a daily inspection before the operation every day and the user of a motor vehicle is obliged to make a periodical inspection and maintenance.

Moreover, it is provided that according to the number of motor vehicles possessed a maintenance and repair supervisor must be appointed and periodical maintenance and repair of the motor vehicles be made with the technology and at the responsibility of such a maintenance and repair supervisor. In addition, in order to improve the ability for maintenance and repair, a system of ability authorization for motor vehicle maintenance and repair mechanics is also provided.

In order to confirm that the disassembling repair of motor vehicles by a motor vehicle disassembling repair business meets the Safety Regulations and to promote the sound development of disassembling repair business, a system of authentication of business is effected based on conditions to the minimum extent required for safety. On the other hand, to rationalize the motor vehicle inspection system and for the convenience of users of motor vehicles, a system is provided to make best use of the inspection ability of private motor vehicle maintenance and repair businesses and to omit the periodical inspection by the Government, if a motor vehicle has received an inspection by a designated maintenance and repair business.

The Road Traffic Law, or 1960-Law No. 105, was enacted on June 25, 1960 and has been revised 16 times up to the present.

This Law provides for traffic control by signals and road signs for the prevention of accidents and smooth traffic on roads and at the same time stipulates the movement of pedestrians and the traffic rules for motor vehicles such as maximum speed, overtaking zones, driving operation, etc.

The Law also stipulates that a person who intends to drive a motor vehicle must obtain a driver's license and other matters to be observed by drivers in driving a motor vehicle such as prohibition of drunken driving, etc.

The Air Pollution Control Law, or 1968-Law No. 97, was enacted on June 10, 1968 and has been revised 6 times up to the present.

The object of this Law is to reduce smoke emitted from industrial plants and harmful gas emitted from motor vehicles to promote the public health.

Especially on motor vehicles, it is provided that the permissible limit of carbon monoxide, hydrocarbon and nitrogen oxides, etc. emitted from motor vehicles must be determined, that prefectures may measure the density of pollutants in the area where air pollution is conspicuous and may, where necessary, make a request or give opinion to the related organizations, etc.

The Noise Control Law, or 1968-Law No. 98, was enacted on June 10, 1968 and has been revised 4 times up to the present.

The object of this Law is to reduce the noise emitted by plants or motor vehicles to protect the living environment.

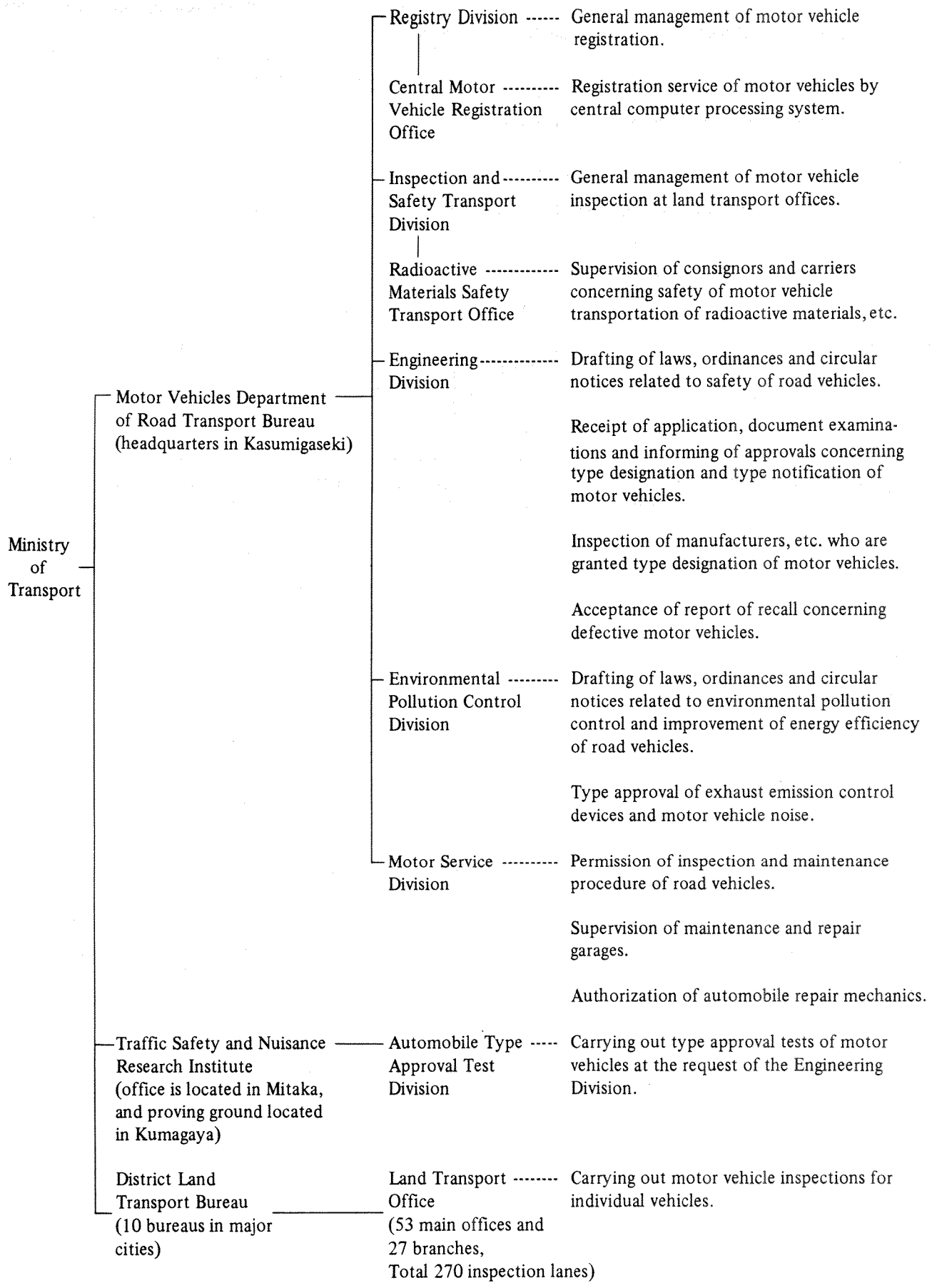
Especially on motor vehicles, it is stipulated that the permissible limit of noise made by motor vehicles must be determined, that prefectures may measure noise in the designated area and may, where necessary, make a request or give opinion to the related organizations, etc.

The Rationalization of Energy Consumption Act, or 1979-Law No. 49, was enacted on June 22, 1979.

The object of this Act is to save energy consumed by plants, buildings, machinery and equipment to utilize fuel resources as effectively as possible in view of the energy situation in Japan where most energy resources must be imported.

As to motor vehicles, manufacturers and importers of motor vehicles designated by the cabinet order are obliged to meet guidelines to improve and indicate the fuel efficiency, etc.

(Reference) Implementation Organization for Road Vehicles Act of Ministry of Transport



The Automobile Liability Security Act, or 1955-Law No. 97, was enacted on July 29, 1955 and has been revised 11 times up to the present.

This Act obliges owners of motor vehicles to take out automobile liability insurance against accidents resulting in injury or death through operation of motor vehicles, in order to aid the victims of accidents by making drivers of motor vehicles which cause accidents indemnify the victims without fail.

The Act also provides for a system whereby the Government carries out the security business to aid the victims of accidents caused by hit-and-run or uninsured motor vehicles.

The Road Act, or 1952-Law No. 180, was enacted on June 10, 1952 and has been revised 29 times up to the present.

This Act stipulates, in order to improve and complete the road networks, that the improvement of sidewalks, bicycle paths, street lighting, etc. as well as the extension of roads through new construction will be carried out.

Moreover, the Act also provides for preventing injuries by road damage and restricts passing roads for motor vehicles exceeding a certain size.

The Government authorities in charge of administering these acts and laws are as follows:

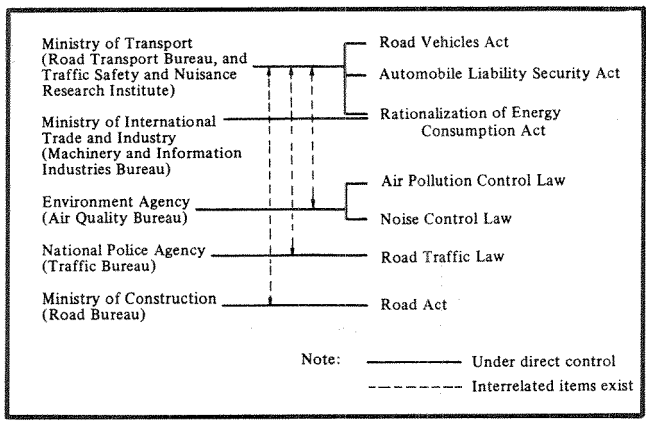


Chart of competent administrative authorities of acts and laws relating to motor vehicles.

Legal System of Japan on Motor Vehicles*

KAZUHIKO MORISAKI**
KUNIO TAKAHASHI**

Part 2: Motor Vehicle Safety Regulations

State of Motor Vehicle Accidents

The number of motor vehicles in Japan was more than 38 million as of the end of July, 1980. Incidental to this figure, the number of persons possessing driver's licenses exceeded 41 million, and motor vehicles are now playing a very important role in society and our daily life. On the other hand, with such an increase in the number of motor vehicles, traffic accidents have also risen sharply, but safety measures against traffic accidents have taken effect resulting in a decrease in the number of traffic accidents which had reached a peak in 1969. Moreover, the number of fatalities also has been decreasing after attaining a peak in 1970. However, even now the number of victims of traffic accidents exceeds 600,000 a year of whom 8,000 are fatalities. Over the past one or two years, the decreasing trend has bottomed out, remaining on the same level (Table 1 and Fig. 1). Compared with traffic accidents in foreign countries, the number of accidents and fatalities had shown a decreasing trend for several years with the number of fatalities in 1976 standing in fourth place after the United States, West Germany and France. The number of fatalities per 100,000 persons was the lowest among 14 countries, the number of fatalities per 10,000 motor vehicles standing thirteenth among the 14 countries (Table 2, Figs. 2 and 3).

According to the number of fatalities by accident patterns in Japan in recent years, while "running weapon-type" accidents (accidents involving pedestrians, bicyclists and motorcyclists) indicate a slightly downward trend, the rate of "running coffin-type" accidents (accidents involving motor vehicle passengers) is rising, so that regarding the number of fatal accidents in 1979 the rates of both were the same (Table 3).

Comparing the number of fatalities by types of accidents with those of foreign countries, we find that while in the United States the number of fatalities among motor vehicle passengers is very large, the number of pedestrian fatalities is considerably larger in European countries, especially in the United Kingdom and West Germany (Fig. 4).

The types of accidents in Japan have been similar to those in European countries, but now there is a tendency toward the types prevailing in the United States.

Next, according to the number of traffic accidents by roads, 69% of the total number of traffic accidents in 1979 occurred in urban areas and the remaining 31% occurred in non-urban areas. Moreover, even in urban areas, most accidents occurred at intersections in cities, and in urban areas other than cities accidents at road sections (road sections excluding intersections, pedestrian crossings, tunnels, curves, etc.) also increased as well as those at intersections.

In non-urban areas, accidents at non-intersected roads are much more common than those at intersections. The number of accidents on expressways is smaller than those on national roads or other roads, but as to fatal accidents, while one fatality occurs with every 59 accidents on ordinary roads, one fatality to 17 accidents occurs on expressways. Therefore, though fewer traffic accidents occur on expressways, traffic accidents on expressways result in a high probability of a fatality.

Traffic accidents by passenger motor vehicles are increasing year by year reflecting an increase in the rate of passenger motor vehicles (Table 4).

However, due to the scale of damage at the time of accidents or the number of fatal accidents per number of motor vehicles, accidents caused by trucks result in serious injuries more often. Recently in Japan, fatal accidents caused by large-sized trucks hitting bicyclists, pedestrians, etc. on their left front or left side in turning

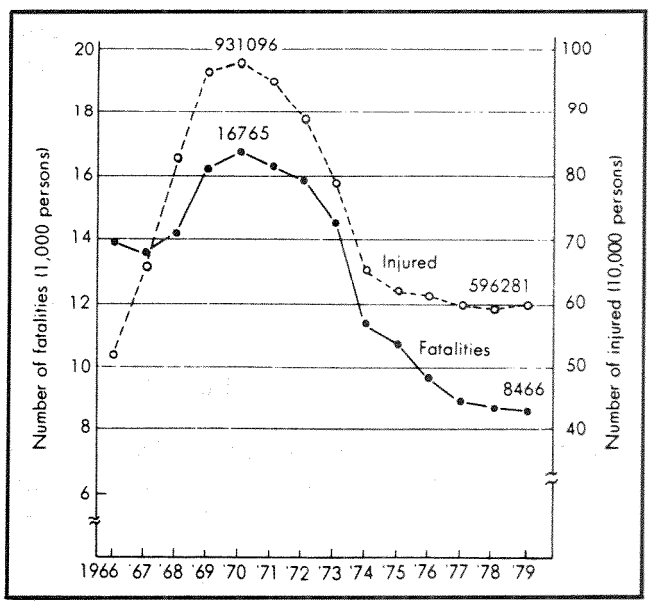


Figure 1. Change in number of fatalities and injured in traffic accidents.

* Received 12th December, 1980
**Engineering Division,
Motor Vehicles Department,
Road Transport Bureau,
Ministry of Transport,
Tokyo

Table 1. Chronological change in number of traffic accident situations.

Year	Number of accidents (cases)	Number of fatalities (persons)	Number of injured (persons)	Population (1,000 persons)	Number of fatalities (per 10,000 motor vehicles)	Number of injured (per 10,000 motor vehicles)	Number of fatalities (per 100,000 population)	Number of injured (per 100,000 population)
1960	449,917	12,055	289,156	94,302	34.9	837.4	12.8	306.6
1965	567,286	12,484	425,666	99,209	15.8	539.0	12.6	429.1
1970	718,080	16,765	981,096	104,665	9.0	527.9	16.0	937.4
1971	700,290	16,278	949,689	106,100	7.8	455.3	15.3	875.1
1972	659,283	15,918	889,198	107,595	6.8	380.5	14.8	826.4
1973	586,713	14,574	789,948	109,104	5.6	304.5	13.4	724.0
1974	490,452	11,432	651,420	110,573	4.1	235.1	10.3	589.1
1975	472,938	10,792	622,467	111,940	3.7	215.1	9.6	556.1
1976	471,041	9,734	613,957	113,089	3.2	198.7	8.6	542.9
1977	460,649	8,945	593,211	114,154	2.7	180.6	7.8	519.7
1978	464,037	8,783	594,116	115,174	2.5	169.7	7.6	515.8
1979	471,573	8,466	596,282	116,130	2.3	160.3	7.3	513.6

Note: Statistics issued by the Ministry of Transport, National Policy Agency and Prime Minister's Office.

Table 2. Change in number of fatalities by traffic accidents in major countries.

Items / Year / Countries	Number of fatalities in traffic accidents				Number of fatalities per 100,000 population				Number of fatalities per 10,000 motor vehicles			
	1975	1976	1977	1978	1975	1976	1977	1978	1975	1976	1977	1978
Canada	6,061	5,307	–	–	–	22.0	–	–	–	4.6	–	–
U.S.A.	46,550	45,422	–	–	22.6	21.6	–	–	3.5	3.5	–	–
West Germany	14,870	14,820	14,978	14,662	–	23.6	24.4	23.9	–	6.9	7.0	6.8
France	12,996	13,577	12,961	–	24.9	25.5	24.3	–	7.6	7.0	6.7	–
Italy	9,511	8,927	8,221	7,965	–	15.7	14.5	14.0	–	5.5	5.0	4.9
U.K.	6,366	6,570	6,614	6,831	–	13.4	13.5	13.9	–	4.1	4.1	4.2
The Netherlands	2,321	2,432	2,583	2,294	–	17.4	18.5	16.5	–	5.8	6.1	5.5
Denmark	827	857	828	849	–	16.8	16.2	16.6	–	5.2	5.0	5.1
Belgium	2,346	2,988	2,522	2,589	24.6	25.3	25.6	26.3	8.2	7.9	8.0	8.2
Norway	539	471	442	434	14.5	11.6	10.9	10.7	5.1	3.7	3.5	3.4
Sweden	1,172	1,168	1,031	1,034	–	14.1	12.5	12.5	–	3.8	3.4	3.4
Switzerland	1,243	1,188	1,302	1,268	19.7	18.7	20.5	20.0	–	5.7	6.2	6.1
Australia	–	2,164	–	–	–	28.8	–	–	–	3.1	–	–
Japan	10,792	9,734	8,945	8,783	9.6	8.6	7.8	7.6	3.7	3.2	2.7	2.5

Note: Data of United Nations Economic Commission for Europe and U.N. Statistical Yearbook.

left at intersections (in Japan, motor vehicles drive on left) have occurred in succession and have become a serious social problem.

For the purpose of preventing traffic accidents, first of all we must analyze the circumstances of accidents thoroughly. Whenever a traffic accident occurs, traffic policemen rush to the scene, administer first-aid to the injured and investigate the situation and cause of the accident. The results of such investigation are collected by each prefecture and issued in the form of accident statistics by the National Police Agency every year, and are considered to be the most authoritative in Japan. In addition, various investigations are carried out to investigate actual situations of traffic accidents scientifically, and for the purpose of ensuring the safety of motor vehicles by examining and analyzing actual accident situations, the Ministry of Transport has been studying in detail several dozen of cases every year since 1973, to determine the relation between the constructions of motor vehicles and physical injuries.

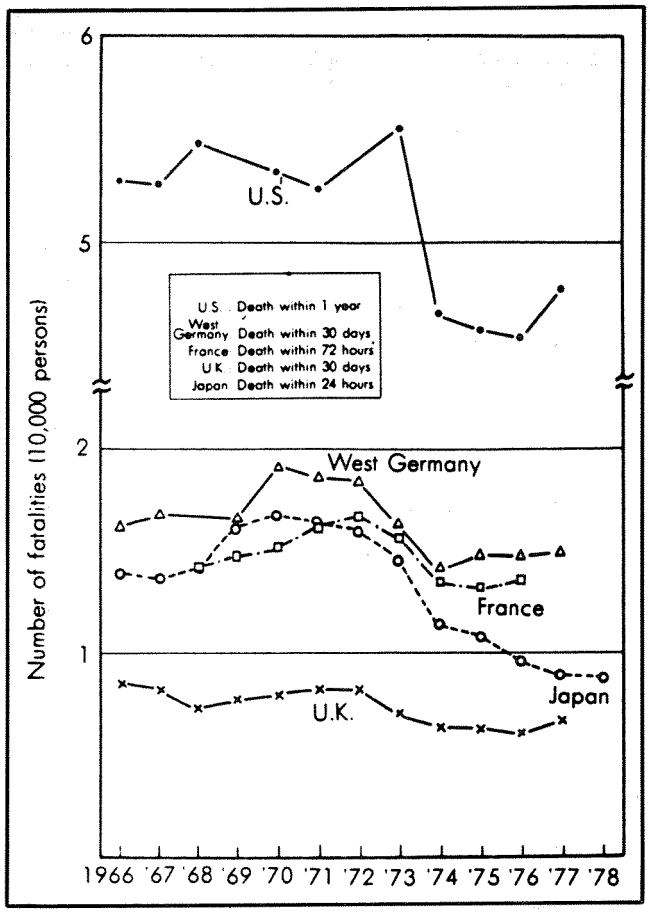


Figure 2. Change in number of fatalities by traffic accidents in major countries.

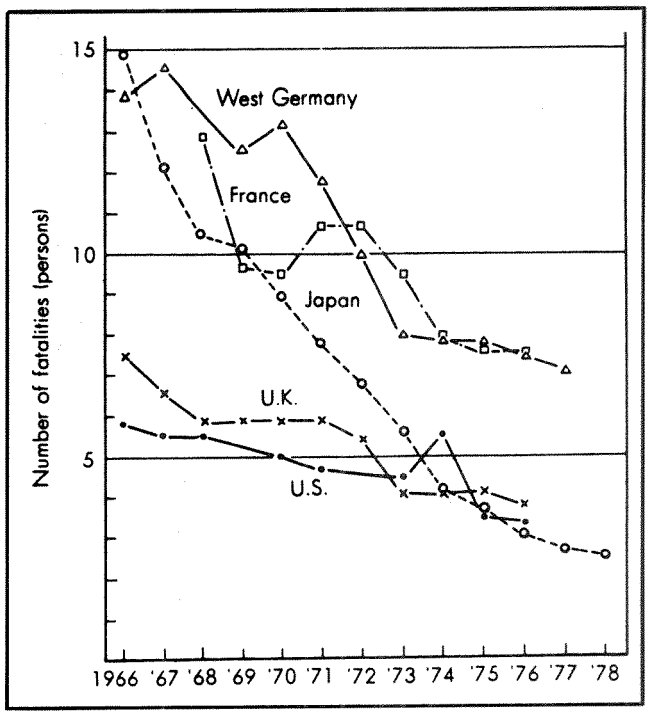


Figure 3. Change in number of fatalities per 10,000 motor vehicles.

Safety Measures in Fields Other Than Motor Vehicles

Most of these traffic accidents are caused by intricately involved factors of drivers, pedestrians, motor vehicles, road environment, etc. Therefore, for ensuring traffic safety, three factors, i.e., the improvement of all environments surrounding motor vehicles (countermeasures taken from the side of environment), elevation of safety consciousness of people such as drivers, passengers and

Table 3. Situation of fatal accidents classified by accident patterns.

Year		1975		1976		1977		1978		1979	
Accident pattern		Number of fatal accidents (cases)	Percentage (%)	Number of fatal accidents (cases)	Percentage (%)	Number of fatal accidents (cases)	Percentage (%)	Number of fatal accidents (cases)	Percentage (%)	Number of fatal accidents (cases)	Percentage (%)
Running weapon-type accident	Man vs. motor vehicle Bicycle vs. motor vehicle	4,632	45.6	4,050	44.0	3,834	45.2	3,770	45.4	3,722	46.2
Running coffin type accident	Motor vehicle vs. motor vehicle Motor vehicle itself	5,055	49.7	4,654	50.6	4,330	51.1	4,251	51.2	4,094	50.9
Railroad crossing accidents		395	3.9	302	3.3	270	3.1	244	2.9	190	2.4
Others		83	0.8	190	2.1	53	0.6	46	0.5	42	0.5
Total		10,165	100.0	9,196	100.0	8,487	100.0	8,311	100.0	8,048	100.0

Note: Statistics of National Police Agency

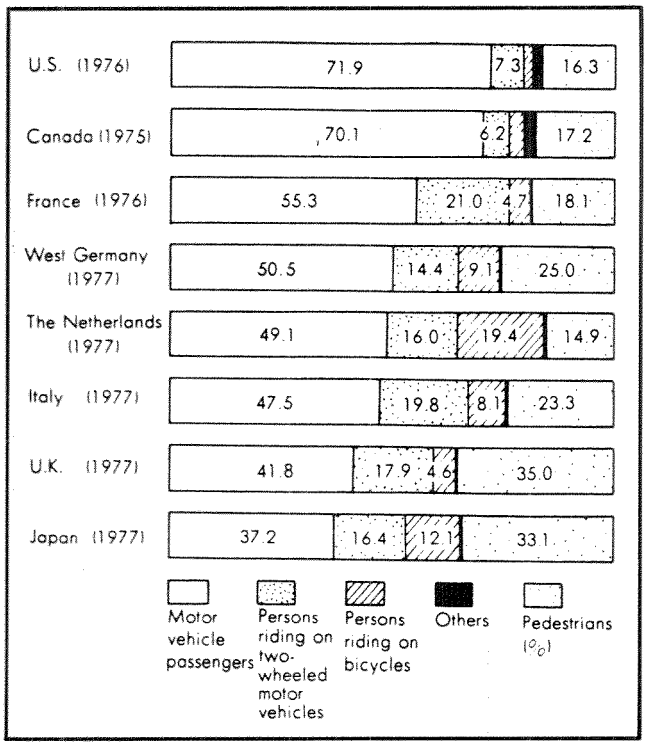


Figure 4. Breakdown of fatalities by traffic accidents in major countries.

pedestrians (countermeasures taken from the human side) and improvement of safety equipment of motor vehicles (safety measures of motor vehicles) must be combined.

Improvement of environment:

As one of three factors of motor vehicle accidents, there is the "environment" surrounding motor vehicles. The environment relating to motor vehicle accidents may be divided into road environment, traffic environment, environment along roads, natural environment, etc. The road environment consists of roads themselves such as expressways, ordinary roads, intersections, median strips and road pavements, and safety facilities such as signals, traffic signs, road lighting, pedestrian crossing bridges, guard rails, etc. The traffic environment consists of the state of traffic such as mixed traffic of motor vehicles and pedestrians, number of pedestrians, volume of traffic, traffic congestion, etc., and traffic regulations such as speed limit, prohibition of parking and stopping, temporary stopping, prohibition of overtaking, prohibition of turning to left or right, one-way passing, etc. As for the environment along roads, they include urban areas, residential areas, commercial areas, fields, mountainous regions, visibility for drivers, state of lighting around roads, etc. Further, concerning natural environment, weather conditions such as rain, snow, fog, wind, etc. are included, and the effect given by the natural environment will be also great.

The total length of roads in Japan was 1,103,731 kilometers in 1978 (including 2,195 kilometers of expressways) paving rate of which is approx. 40%. Compared with foreign countries, the road extension per motor vehicle and the road extension per area in Japan are better than those in foreign countries, but if we consider the quality of roads such as expressway networks, paving rate, width and their visibility, they are not always better.

As for the nation's road improvement program we have the 8th Five-Year Road Improvement Program (term: 1978-1982; total budget: ¥28,500 billion), which places importance on the establishment of a road network system such as national highways, main local roads, improvement

Table 4. Situation of traffic accidents classified by parties concerned causing accidents (1979).

First party \ Classification	Number of cases	Percentage
Passenger motor vehicles		
Buses	3,646	0.8
Micro-buses	1,159	0.2
Ordinary	236,741	50.2
Light	15,659	3.3
Sub-total	257,205	54.5
Trucks		
Special large-sized	6,977	1.5
Large-sized	6,355	1.3
Trailers	765	0.2
Ordinary	71,533	15.2
Light-vans	25,687	5.5
Three-wheelers	71	0.0
Light	23,449	5.0
Light-vans	3,019	0.6
Light three-wheelers	5	0.0
Sub-total	137,861	29.3
Special motor vehicles		
Large-sized	223	0.0
Small-sized	227	0.0
Agricultural vehicles	173	0.0
Sub-total	623	0.0
Two-wheeled motor vehicles		
Small-sized	7,263	1.5
Light	2,190	0.5
2nd class motor-driven cycles	6,477	1.4
Sub-total	15,930	3.4
Total of motor vehicles	411,619	87.2
1st motor-driven cycles	27,059	5.7
Total of motor vehicles and motor-driven cycles	438,678	92.9
Bicycles	14,427	3.1
Other vehicles		
Street cars	42	0.0
Trains	4	0.0
Light vehicles other than bicycles	33	0.0
Sub-total	79	0.0
Pedestrians	15,321	3.3
Unknown	3,141	0.7
Overlapped data	73	–
Total	471,573	100.0

and completion of national expressways, main roads around cities, etc. If this program is successfully implemented, national expressways will be extended to 3,490 kilometers and expressways around cities to 1.5 times the present length. In parallel with the above program, the Five-Year Traffic Safety Facility Improvement Program (1976-1980; total budget ¥1,361 billion) is also in progress for the improvement of sidewalks, construction of bicycle paths, installation of road lights, traffic signals and traffic signs and establishment of traffic control centers. By these programs, the expansion and completion of roads and safety facilities will be realized and such improvements of the road environment, especially separation of sidewalks from roadways, conversion of railroad crossings to flyovers, etc. are expected to significantly reduce the number of cases of man vs. motor vehicle accidents, and railroad crossing accidents (Table 5).

Countermeasures from human side:

Accidents occur when any of three factors, environment, man and motor vehicle, becomes unstable or unbalanced. The most unstable factor among these three is "man". People's mental and physical performance levels are constantly fluctuating, and consequently the "unstable nature of man" is considered to be the most common cause of accident. Of all accidents, accidents caused by drivers account for 97%, accidents by pedestrians are 3% and accidents due to defect or incomplete repair of motor vehicle 0.1%, respectively. It is said that most accidents are caused by drivers. As direct causes of accidents, we can cite violation of speed limits, uncertain handling of the steering wheel, failure to keep an adequate following distance, uncertain operation of brakes, etc. When driving motor vehicles, it is necessary for drivers to recognize at first such information as roads and traffic conditions, etc. and then make judgment accordingly, before starting to drive. Driving should be performed by combining these factors organically. As indirect causes of accidents, 50% are due to delay in recognition, 40% to mistake in judgment, 5% to mistake in operation and 5% to other causes. Behind these causes, there are mental factors such as character of drivers themselves, mentality, frustration, worry, etc. and physical factors such as fatigue, disease, poor vision, etc. Thus, the true causes of accidents are deeply rooted in man's own mental and physical nature and are intricately connected to one another. Therefore, as long as many accidents are caused by human factors and the person behind the wheel of a motor vehicle is a human being, countermeasures against human beings will be required.

As of 1979, the number of persons who possessed driver's licenses was 41,042,876, which is 35% of the total population, or at a rate of one out of three persons. Therefore, education on safety for drivers who cause most accidents will be important from the viewpoint of accident prevention. As the main forms of education on safety presently carried out, there are training at designated driving schools at the time of obtaining one's driver's license, instruction on acts and laws given while a national traffic safety campaign is being carried out, safe driving instruction given to traffic law violators and various instructional activities given by local public entities and the private sector. On the other hand, instruction on traffic safety and operation control in working places are conducted under two representative systems such as the safe driving supervisor system and operation supervisor system. Under the safe driving supervisor system, "users of motor vehicles shall, in order to cause necessary business to be conducted for the safe operation of motor vehicles, appoint a safe operation supervisor at each place of business using five or more motor vehicles and notify the Public Safety Committee of each prefecture related to such supervisor." The safe operation supervisor will prepare an operational plan and prevent any overwork and

Table 5. Improvement of traffic safety facilities.

Classification / Year	Sidewalks (km)	Bicycle paths (km)	Pedestrian crossing bridges (places)	Underground crossings (places)	Road lighting	Signals	Pedestrian crossings
1967	5,590	–	680	160	190,150	10,067	77,643
1968	12,990	–	2,725	265	290,419	13,441	94,956
1969	16,620	–	4,190	304	340,137	16,941	116,934
1970	21,794	–	5,090	388	387,000	19,517	128,125
1971	24,996	1,197	5,865	499	433,968	23,290	134,176
1972	28,656	3,297	6,666	601	484,000	29,396	194,536
1973	35,362	4,967	7,210	838	581,909	38,244	233,011
1974	39,008	7,609	7,630	997	707,458	46,824	280,350
1975	41,738	10,558	7,984	1,210	833,287	55,630	335,123
1976	42,900	14,800	8,389	1,248	873,245	63,846	342,842
1977	46,753	17,385	8,562	1,358	931,281	71,728	379,604
1978	49,660	19,730	8,700	1,390	994,061	79,359	420,889
1979	50,494	26,121	8,930	1,521	1,069,069	87,081	463,984

secure safe operation in unusual weather conditions. On the other hand, under the operation supervisor system, "motor vehicle transportation business entities shall, in order to secure the operation of motor vehicles for business purpose to be disposed of, appoint a qualified operation supervisor at each place of business". The duties of the operation supervisor are to carry out preparation of a work schedule, calling of roll, guidance and supervision of drivers, etc.

Present Situation of Safety Regulations for Motor Vehicles

(1) Safety regulations for road vehicles:

Under the Road Vehicles Act, technical safety requirements are specified in the Ministry of Transport Ordinance on constructions and systems of motor vehicles, riding capacity and maximum loading capacity in order to secure the safety of motor vehicles (refer to Articles 40 to 42 of the Act). In addition to those for motor vehicles, technical safety requirements for motor-driven cycles and light vehicles are also specified in the Ordinance.

Road Vehicles Act (extracts)

CHAPTER III SAFETY REGULATIONS FOR ROAD VEHICLES

Article 40 (Constructions of Motor Vehicles)

No motor vehicle shall be licensed for operation unless its constructions conform to the technical safety requirements to be specified by the Ministry of Transport Ordinance as to the matters enumerated in each of the following Items:

(1) Length, width and height;
(2) Minimum ground clearance;
(3) Gross vehicle weight (referring to the total amount of vehicle weight, maximum loading capacity and the weight obtained by multiplying riding capacity with 55 kg);
(4) Load onto the wheel;
(5) The rate of the load onto the wheel and the vehicle weight (referring to the weight of motor vehicle of the state with necessary equipments for operation);
(6) The rate of the load onto the wheel and the gross vehicle weight;
(7) Maximum stable inclination angle;
(8) Minimum turning radius; and
(9) Road-contact point and its pressure.

Article 41 (Systems and Devices of Motor Vehicles)

No motor vehicle shall be licensed for operation unless it conforms to the technical safety requirements to be specified by the Ministry of Transport Ordinance, concerning the systems and devices enumerated in each of the following Items:

(1) Prime mover (engine) and power train system;
(2) Running system, such as wheel and axle, sled, etc.;
(3) Control system;
(4) Braking system;
(5) Buffer system, such as spring, etc.;
(6) Fuel system and electric system;
(7) Frame and body;
(8) Coupling device;
(9) Riding accommodation and goods-loading accommodation;
(10) Window glasses, such as windshields, etc.;
(11) Noise control device, such as silencer, etc.;
(12) Emission control device;
(13) Lighting system and reflector, such as headlamp, number plate lamp, tail lamp, stop lamp, clearance lamp, etc.;
(14) Warning device, such as horn, etc.;
(15) Indication device, such as direction indicator, etc.;
(16) Visibility ensuring device, such as rear-view mirror, windshield wiper, etc.;
(17) Meter, such as speedometer, odometer, etc.;
(18) Fire-prevention device, such as fire extinguisher, etc.;
(19) Pressure container and accessories thereof; and
(20) Other especially necessary systems and devices of motor vehicles specified by the Cabinet Order.

Article 42 (Riding Capacity or Maximum Loading Capacity)

No motor vehicle shall be licensed for operation unless it conforms to the technical safety requirements to be specified by the Ministry of Transport Ordinance as to the riding capacity or maximum loading capacity.

Table 6. Outline of safety regulations.

Items	Article	Outline of regulations
Definition	1	Definition of technical term
Length, width, and height	2	Not exceeding 12 (length) × 2.5 (width) × 3.8 (height) m 250 mm or less outward from the right and left sides 300 mm or less upward
	3	Minimum ground clearance
Gross vehicle weight	4	Gross vehicle weight: Not exceeding 20 tons
Axle weight and wheel weight	4-2	Axle weight: Not exceeding 10 tons Wheel weight: Not exceeding 5 tons
Stability	5	Total weight rate imposed on the steering tire: 20% or more. Maximum stable inclination angle: 35° or more
Minimum turning radius	6	12m or less
Road contact pressure	7	Tire: Not exceeding 150 kg/cm Caterpillars: Not exceeding 3 kg/cm^2
Engine and power train system	8	Starting can be done by the driver in his seat
Running system	9	Provisions of tire load rate
Control system	10	To be located within 500 mm from the center of the steering wheel, indication for control devices.
	11	Equipping of impact absorption steering wheel on passenger motor vehicles
Locking device	11-2	Locking device
Braking system	12	Equipping of at least two separate braking systems. Stopping distance for service brake system: Max. speed / Initial speed / Stopping distance 80 km/h / 50 km/h / 22m or less 35-80 / 35 / 14m or less 20-35 / 20 / 5m or less Less than 20 / Max. speed / 5m or less Operating force: 90 kg or less. Dual safety brake systems. Brake-fluid leakage warning devices. Pneumatic pressure warning devices (motor vehicle using pneumatic brake system).
	13	Braking system for tractors and trailers
Buffer system	14	Spring, etc.: performance of impact absorption
Fuel system	15	The filler, etc. must be located 300 mm or more apart from open part of exhaust pipe and 200 mm or more apart from exposed electric terminal. The filler, etc. must not open inside passenger compartment.
	16	Fuel system for producer gas.
	17	Provision on LPG-fueled motor vehicles
Electric system	17-2	Secure mounting of wiring, insulation of terminal, etc.
Body	18	External shape must have no sharp protrusion. Rear body overhang must be ½ or less of wheelbase. (⅔ in case of passenger motor vehicles, etc. and 11/20 in case of small-sized motor vehicles) Indication of school bus
Pedestrian protection, side guard etc.	18-2	Equipping of side guard on ordinary trucks and ordinary motor vehicles with gross vehicle weight of 8 tons or more (except buses) Equipping of rear under-ride bumper on ordinary trucks
Coupling device	19	Coupling device for tractor and trailer
Riding accommodation	20	Safe boarding must be secured. Absorption of impact by instrument panel in case of collision
Driver's seat	21	Control of motor vehicle shall not be obstructed. Driver's field of vision shall be secured
Seat	22	400 mm or more in depth and width (spare seat, etc.: 250 × 300 mm or more) (child's seat: 230 × 270 mm or more). Space between seats: 200 mm or more (child's seat: 150 mm). Absorption of impact by seatback in case of collision
Seat belt	22-3	Driver's seat and other front seat of passenger motor vehicles, small-sized and light trucks: lap and shoulder seat belt. Rear seats of the above: lap seat belt. Driver's seat and other front seat of ordinary trucks: lap seat belt. Performance of seat belt anchorages
Head restraint	22-4	Driver's seat and another front seat of passenger motor vehicles, small-sized and light trucks (4 seats in case of taxicab). Performance of head protection in case of collision
Aisle	23	Bus: (width) 300 mm or more (height) 1,600 mm or more
Standing space	24	Area for one person: 0.14 m^2
Entrance	25	Bus: 1 or more entrances on the left side; (width) 600 mm or more (height) 1,600 mm or more (height of one step) 400 mm or less with anti-slipping devices
Emergency exit	26	Bus: On the right side or rear (width) 400 mm or more (height) 1,200 mm or more
Good-loading accommodation	27	Loading accommodation of dump truck must be designed so that it prohibits overloading
High-pressure gas transport device	28	Requirement for pressure container and piping
Window glass	29	Windshield glass: Safety glass, ensuring driver's visibility in case of damage Side and rear glasses: Safety glass
Noise control device	30	Steady running noise and stationary noise must be 85 dB or less.

Items	Article	Outline of regulations
		Trucks and buses: Steady running noise / Accelerated stationary running noise Gross vehicle weight exceeding 3.5 tons and engine power exceeding 200 PS. 80 dB / 86 dB Gross vehicle weight exceeding 3.5 tons and engine power not exceeding 200 PS. 78 dB / 86 dB Gross vehicle weight not exceeding 3.5 tons 74 dB / 81 dB Passenger motor vehicles: 70 dB / 81 dB Two-wheeled motor vehicles: 74 dB / 78 dB
Emission control device	31	Gasoline or LPG-fueled light-duty motor vehicle and passenger motor vehicle: 10-mode exhaust emission standards, 11-mode exhaust emission standards Gasoline or LPG-fueled heavy-duty motor vehicle: 6-mode exhaust emission standards Diesel-powered motor vehicle: Diesel-6 mode exhaust emission standards All vehicles: CO, 4.5% or less (idling) HC, 1200 ppm or less (idling) Equipping of blow-by gas ventilation devices Equipping of devices preventing evaporative emissions (gasoline-fueled motor vehicle) Restriction of diesel smoke
Headlamp	32	A headlamp must be equipped on each side at the front of the motor vehicle and be capable of discerning an obstacle at a distance of 100 m forward at night. The intensity can be dimmed or the direction of beam can be dipped. The main beam must be directed downward. Mounting height: 1.2 m or less above the ground Color of light: white or light yellow
Auxiliary headlamp	33	Intensity: 10,000 candle power or less Main beam must be directed downward.
Clearance lamp	34	To be equipped on both sides at the front. Clearly visible at night at a distance of 300 m from the front. Color: white, light yellow or amber Mounting height: 2 m or less above the ground
Front reflector	35	To be equipped on trailers
Side marker lamp and side reflector	35-2	To be equipped on large-sized trucks and trailers
Number plate lamp	36	Number plate must be visible at night at a distance of 20 m to the rear Color: white

Items	Article	Outline of regulations
Tail lamp	37	On each side at the rear; visible at night at a distance of 300 m to the rear Color: red Mounting height: 2 m or less above the ground
Parking lamp	37-2	On each side at the front and the rear; visible at night at a distance of 150 m to the front rear. Requirement of the lamp is identical with clearance lamp or tail lamp
Rear reflector	38	To be equipped at the rear. Size: Area covering a 30 mm diameter circle, visible at night at a distance of 150 m to the rear. Color: red Mounting height: 1.5 m or less above the ground
Stop lamp	39	To be equipped at the rear, visible in the daytime at a distance of 100 m to the rear. Color: red Mounting height: 2 m or less above the ground
Back-up lamp	40	Intensity: 5,000 candle power or less. Color: white or light yellow. Mounting height: 1.2 m or less above the ground. Main beam must be directed downward and not strike 75 m rearward or more
Direction indicator	41	One each on the left and the right; visible in the daytime at a distance of 100 m to the front and rear. To be equipped on each side of the rear. Size: Motor vehicles with length of 6 m or more: 40 cm^2 or more. Motorcycles: 7 cm^2 or more. Others: 20 cm^2 or more. Color: amber. Mounting height: 2.3 m or less above the ground. To be equipped on both sides of the central part of body for large-sized trucks, etc.
Additional direction indicator	41-2	May be equipped
Hazard warning lamp	41-3	To be designed to actuate all of lamps simultaneously. Color: amber. Mounting height: 2.3 m or less above the ground
Other lights	42	Restriction of light, etc.
Horn	43	Sound level: 115-90 dB at a distance of 2 m to the front. Continuously emit sound whose level and tone are constant
Emergency signal equipment	43-2	Visible at night at a distance of 200 m; red color
Warning reflector	43-3	Visible at night at a distance of 150 m; red triangle
Emergency stop indication device	43-4	Reflected light is visible at night at a distance of 150 m; red color. Fluorescent light is visible in the daytime at a distance of 200 m; red triangle
Rear-view mirror	44	The driver is able to recognize clearly traffic conditions of other vehicles at right and left

Items	Article	Outline of regulations
		sides, straight backwards up to 50 m; structure unlikely to give excessive impact. Large-sized motor vehicles: within 0.3 m from the front and left side is recognizable. Cab-over type large-sized motor vehicles: within 2 m from the front and 3 m from left side is recognizable
Windshield wiper Windshield washing system	45	To be equipped on the windshield
Defroster		Reduction of impact on sunvisor
Speedometer	46	Indication error: $+15 \sim -10\%$ (at 35 km/h) Vibration of pointers: ± 3 km/h or less (at 35 km/h) Indication and warning devices over speed limit
Fire extinguisher	47	To be installed on bus, child-carrying motor vehicles, motor vehicles carrying dangerous articles. Requirements for extinguishers
Pressure container and accessories	48	Requirement for pressure containers
Tachograph	48-2	To be equipped on large-sized trucks, etc. Requirements for structures
Speed indication device	48-3	To be equipped on large-sized trucks, etc. Requirements for structures
Riding capacity or maximum loading capacity	53	Maximum capacity to be secured to ride or load
Others	54～58-2	Exceptions, etc.

The Ministerial Ordinance comprises the Safety Regulations for Road Vehicles (Ministry of Transport Ordinance No. 67 of 1951) providing for the minimum requirements for constructions, devices and performance of motor vehicles as measures for avoiding accidents caused by constructions and devices of motor vehicles, damage-reducing measures for minimizing injury to passengers as far as possible in case of accidents and fire prevention measures. (Table 6: Outline of safety regulations.)

These Safety Regulations are not only standards to be applied at the time of designing and manufacturing motor vehicles, but also standards for the daily maintenance of motor vehicles by the users. If any motor vehicle fails to meet these regulations, it shall be prohibited to operate such motor vehicle as it may endanger the traffic. Furthermore, the actual manner of the test and interpretation of provisions in detail in applying the respective provisions of the Safety Regulations are published by the Ministry of Transport in circular notices. In the provisions of the Safety Regulations, the pollution control standards as well as safety standards are included from the viewpoint of public welfare, details of which will be stated in the next installment. The Safety Regulations were amended 46 times up to the end of 1980 since their establishment in 1951, and the outline of main amendments relating to the Safety Regulations is set forth in Table 7.

These amendments to the Safety Regulations were made to strengthen the safety of motor vehicles directly corresponding to changes in traffic environments of motor vehicles such as increase of traffic accidents, changes of situation of traffic accidents, sharp increase in the number of motor vehicles in use, congested traffic conditions, extension of expressways, etc.

Main amendments to the safety regulations made recently:

In September, 1972, the first program plan for future motor vehicle safety under the title "Technical Measures for Safety of Motor Vehicles" was presented as a recommendation by the Council for Transport Technics, an advisory organ of the Ministry of Transport, and under this program, amendments to the Safety Regulations were made in 1973 and 1974, respectively. The recommendation stated that strengthening of safety regulations for motor vehicles must be enforced synthetically and systematically. The programs to expand and strengthen Safety Regulations for motor vehicles for five years categorized on 63 items including measures to prevent accidents, measures to reduce injuries and measures to prevent fires (Table 8). Under the recommendation, in July 1973, the safety requirements for 20 items such as strengthening of regulations on lighting apparatus for the prevention of head-on or rear-end collisions as well as expansion of scope of motor vehicles equipped with dual safety braking systems were determined. In November 1974, as countermeasures for preventing accidents, the installation of defrosters became obligatory, and installation of mirrors on large-sized motor vehicles to improve side visibility, installation of side lights or side reflectors on both sides of large-sized trucks, etc., installation of warning devices for drivers in case of trouble of service brake system, improvement of quality of brake-fluid, etc. became statutory respectively. Moreover, as countermeasures to reduce injuries among passengers, the regulations wre strengthened by providing for improvement of strength of seats and seat anchorages, increase in number of seats with seat belts, installation of lap and shoulder seat belts on the front seats and to prevent fire, the prevention of fuel leakage at the time of head-on collision in order to avoid damage to fuel tanks and fuel pipings.

Table 7. Table of main amendments to safety regulations for road vehicles (relating to safety).

Date of amendment	Matters amended
Apr. 11, 1953	Requirements of electrical equipment, requirements for tires, prohibition of exhaust pipe in inside compartment, equipping of number plate lamp (motor-driven cycles), etc.
Sept. 17, 1955	Restrictions on axle weight and wheel weight, restriction on spare seats, equipping of speedometer (motor-driven cycles).
Dec. 27, 1956	Use of safety glass, prohibition of irregular flashers.
Sept. 25, 1958	Provisions on maximum riding capacity of two-wheeled motor vehicles.
Sept. 15, 1959	Prohibition of protrusions, regulations on parking brake of trailers, regulations on rear over-hang constructions of microbus, child-carrying motor vehicles and one-man bus, fire prevention regulations of motor vehicles carrying gunpowders, etc., safety requirements of pole-trailers.
Feb. 1, 1960	Restriction on color of light, improvement of performance of headlamp, restriction on auxiliary headlamp, equipping of rear reflector, mirrors to confirm front of bus, improvement of safety of light three-wheeled vehicles, prevention of fire of motor vehicles carrying dangerous articles.
Sept. 28, 1962	Independent brakes of trailers, equipping of rear-view mirrors on both sides, prohibition of using two-door car for taxi-cab, requirements for conductor's seat of bus.
Oct. 1, 1963	Constructions of LPG-fueled vehicles, strengthening of restrictions on motor-driven cycles (stop lamp, rear-view mirror, number plate lamp, direction indicator, etc.), performance of headlamp of special-purpose motor vehicles, lamp of motor vehicles for road maintenance works.
Sept. 5, 1964	Simplifying and clarifying lamps such as direction indicators and prohibition of use of confusing lamps.
May 16, 1967	Obligation to attach tachograph to large-sized motor vehicles.
Aug. 1, 1967	Obligation to attach dual safety brake systems, rear and side guards and speed indicating devices to large-sized motor vehicles.
July 4, 1968	Regulations of 4 items such as under-mirror (large-sized trucks, etc.), side direction indicator, etc. as safety measures for pedestrians, 6 items such as mounting position of tail lamp, hazard warning lamp, parking lamp, etc. as measures to prevent accidents, and two items such as seat belts, head restraints, etc. as measures for reducing injuries in collision.
June 12, 1969	Warning devices of air brake, indication of school bus, partially tempered glass, fire extinguisher.
Dec. 14, 1970	Improvement of performance of tires, trailer brakes, washer, etc. as measures for higher speed, improvement of performance of parking brake and horn as measures to prevent accidents, requirements for locking devices, defroster of one-man bus, fixing of LPG container, prevention of radio interference.
Mar. 31, 1972	Impact absorption of steering wheel, relaxation of limitation on height (3.5 m to 3.8 m).
Apr. 28, 1973	Technical standards for warning reflector.
July 6, 1973	10 items such as improvement of field of view, improvement of visibility of lamps, improvement of performance of braking system, indication of control device, etc. as measures to avoid accidents, 5 items such as increased use of seat belts and head restraints, use of safety glass, measures for protecting pedestrians as measures to reduce injuries, 5 items such as equipping of locking devices, prevention of overloading of dump trucks, safety measures for motor-driven cycles as safety measures; 20 items in total.
Nov. 21, 1974	Improvement of field of view to the left side, equipping of side marker lamp or side reflector, warning devices of service brake system and speed warning devices and indicators, door retention system, improvement of strength of seats and seat anchorages, stricter regulations on seat belts, absorption of impact from seatback and instrument panel, prevention of fuel leakage in collision.
May 7, 1976	Equipping of rear bumpers to motor vehicles, etc. equipped with gas-transporting container.
Nov. 27, 1978	Technical standards, etc. for emergency stop indication device.
Mar. 15, 1979	Safety measures for preventing accidents from left-turning large-sized trucks.

Table 8. First program plan for future motor vehicle safety regulations. (September, 1972)

(1) Measures to prevent accidents:	34 items
Field of vision	7 items
Visibility	5 items
Anti-glare	3 items
Controllability and stability	1 item
Tires	3 items
Brakes	7 items
Warning devices	4 items
Control systems	2 items
Driving environment	2 items
(2) Measures to reduce injuries	26 items
Strength of vehicle body	6 items
Occupant restraint systems	7 items
Interior impact protection	7 items
Protection of pedestrians	4 items
Measures against motor vehicle damage	2 items
(3) Measures to prevent fire	3 items

Recently, for the prevention of accidents by large-sized trucks when they are turning left, improvement of mirror visibility for drivers, increase of side direction indicators and improvement of pedestrian protection side guards were effected.

Future Trend of Motor Vehicle Safety Regulations

Second program plan for future motor vehicle safety standards:

As to the future trend of Safety Regulations, the Council for Transport Technics had, based on the measures taken on the recommendation of the Council in 1972, updated the recommendation of 1972 for the purpose of meeting the situations surrounding motor vehicles such as occurrence of traffic accidents, changes in motor vehicle use, progress of technological development, etc. As a result, in October 1980, the Council submitted a recommendation to the Minister of Transport on the "Technical Measures for Safety of Motor Vehicles". The recommendation sets forth the second program plan for future safety standards following the first program under the recommendation in September 1972 and will be a foundation for the future strengthening of the Safety Regulations. According to the recommendation, the Ministry of Transport is planning to take necessary administrative measures, mainly amendments to the Safety Regulations.

The following is the outline of the recommendations:

Traffic accidents in Japan had shown a downward trend from around 1970 due to the enforcement of various measures for preventing accidents, but during these past few years they have remained on the same level. In 1980 there were, in fact, signs of an increase in the number of fatal accidents. Therefore, we will have to make greater efforts to reduce accidents further. For that purpose, in consideration of the occurrence of traffic accidents, situation of motor vehicle use, preservation of the environment, resources and energy problems, and international trends, the second program plan for future motor vehicle safety standards was established. The plan recommended strengthening the existing regulations under a long-term plan and consists of 57 items, each of which sets forth the kinds of administrative measures such as regulatory, study, etc., target time of accomplishment outline of item and applicable motor vehicles. (Table 9: Items of 2nd program plan for future motor vehicle safety standard.)

Furthermore, as important items of the Plan, the following three measures are set forth:

(1) Measures for high-speed driving

With the completion of expressways, there has been an increase in the number of accidents when travelling at high speed and the damage is heavy, so that it will be necessary to improve the performance of the brakes, quality of tires and windshield glass, etc.

(2) Measures to prevent fire

Cases of the accidents in vehicles including large-scale conflagration are increasing, so it will be necessary to adopt measures to prevent fuel leakage in the event of rear-end collisions and to improve the non-flammability of interior materials.

(3) Safety measures for trucks

Since trucks are different from passenger motor vehicles in their constructions and use and tend to sustain heavier damage in accidents compared with passenger motor vehicles, it will be necessary to take measures especially for trucks such as the improvement of braking performance, visibility from driver's seat, visibility of rear end of body, etc.

Further, the recommendation points out the improvement of investigation and analysis of motor vehicle accidents, establishment of requirements for performance and quantitative standards of performance, harmonization with international standards and with environmental, resources and energy issues, etc.

Measures for preventing large-sized motor-vehicle accidents occurring during left-hand turns

In order to reach a fundamental solution for the prevention of left-turn accidents, we had motor vehicle manufacturers produce test vehicles of large-sized trucks with improved direct field of vision from the driver's seat (these included vehicles with lowered driver's seat, door partially changed to glass, or steering wheel shifted to the left. In Japan, vehicles drive on the left, so the steering wheel is generally on the right) and we are carrying out technological evaluation and examination at present.

Table 8. 1st program plan for future motor vehicle safety regulations.

I. Measures to prevent accidents			
	Item		Application
Field of vision	I-1	Field of vision of heavy trucks (S, S)	HT
	I-2	Field of vision of rear-view mirrors (R, S)	P, MP, MC
	I-3	Windshield wiping area (R, S or M)	P, MP, T, B
	I-4	Improvement of headlamp performance (R, S)	P, MP, T, B, MC
	I-5	Rear window defoggers (V, S)	P, MP
	I-6	Headlamp cleaners (V, S)	D
	I-7	Performance of windshield defrosters (A, S)	D
	I-8	Performance of front fog lamps (V, M)	D
	I-9	Cornering lamps (R, M)	D
Visibility	I-10	Color unification of side marker lamps and side reflectors (V, S)	D
	I-11	Rear fog lamps (S, M)	D
	I-12	Visibility of front direction indicators (S, M)	D
	I-13	Chromaticity range of lamps and reflectors (R, M)	P, MP, T, B, MC
	I-14	Visibility of rear end of heavy trucks (S, M)	HT
	I-15	Luminous intensity of rear lamps (S, L)	D
	I-16	Mounting height of rear reflectors (R, S)	P, MP, T, B, MC
Anti-glare	I-17	Adjusting mechanism of headlamp alignment (S, L)	D
	I-18	Polarized headlamps (S, L)	D
Controllability and stability	I-19	Controllability and stability (S, L)	–
	I-20	Minimum ground clearance (S, L)	–
Tires	I-21	Quality of tires (R, S)	P, MP, T, B, MC
	I-22	Tire-rim combinations (R, S)	P, MP, T, B, MC
	I-23	Retentivity of rims in case of tire puncture (R, S)	P, MP
Brakes	I-24	Brake performance at high speed (R, M)	P, MP, T, B
	I-25	Brake performance for fade and recovery (R, M)	P, MP, T, B, MC
	I-26	Directional stability during braking (R, M)	P, MP, T, B
	I-27	Quality of brake hoses (R, S)	P, MP, T, B, MC
	I-28	Brake performance in case of partial failure of dual brake systems (R, S)	P, MP, T, B
	I-29	Parking brake system for working purpose (V, S)	T
	I-30	Automatic brake adjusters and wear indicators (A, S)	D
	I-31	Anti skid brake systems (A, S)	D
Warning devices	I-32	Lamp failure warning systems (A, S)	D
	I-33	Reverse warning devices (S, M)	D
	I-34	Dual-level horns (S, M)	D
	I-35	Warning devices for left-turn and obstacle detecting devices (S, S)	HT, HB
Control system	I-36	Location of steering wheel of heavy truck (S, S)	HT
Driving environment	I-37	Interior compartment noise (S, M)	T
Restriction of maximum speed	I-38	Constructional restriction of maximum speed (S, L)	D
	I-39	Maximum range of speedometers (S, L)	D
Good-loading accommodation	I-40	Overloading prevention devices (S, L)	T

II. Measures to reduce injuries			
	Item		Application
Injury Criteria	II-1	Injury Criteria (S, L)	–
Strength of vehicle body	II-2	Amount of deformation into passenger compartment (S, L)	P, MP, T
	II-3	Strength of side doors (S, M)	P, MP, LT
	II-4	Easy opening of doors after collision (S, L)	P, MP, T
Occupant restraint systems	II-5	Easy fastening of seat belts (R, S)	P, MP, LT
	II-6	Lap and shoulder seat belts for rear-outer seats (V, S)	P, MP
	II-7	Seat belts for seats other than outer seats (R, M)	P, MP, T

		Item	Application
	II-8	Child restraint systems (V, M)	D
	II-9	Passive restraint systems (S, M)	P
Interior impact protection	II-10	Performance of windshield glasses (R, M)	P, MP, LT
	II-11	Windshield mounting (R, M)	P, MP, LT
	II-12	Interior projections (V, S)	P, MP
Constructions of body	II-13	Improvement of rear under-ride bumper (S, M)	HT
Protection of pedestrians	II-14	Impact reduction for pedestrians in collision (S, L)	–
III. Measures to prevent fire			
		Item	Application
Prevention of fire	III-1	Prevention of fuel leakage in collision (R, S)	P, MP
	III-2	Non-flammability of interior materials (R, S)	P, MP, T, B
	III-3	Prevention of combustion (S, M)	–

Table 9. Items of 2nd program plan for future motor vehicle safety standards.

Notes:

1. In the parentheses of items, the following abbreviations are shown;

(0, 0)

- Target time of Accomplishment
  - S: Short-term (1 ~ 2 years)
  - M: Middle-term (3 ~ 4 years)
  - L: Long-term (5 or more years)
- R: Regulatory items (Items to be regulated newly hereafter or items, contents of which are to be completed or strengthened)
- V: Regulatory items for optional devices (In case devices are fitted voluntarily, items which must be regulated so as not to reduce the safety)
- A: Recommended items (Items which are desirable to be equipped or to improve the performance)
- S: Study items (Items which are to be investigated actively and studied to introduce the technological development and of which necessary measures must be taken according to the results)

2. In the column of subject motor vehicles, P: means passenger motor vehicle, MP: multi-purpose motor vehicle, T: truck, LT: light truck, HT: heavy truck, B: bus, HB: heavy bus, MC: motorcycle (two-wheeled motor vehicles), and D: device, respectively.

Legal System of Japan on Motor Vehicles*

RYOICHI MUKAI

Part 3: Environmental Pollution Control Measures and Energy-Saving Measures for Motor Vehicles

Measures Against Environmental Pollution by Motor Vehicles

Along with the rapid growth of the national economy, environmental pollution came to the fore in Japan in the 1960's. From the beginning of the 1970's, however, the general situation of environmental pollution has begun to improve gradually through the active promotion of environmental pollution control measures coupled with the growth of the nationwide movements for promoting the saving of resources including energy. Moreover, such movements have been considerably accelerated as the national economy has entered the stage of low economic growth. On the other hand, public attention has come to be directed towards environmental pollution (or public nuisances) related to the people's individual living environment or urban living environment rather than industrial pollution, and along with this trend, the problems concerning environmental pollution have entered a new phase. As for the traffic pollution, especially motor-vehicle pollution, which is closely related with the lives of the general public, it is now frequently leading to various law suits and disputes among the people, and thus solution of the pollution problem has become a serious social problem.

In this chapter, we are going to discuss mainly exhaust gas pollution and noise pollution caused by motor vehicles in conjunction with the legal control of motor vehicles through the enforcement of the regulations concerning their construction and equipments.

Measures against exhaust emissions from motor vehicles

A. Present condition and trend of air pollution by motor vehicles

Air pollution in Japan has become a serious social problem with the increased consumption of fossil fuels, especially petroleum, accompanying the rapid growth of the national economy. Moreover, air pollution caused by motor vehicles has been posing a particular problem, es-

* Received 25th February 1981.

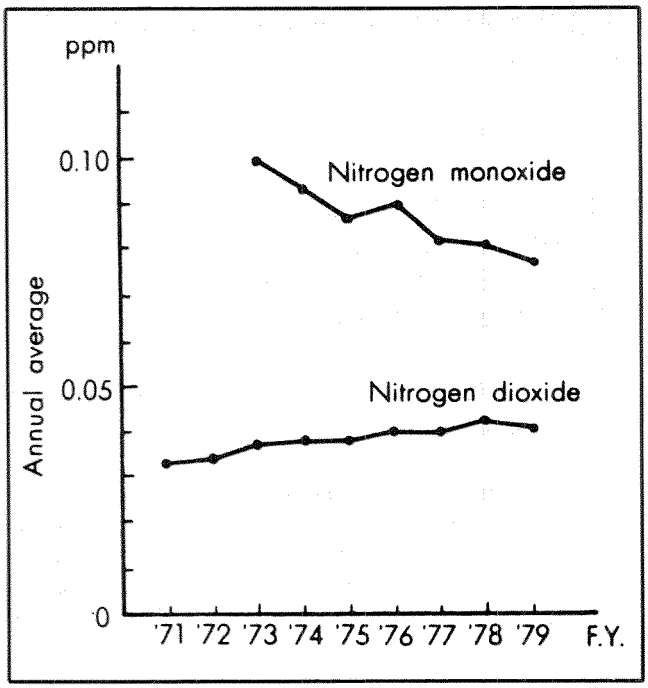


Figure 1. Trend of annual averages of nitrogen dioxide and nitrogen monoxide measured continuously at 26 monitoring stations.

pecially in large cities and areas bordering major highways, due to the rapid advance in motorization since the latter half of the 1970's.

In the following, we take a look at the present condition and trend of air pollution caused by the exhaust emissions from motor vehicles referring to the data concerning air pollutants measured by local public bodies at several monitoring stations along major highways throughout the country.

(i) Nitrogen oxides (NOx)

Nitrogen dioxide (NO_2) demonstrated a slight decreasing trend in 1979 though it had been constantly increasing until that time, according to the trend of change in the annual average of measured values of exhaust emissions from motor vehicles which has been measured consecutively from 1971 at 26 roadside air monitoring stations in various locations throughout the country (see Fig. 1). On the other hand, however, according to the data compiled by 213 monitoring stations which have made effective measurements (stations whose total annual measurement time exceeds 6,000 hours), the concentration of nitrogen dioxide has not been reduced to the level required by the environmental quality standard for air pollution (see 2 B (i) b) as seen in Table 1.

Nitrogen monoxide (NO), too, has been showing a decreasing trend in general (see Fig. 1) according to the

Table 1. Relation with environmental quality standard of NO_2.

Level of annual 98% value of daily average	1979	
	Number of stations	Ratio (%)
Over 0.06 ppm	64	30.0
Over 0.04 ppm and under 0.06 ppm	112	52.6
Under 0.04 ppm	37	17.4
Total	213	100.0

trend of change in annual averages of values measured by the aforementioned 26 monitoring stations which also measure nitrogen dioxide.

(ii) Carbon monoxide (CO)

The concentration of carbon monoxide in the air began to demonstrate a decreasing trend from around 1970, the peak year, as a result of the active enforcement of control measures, according to the trend of change in annual averages of values measured consecutively from 1971 by 23 monitoring stations (see Fig. 2). Also, according to the results of effective measurements in 1979 by 309 monitoring stations, the requirement of the environmental quality standard for the concentration of carbon monoxide has been satisfied in the areas covered by 306 monitoring stations (99.0% of total area covered) when evaluated on a long-term basis, and in the areas covered by 304 monitoring stations (99.4% of total area covered) when measured on a short-term basis.

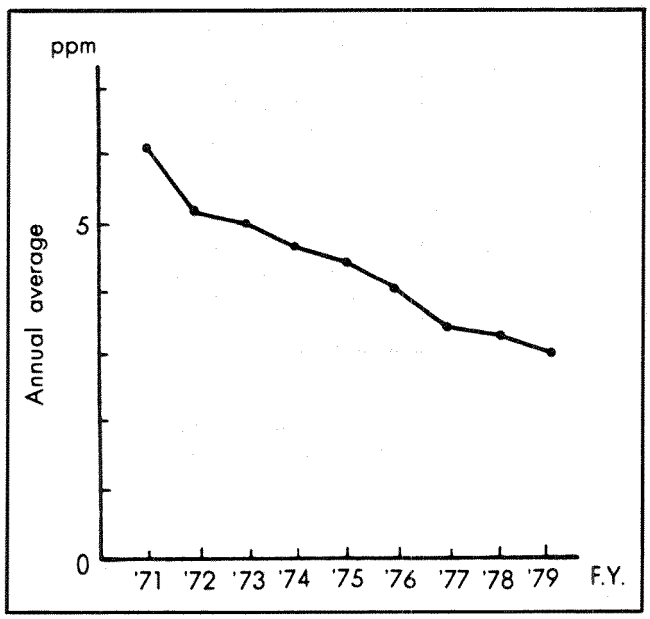


Figure 2. Trend of annual average of carbon monoxide measured continuously at 23 monitoring stations.

(iii) Hydrocarbons (HC)

As for non-methane hydrocarbons, they have been showing decreasing trends as a result of active enforcement of control measures, according to the trends of changes in annual averages of values measured consecutively from 1977 by 18 monitoring stations (see Fig. 3).

As far as total hydrocarbons are concerned, they have been also showing decreasing trends as a result of active enforcement of control measures, according to the trends of changes in annual averages of values measured consecutively from 1971 by 3 monitoring stations (see Fig. 3).

(iv) Suspended particulates

This type of pollutant has been showing a slight increasing trend according to the trend of change in annual averages of values measured consecutively from 1975 by 7 monitoring stations (see Fig. 4). Also, according to the result of long-term basis evaluation of the effective measured values in 1979 by 11 monitoring stations, the requirements of the environment quality standard concerning this type of pollutant were not satisfied in any of the areas covered by these monitoring stations.

B. Measures against motor vehicle exhaust gas

(i) Legal support

a. Basic Law for Environmental Pollution Control (Enacted in 1967)

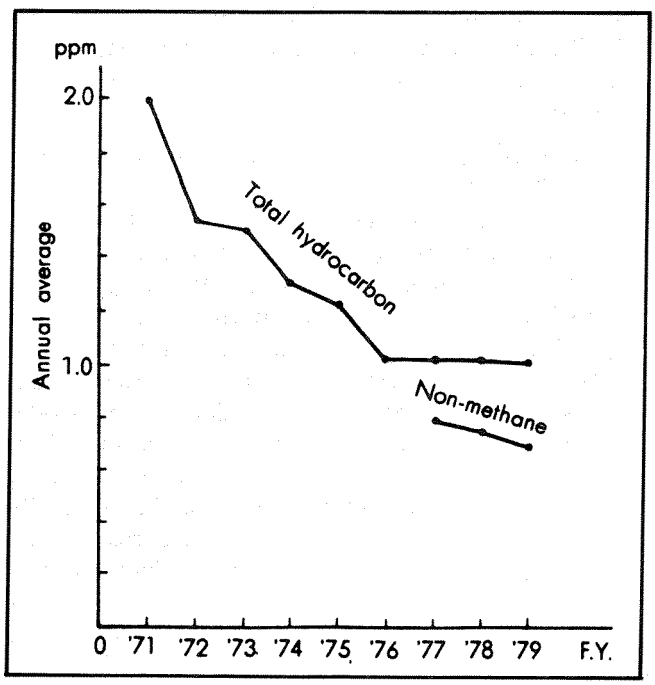


Figure 3. Trend of annual averages of total hydrocarbon and non-methane hydrocarbon measured continuously at several monitoring stations.

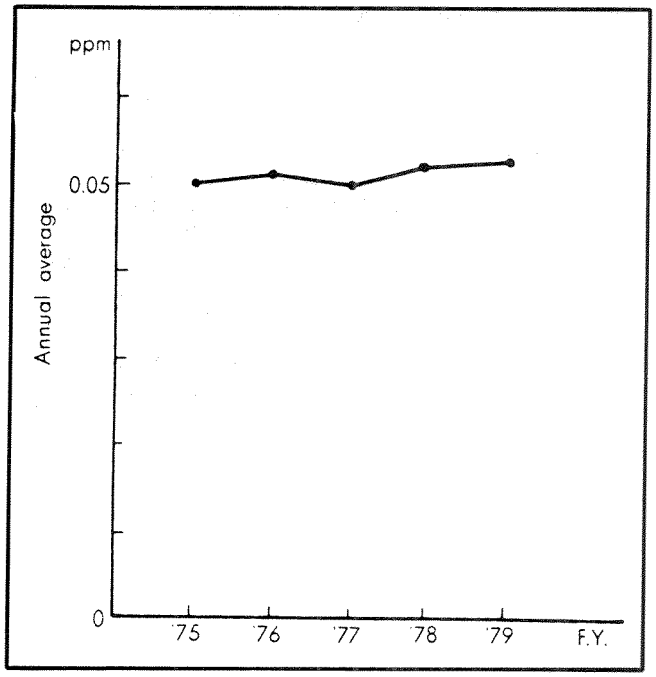


Figure 4. Trend of annual average of suspended particulates measured continuously at seven monitoring stations.

This law was enacted to define the responsibilities of business enterprises, local public bodies and the government for the control of environmental pollution, and to provide the basic requirements for measures to be taken to control environmental pollution.

b. Environmental Quality Standards for Air Pollution (Enacted in 1970 to 1978 for each pollutant in conformity with Notification of Environment Agency)
These standards govern concentrations of pollutants such as the sulfur dioxide, carbon monoxide, suspended particulates, photochemical oxidant and nitrogen dioxide and were established in conformity with the provisions of the Basic Law for Environmental Pollution Control in order not only to protect people's health from air pollution but also to preserve a good living environment (see Table 2). The Basic Law for Environmental Pollution Control requires the government to strive to ensure the requirements set forth under these standards.

c. Air Pollution Control Law (Enacted in 1968)
Under this law, the general director of the Environment Agency is authorized to set the permissible limits for exhaust emissions of motor vehicles, and the governor of each prefecture is authorized not only to request the Prefectural Public Safety Commission to regulate motor vehicle traffic according to the Road Traffic Law when the degree of air pollution by motor vehicle exhaust emissions exceeds the set limit but also to express his opinion, whenever necessary, to the road administration or the head of the related

Table 2. Environmental quality standard for air pollution.

Substance	Sulfur dioxide	Carbon monoxide	Suspended particulates	Photochemical oxidants	Nitrogen dioxide
Environmental conditions	Daily average of hourly values shall be below 0.04 ppm, and one hour value shall be below 0.1 ppm.	Daily average of hourly values shall be below 10 ppm, and eight hour mean value shall be below 20 ppm.	Daily average of hourly values shall be below 0.10 mg/m³, and one hour value shall be 0.20 mg/m³.	One hour value shall be below 0.06 ppm.	Daily average of hourly values shall be within the range between 0.04 ppm and 0.06 ppm or below.
Measuring methods	Conductometric method	Nondispersive infrared analyzer method	Weight concentration measuring methods based on filtration collection, or light scattering method yielding values having a linear relation with the values of the above method	Absorptiometry using neutral potassium iodide solution, or coulometry	Colorimetry employing Saltzman reagent

government agency, concerning the improvement of the construction or system of roads.

This law also provides for the control of smoke and soot emanating from factories and business facilities, and defines the responsibilities of the operators of such factories or business facilities regarding the payment of compensation in case the human health is injured by air pollution caused by their activities.

d. Maximum Permissible Limits of Motor Vehicle Emissions

(Enacted in 1974 according to the Notification of Environment Agency)

These regulations specify the maximum permissible limits of carbon monoxide, hydrocarbon, nitrogen oxide and the diesel smoke emitted from running motor vehicles established in conformity with the Air Pollution Control Law.

The Air Pollution Control Law states that the Minister of Transport must endeavor to enforce these maximum permissible limits in case he establishes by an order pursuant to the Road Vehicles Act necessary matters on control of motor vehicle emissions.

e. Road Vehicles Law (Enacted in 1951)

This law sets forth the requirements concerning the registration, standards for safety and environmental pollution, maintenance and inspection of motor vehicles (Refer to previous report).

f. Safety Regulations for Road Vehicles

(Enacted in 1951 according to Ministry of Transport Ordinance)

These regulations set forth the technical standards for the construction and equipment of motor vehicles to be met for the purposes of ensuring safety and environmental pollution control, in conformity with the Road Vehicles Law. (Refer to previous report). The technical standard concerning exhaust gas will be discussed in detail in the following section.

(ii) Measures for the control of exhaust emissions through the establishment of regulations concerning the construction and equipment of motor vehicles

Since 1952, running motor vehicles have been prohibited from emitting excessive harmful gases by the Safety Regulations for Road Vehicles. More recently, however, the Regulations were amended to include quantitative requirements for motor vehicles not including two-wheeled motor vehicles and special motor vehicles and such quantitative requirements have been made increasingly stringent.

a. Stringency of regulations for new vehicles (see Table 3)

Regulations governing gasoline-fueled vehicles commenced with the regulation of CO concentration by 4-modes in 1966, and this was followed by the regulation of blow-by gas (mainly consisting of HC) in 1970 and fuel evaporation gas (mainly consisting of HC). Regulations governing motor vehicles were thus gradually strengthened. As for diesel-powered vehicles, the regulation of smoke by 3-modes (see Table 4) was started in 1972. In 1973, the regulation by weight of three substances (CO, HC and NOx) by 10-modes (see Fig. 5) or gasoline 6-modes (see Table 5) was commenced for gasoline-fueled vehicles, and in 1974, regulation governing concentration of the same three substances by diesel 6-modes (see Table 6) were enacted for diesel-powered vehicles.

Later, in 1975, the regulations governing the aforementioned three substances for gasoline-fueled passenger vehicles were intensified. As a result, the

requirements for the reduction of CO and HC have been intensified by more than 90% compared with their levels before the enforcement of the regulations, while the same for NOx has also been strengthened by more than 90% compared with its level before the enforcement of the regulation as a result of the strengthening of the regulations in 1976 and 1978. On the other hand, concerning gasoline-fueled trucks and buses and diesel-powered vehicles, in 1975, the regulations of CO, HC and NOx for small- and medium-sized gasoline-fueled vehicles were strengthened, and in 1977, the NOx regulation for large-sized gasoline-fueled vehicles and diesel-powered vehicles was intensified. Also, in December, 1977, the Central Council for Control of Environmental Pollution, an advisory organization to the Director-General of the Environ-

Table 3. Details of motor vehicle (including new vehicles) exhaust gas regulations.

		1973	1974	1975	1976	1977	1978	1979
Gasoline-fueled passenger motor vehicles (10-mode)	CO HC NOx	1973 regulation 45 48 71		1975 regulation 5 8 39	1976 regulation (Equivalent inertia weight: under 1 ton) 20 27 (Equivalent inertia weight: over 1 ton)		1978 regulation 8	
Gasoline-fueled small- and medium-sized trucks and buses and light trucks (Gross vehicle weight: under 2.5 tons) (10-mode)	CO HC NOx	1973 regulation 45 48 71		1975 regulation 32 35 59				1979 regulation (Small trucks and buses) 32 (Medium-sized trucks 39 and buses and light trucks)
Gasoline-fueled large-sized trucks and buses (Gross vehicle weight: over 2.5 tons) (Gasoline 6-mode)	CO HC NOx	1973 regulation 45 48 70				1977 regulation 59		1979 regulation 42
Diesel-powered motor vehicles (Diesel 6-mode)	CO HC NOx		1974 regulation 95 90 80			1977 regulation 68		1979 regulation (Direct injection type) 56 (Indirect injection type) 60

	1980 (Current regulation)		1981		1982	
Gasoline-fueled passenger motor vehicles (10-mode)	Max. value (Average value) CO 2.70 g/km (2.10) HC 0.39 g/km (0.25) NOx 0.48 g/km (0.25)	5 8 8				
Gasoline-fueled small- and medium-sized trucks and buses and light trucks (Gross vehicle weight: under 2.5 tons) (10-mode)	CO 17.0 g/km (13.0) HC 2.70 g/km (2.10) 1.40 g/km (1.00) NOx 1.60 g/km (1.20)	32 35 32 (Small trucks and buses) 39 (Medium-sized trucks and buses and light trucks)	1981 regulation Max. value (Average value) NOx 0.84 g/km (0.60) 1.26 g/km (0.90)	19 (Small trucks and buses) 29 (Medium-sized trucks and buses)	1982 regulation Light trucks Max. value (Average value) NOx 1.26 g/km (0.90)	29 (Light trucks)
Gasoline-fueled large-sized trucks and buses (Gross vehicle weight: over 2.5 tons) (Gasoline 6-mode)	CO 1.60% (1.20) HC 520 ppm (410) NOx 1390 ppm (1,100)	45 48 42			1982 regulation NOx 990 ppm (750)	29
Diesel-powered motor vehicles (Diesel 6-mode)	CO 980 ppm (790) HC 670 ppm (510) 700 ppm (540) NOx 450 ppm (340)	95 90 56 (Direct injection type) 60 (Indirect injection type)			1982 regulation NOx 390 ppm (290)	(Indirect injection type) 52

Quantity of exhaust gas before regulation
45

Ratio (%) of exhaust gas level to that before regulation

(10-mode)

Exhaust gas measuring mode

Table 3. Details of motor vehicle (including new vehicles) exhaust gas regulations (continued).
(Year of enforcement)

	New Models	Models in continuous production	Imported motor vehicles
1973 regulation	1973.4.1	1973.12.1	—
1974 regulation	1974.9.1	1975.4.1	—
1975 regulation	1975.4.1	1975.12.1	1976.4.1 (Applicable only to models in continuous production)
1976 regulation	1976.4.1	1977.12.1	1978.4.1 (Applicable only to models in continuous production)
1977 regulation	1977.8.1	1978.4.1	—
1978 regulation	1978.4.1	1979.3.1	1981.4.1
1979 regulation	1979.1.1	1979.11.1	1981.4.1
1981 regulation	1981.1.1 (Applicable to gasoline-fueled medium-sized trucks and buses from December 1, 1981)	1981.12.1 (Applicable to gasoline-fueled medium-sized trucks and buses from November 1, 1982)	1983.4.1 (Applicable to gasoline-fueled medium-sized trucks and buses from April 1, 1984)
1982 regulation	1982.1.1 (Applicable to diesel-powered vehicles with indirect injection type from October 1, 1982)	1982.12.1 (Applicable to diesel-powered vehicles with indirect injection type from September 1, 1983)	1984.4.1

ment Agency, submitted a Report on the Long-term Policy for Establishment of Maximum Permissible Limits of Motor Vehicle Emissions (see Table 7). Subsequently, the NOx regulation for gasoline-fueled trucks and buses and diesel-powered vehicles was intensified in 1979 as the first phase of the intensification program. Similarly, in the second phase, the NOx regulation for small- and medium-sized gasoline-fueled trucks and buses was intensified in 1981, and the same regulation for diesel-powered vehicles with indirect injection type of engines is expected to be strengthened in 1982.

Table 4. Three modes of black exhaust gas from diesel engines.

	Mode
1	While the engine is running with a full-load at the speed of revolution equal to 40% of the speed at which it produces its maximum output (at 1,000 rpm., if the speed of revolution is less than 1,000 rpm.);
2	While the engine is running with a full-load at the speed of revolution equal to 60% of the speed at which it produces its maximum output; and
3	While the engine is running with a full-load at the speed of revolution at which it produces its maximum output.

As a result of such gradual strengthening of the regulations, as discussed in the preceding section, the air pollution by CO and HC has been considerably alleviated, but NOx pollution has not been reduced significantly. Thus, in order to solve this problem, it is essential to strengthen the regulation governing NOx for diesel-powered vehicles with direct injection type of engines as soon as possible.

Table 5. Six modes of driving pattern of gasoline engine.

	Mode	Weighting factor
1	Engine is idling with no-load.	0.125
2	Engine is operated at a speed of 2,000 rpm with an inlet vacuum of 125 mmHg at intake manifold.	0.114
3	Engine is operated at a speed of 3,000 rpm with an inlet vacuum of 125 mmHg at intake manifold.	0.277
4	Engine is operated at a speed of 3,000 rpm with an inlet vacuum of 2,000 mmHg at intake manifold.	0.254
5	Engine is operated at a speed of 2,000 rpm with an inlet vacuum of 420 mmHg at intake manifold.	0.139
6	Engine is decelerated, with its carburetor gas valve completely closed, from 2,000 rpm with an inlet vacuum of 420 mmHg at intake manifold to 1,000 rpm in 10 sec.	0.091

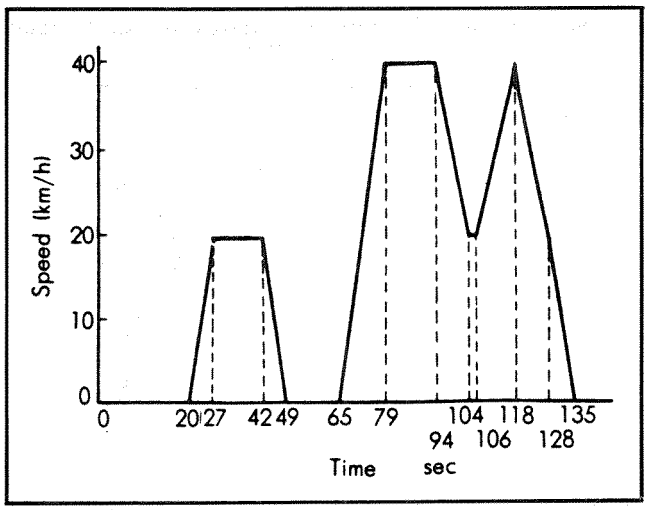


Figure 5. 10-mode driving cycle.

b. Strengthening of regulations for vehicles in use (including new vehicles)
Concerning gasoline-fueled vehicles, a regulation governing CO concentration at idling was enacted in 1970, and this was followed in 1974 by a regulation controlling HC concentration at idling.
For diesel-powered vehicles, a regulation governing smoke emission at no-load acceleration has been in force since 1970.

(iii) Other measures against automotive exhaust emissions

As measures against environmental pollution through traffic control, the government has been promoting not only a more stable and smooth traffic flow but also the normalization (optimization) of traffic flow and reduction of total traffic volume by intensifying the enforcement of comprehensive urban traffic controls.

On the other hand, as measures against environmental pollution through the improvement of the road system,

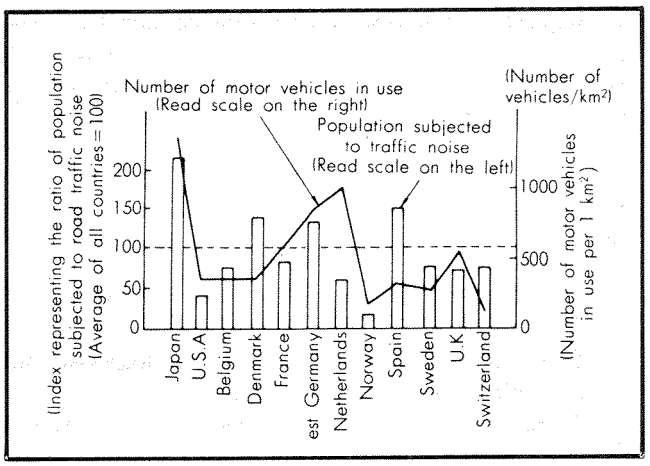


Figure 6. International comparison of road traffic noise (Over 65 dBA (Leq): In the middle of 1970).

Table 6. Six modes of driving pattern of diesel engine.

	Mode	Weighting factor
1	Engine is idling with no-load.	0.355
2	Engine is operated with a full-load and a speed of revolution equal to 40% of the speed at which it produces its maximum power.	0.071
3	Engine is operated with a 25% load of the full-load and at a speed of revolution equal to 40% of the speed at which it produces its maximum power.	0.059
4	Engine is operated with a full-load and at a speed of revolution equal to 60% of the speed at which it produces its maximum power.	0.107
5	Engine is operated with a 25% load of the full-load and a t a speed of revolution equal to 60% of the speed at which it produces its maximum power.	0.122
6	Engine is operated with a 75% load of the full-load and at a speed of revolution equal to 80% of the speed at which it produces its maximum power.	0.286

the government has been promoting the construction and improvement of by-passes and ring roads in order to sharply reduce the volume of traffic including that of large vehicles passing through residential areas, and in parallel with such measures, the government has also been promoting the establishment of environmental protection zones.

Furthermore, the government has been striving to reduce the total traffic volume of motor vehicles through the construction and improvement of public mass-transportation means such as subway systems and bus services so that part of the users of individual motor vehicles can switch to using such mass-transportation means, and in parallel with such measures, the government is also promoting the construction and improvement of physical distribution systems and facilities such as distribution business centers and truck terminals in order to realize the rationalization of physical distribution since this also can contribute to the reduction of the total traffic volume of motor vehicles.

Measures against automobile noise

A. Present condition and trend of automobile noise

During the formation of its highly developed economic society, Japan has seen not only the concentration of population and production in large cities but also the rapid progress of motorization, and such rapid progress of motorization coupled with the special condition that the share of trucks in the total number of motor vehicles

Table 7. Report on the long-term policy for establishment of maximum permissible limits of motor vehicle emissions (report submitted by Central Council for Control of Environmental Pollution on December 26, 1977).

Category of motor vehicle		Target values of maximum permissible limits (average values)		Measurement method
		1st stage	2nd stage	
Diesel-fueled ordinary & small-sized motor vehicles	Direct injection type	540 ppm	470 ppm	Diesel 6-mode
	Indirect injection type	340 ppm	290 ppm	Diesel 6-mode
Gasoline- or LPG-fueled ordinary & small-sized motor vehicles*	With GVW** exceeding 2,500 kg	1,100 ppm	750 ppm	6-mode
	With GVW 1,700 ~ 2,500 kg	1.2 g/km	0.9 g/km	10-mode
	With GVW 1,700 kg or less	1.0 g/km	0.6 g/km	10-mode
Light motor vehicles***		1.2 g/km	0.9 g/km	10-mode

* Excluding those exclusively used for carrying passengers with a riding capacity of 10 persons or less.
** Gross vehicle weight.
*** Excluding those exclusively used for carrying passengers and equipped with two-stroke engine.

is relatively large compared with other industrialized countries has been causing serious environmental pollution (public nuisances) resulting from automotive noise especially in areas along major highways where motor vehicle traffic is particularly heavy (see Fig. 6).

According to the results of the measurements of automobile noise levels carried out by various prefectural authorities in 1979 at 3,582 monitoring stations considered to represent various noise levels in each of these prefectures, there were 608 monitoring stations (17%) where the requirement of environmental quality standard for noise (see 2 B b.) was satisfied, and 782 monitoring stations (22%) where the noise levels were higher than the permissible limits (see 2 B c.) (see Fig. 7).

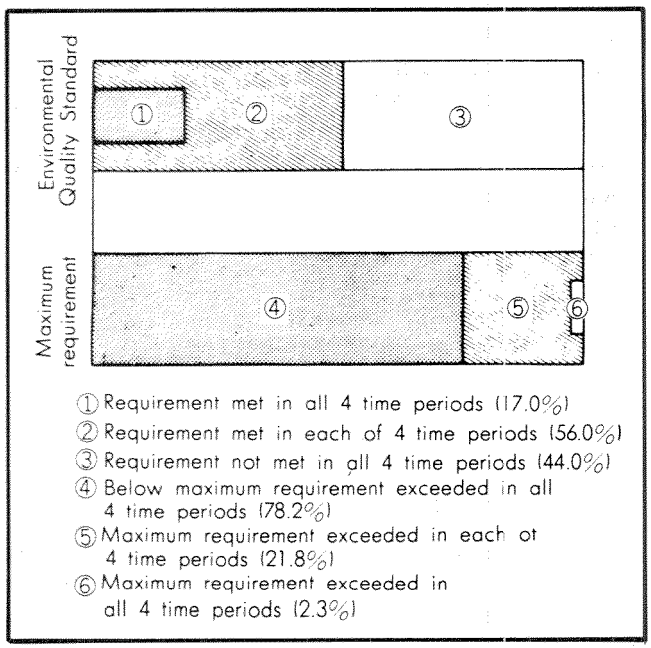


Figure 7. Conditions of conformity and non-conformity to requirements of Environmental Quality Standard by time period.

Analyzing the above measurement results by kinds of area, in residential areas where the maintenance of quietness is most desired, it was found not only that the ratio of satisfaction of the environmental quality standard for noise was markedly low but also that the ratio of the noise levels higher than the permissible limits was high.

Also, when the same is analyzed by time period, it was found that in general, the ratio of satisfaction of the environmental quality standard for noise during nighttime was highest compared with other time periods, but it was also found that the number of areas where the noise levels were higher than those specified by the environmental quality standard were increasing.

B. Measures against automobile noise

(i) Legal system for the regulation of noise

a. Basic Law for Environmental Pollution Control
Refer to 1. B. (ii).

b. Environmental Quality Standards for Noise (Adopted at Cabinet Conference in 1971)
These standards were established in conformity with the Basic Law for Environmental Pollution Control and as the desirable standards to be met concerning noise pollution, similar to the case of air pollution,

Table 8. Details of motor vehicle exhaust gas regulations (for vehicles currently in use).

Category of motor vehicles	Substance to be controlled	1970	1971	1972	1973 ~ 1974	1975	1976 ~ 1981
Gasoline-fueled motor vehicles	Idling CO	5.5%	←	4.5%	←	←	←
	Idling HC	–	–	–	–	1200 ppm	←
Diesel-powered motor vehicles	Diesel smoke emission at no-load acceleration	–	–	–	–	50%	←

Table 9. Environmental quality standard for noise.

Category of area	Time period			Area concerned
	Daytime	Morning/ evening	Nighttime	
AA	Under 45 dB (A)	Under 40 dB (A)	Under 35 dB (A)	Area to be designated by the governor of each prefecture according to Paragraph 2 of government ordinance (No. 159, 1971) concerning the delegation of authority to designate water area and land area in conjunction with Environmental Quality Standard.
A	Under 50 dB (A)	Under 45 dB (A)	Under 40 dB (A)	
B	Under 60 dB (A)	Under 55 dB (A)	Under 50 dB (A)	

Notes: 1. Category AA represents area where special quietness is requires such as one where medical center is located.
2. Category A represents area mainly used as residential area.
3. Category B represents area where considerable number of residences, commercial and industrial facilities are located together.
As for areas along roads, the following standards have been established.

Category of area	Time period		
	Daytime	Morning/ evening	Nighttime
Of the area of category A, area located along 2-lane road.	Under 55 dB (A)	Under 50 dB (A)	Under 45 dB (A)
Of the area of category A, area located along road with more than two lanes.	Under 60 dB (A)	Under 55 dB (A)	Under 50 dB (A)
Of the area of category B, area located along road with less than two lanes.	Under 65 dB (A)	Under 60 dB (A)	Under 55 dB (A)
Of the area of category B, area located along road with more than two lanes.	Under 65 dB (A)	Under 65 dB (A)	Under 60 dB (A)

from the standpoint of environmental pollution control (see Table 9).

c. Noise Control Law (Enacted in 1968)
As for automobile noise, this law provides that, as in the case of the Air Pollution Control Law, the Director-General of the Environment Agency is authorized to set the permissible limits concerning motor vehicle noise, and that the governor of each prefecture is authorized not only to make requests concerning the traffic regulations in conformity with the Road Traffic Law to the Prefectural Public Safety Commission when the measured noise level exceeds a certain limit (see Table 10) and the living environment along the road concerned is conspicuously disturbed by such noise, but also to express his opinion, whenever necessary, to the road administration or the head of the related governmental agency concerning the improvement of the construction or system of roads.

d. Maximum Permissible Limits of Motor Vehicle Noise Emission (Established in 1970 by Environment Agency Notification)
This standard specifies the maximum permissible lim-

Table 10. Maximum permissible limit. (Unit: dB(A))

	Category of area	Time period		
		Daytime	Morning/ evening	Nighttime
1	Of class-1 area, area located along one-lane road.	55	50	45
2	Of class-2 area, area located along one-lane road.	60	55	50
3	Of class-1 and class-2 areas, areas located along two-lane road.	70	65	55
4	Of class-1 and class-2 areas, areas located along roads with more than two lanes.	75	70	60
5	In class-3 and class-4 areas, areas located along one-lane road.	70	65	60
6	In class-3 and class-4 areas, areas located along two-lane road.	75	70	65
7	In class-3 and class-4 areas, areas located along road with more than two lanes.	80	75	65

Note: *Classes-1, 2, 3 and 4 areas are those designated respectively by the governor of each prefecture according to the following criteria:

(Class-1 area) Area where the maintenance of quietness is specially required in order to preserve desirable living environment.
(Class-2 area) Residential area where the maintenance of quietness is necessary.
(Class-3 area) Area where residential, commercial and industrial districts are located together, and the residential district has to be protected from noise.
(Class-4 area) Area mainly used for industrial purposes, but extremely offensive noises must be prevented in order to prevent the deterioration of living environment of the people inhabiting in such an area.

its of steady running noise, stationary noise and accelerated running noise for motor vehicles, in conformity with the Noise Pollution Regulation.
The Noise Pollution Regulation provides, just as in the case of the Air Pollution Control Law, that the Minister of Transport must endeavor to enforce this maximum permissible limit in case he establishes by an order pursuant to the Road Vehicle Act necessary matters on control of motor vehicle noise.

e. Road Vehicles Law
Refer to 1. B. (i).

f. Safety Regulations for Road Vehicles
Refer to 1. B. (i).
Technical standards concerning motor vehicle noise will be discussed in detail in the following section.

(ii) Measures against motor vehicle noise through the regulation of the construction and equipments of motor vehicles

The regulations of steady running noise and stationary noise (see Table 12) concerning motor vehicles and motor-driven cycles in use (including new ones), except special motor vehicles have been enforced in conformity with the Safety Regulations for Road Vehicles since 1952 and these regulations were strengthened in 1971.

As for new motor vehicles, in addition to the above-mentioned regulations, the regulation governing accelerated running noise (see Table 12) which is the greatest noise produced by any motor vehicle running on roads in urban areas has been enforced since 1971, and this regulation was further strengthened in 1976 for motor vehicles except passenger motor vehicles and small-sized motor vehicles and for motor-driven cycles, and in 1977 for passenger motor vehicles and small-sized motor vehicles. In the meantime, the Central Council for Control of Environmental Pollution completed a Report on Long-term Targets for Permissible Limits on Motor Vehicle Noise (see Table 13) in June, 1976. In response to this report, as the first phase of measures to be taken, the regulation of accelerated running noise of motor vehicles has been strengthened since 1979, and as the second phase, the regulation of accelerated running noise of passenger motor vehicles is expected to be strengthened in 1982.

As mentioned in the preceding section, the situation concerning motor vehicle noise has still not been im-

Table 11. Outline of motor vehicle noise.

(Unit: dB)

Type of motor vehicle				1971		1976		1977		1979		1982	
				Steady running and stationary noise	Accelerated running noise	Steady running and stationary noise	Accelerated running noise	Steady running and stationary noise	Accelerated running noise	Steady running and stationary noise	Accelerated running noise	Steady running and stationary noise	Accelerated running noise
Trucks and buses	Large-sized	Gross vehicle weight > 3.5 t	Max. power > 200 PS	80	92	←	89	←	←	←	86	←	←
	Medium-sized		≦ 200 PS	78	89	←	87	←	←	←		←	
	Small-sized	Gross vehicle weight ≦ 3.5 t		74	85	←	←	←	83	←	81	←	←
Passenger motor vehicles				70	84	←	←	←	82	←		←	78
Motorcycles		Small-sized motor vehicle	Engine displacement > 250 cc	74	86	←	83	←	←	←	78	←	←
		Light motor vehicle	≦ 250 cc > 125 cc		84	←		←	←				
Motor driven cycles		Class-1	≦ 50 cc	70	80	←	79	←	←	←	75	←	←
		Class-2	≦ 125 cc > 50 cc		82	←		←	←				

(Date of enforcement)

	Domestic models		Imported motor vehicles
	New models	Models in continuous production	
1971 regulation	1971. 4. 1	1972. 1. 1	
1976 regulation	1976. 1. 1	1976. 9. 1	
1977 regulation	1977. 1. 1	1977. 9. 1	
1979 regulation	1979. 1. 1 (Applicable to diesel-powered motor vehicles, motorcycles and motor-driven cycles from April 1, 1979)	Passenger motor vehicles 1979. 9. 1 (Applicable to diesel-powered two-wheeled and other motor vehicles from December 1, 1979)	1981. 4. 1
1982 regulation	1982. 10. 1	1983. 9. 1	1984. 4. 1

proved to the desirable degree, and thus it is also necessary to enforce the regulation of accelerated running noise for categories of motor vehicles other than passenger motor vehicles as soon as possible as part of the forthcoming second phase of measures.

(iii) Other measures against motor vehicle noise

As measures to protect the living environment, the government is now promoting the transfer of motor vehicle traffic to other means of transport, intensification of traffic control measures, improvement of road structure and improvement of environmental conditions along roads (see 1.B.(iii)).

Energy-Saving Measures for Motor Vehicles

Even if the oil crises in 1974 and 1979 hadn't occurred, the world faces the strong probability of a shortage of energy supplies in the future due to the finite nature of oil resources coupled with the growing trend on the part of the oil producing countries to preserve their resources. For instance, some predict that the gap between supply and demand for oil will become clearly apparent from around the middle of the 1980's.

Japan's energy consumption is now 410 million tons, having increased by about 30% from the 1970 level. As a result, Japan is now the second largest energy consumer next to the U.S. in the free world.

Table 12. Measuring methods of noises.

Classification	Measuring method
Steady running noise	When a motor vehicle or motor-driven cycle is running on a dry, level and paved road at a steady speed corresponding to either an engine rotating speed equal to 60% of the speed at which the engine produces its maximum power or (a) in the case of a motor vehicle or a 2nd class motor-driven cycle, 35 km/h, (b) in the case of a 1st class motor-driven cycle, 25 km/h, whichever is lower, the noise level shall be measured at a point 1.2 meters from the ground and 7 meters leftward from the longitudinal axis of the vehicle or cycle.
Stationary noise	When an engine is running with no load at a speed of revolution equal to 60% of the speed at which the engine produces its maximum power, the noise level shall be measured at a point 1.2 meters above the ground and 20 meters to the rear from the opening of the exhaust pipe.
Accelerated running noise	A motor vehicle or motor-driven cycle to be tested shall run on a dry, level and paved road at a steady speed corresponding to either an engine rotating speed equal to 75% of the speed at which the engine produces its maximum power or (a) in the case of a motor vehicle other than a light motorcycle with or without sidecar, 50 km/h, (b) in the case of a light motorcycle or a 2nd class motor-driven cycle, 40 km/h, (c) in the case of a 1st class motor-driven cycle, 25 km/h, whichever is lower, and as soon as the vehicle or cycle reaches the acceleration start line, it shall be accelerated and run the 20 meters testing distance with its accelerator pedal fully depressed or its throttle valve fully opened. Meantime, the noise level shall be measured, in the middle of the testing distance, at a point 1.2 meters from the ground and 7.5 meters leftward from the longitudinal axis of the vehicle or cycle.

It is characteristic of the energy supply structure of this country, however, that not only the dependency on oil (74% in 1978) is much higher compared with other major developed countries but also the dependency on imported energy resources is extremely high (88%; figure for oil imports was 99.8% in 1978), and such an energy supply structure is considered to be most vulnerable in case of instability of supply and rising prices of energy

Table 13. Report on long-term targets for permissible limits on motor vehicle noise (Reports submitted by Central Council for Control of Environmental Pollution on June 15, 1976).

Types of vehicle	Target values dB (A)	
	Phase I	Phase II
Vehicles with gross vehicle weight exceeding 3.5 tons	86	83
Vehicles with gross vehicle weight not exceeding 3.5 tons, passenger cars and motorcycles (excluding motor-driven cycles)	81 78	78 75

Note: The figures stand for values obtained by JIS (Japanese Industrial Standard) 1024 (measurements of noise emitted by automobiles).

sources, situations which are predicted to become increasingly common from now on.

Thus, it is necessary for Japan to promote energy-saving measures actively, and this is especially important in the field of transportation, particularly motor vehicles, which are one of the main consumers of energy.

This chapter is primarily devoted to discussions on energy-saving measures concerning motor vehicles mainly in the light of the legal regulations.

Present condition of energy consumption by motor vehicles

Of the total consumption of energy in this country which has been increasing year by year (see Fig. 8), transportation accounted for 16% as of 1978 (see Fig. 9), but this share is 26% as far as the share of oil consumption is concerned (see Fig. 10).

Of the total consumption of energy in the field of transportation, motor vehicles account for 79% of which the consumption by passenger motor vehicles accounts for 40%.

Looking at the trend of fuel efficiency of passenger motor vehicle (see Fig. 11), it continued to increase up to 1975 mainly due to the increase in the number of large-

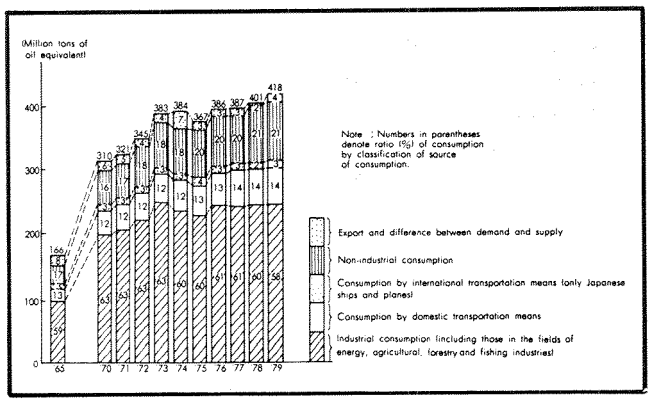


Figure 8. Trend of energy consumption in Japan (Unit: Million tons in terms of oil).

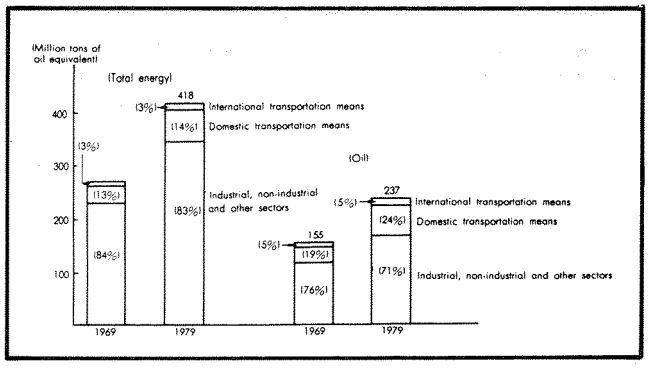


Figure 9. Share of transportation sector in final demand for energy in Japan.

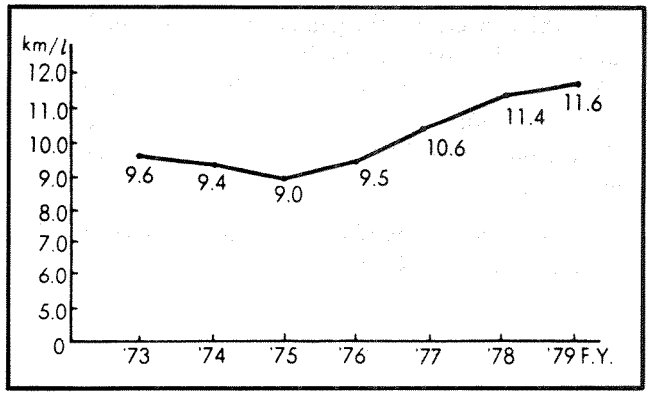


Figure 11. Average 10-mode fuel efficiency of passenger motor vehicles for domestic market.

sized passenger motor vehicles coupled with the increasingly stringent exhaust gas regulations, but it started to mark a down-trend after 1976 mainly thanks to technological advances in automotive engineering.

Energy-saving measures for motor vehicles

A. Legal support

(i) Rationalization of energy consumption law

As for the energy-consuming machines and equipment including motor vehicles, this law stipulates:

a. Manufacturers (including importers) shall strive to bring about a reduction of energy consumption through improvement in the performance of their machines and equipments.
b. Minister of International Trade and Industry or Minister of Transport shall be authorized to establish standards for the improvement of performance as to special machines and equipments designated as ones requiring improvement in their performance by Cabinet Order.
c. Manufacturers shall be required to indicate the energy efficiencies of designated machines and equipments.
d. Minister of International Trade and Industry or Minister of Transport, whenever necessary, shall be authorized to require the manufacturers of designated machines and equipments to report on the conditions of their businesses, or let the personnel of the ministry conduct on-the-spot inspection of the designated machines and equipments at the factories or offices of the manufacturers. In addition, the law stipulates that the entrepreneurs and owners of buildings must meet the requirements and standards laid down, and for the right of relevant ministries not only to give necessary guidance and advice but also to let their staff conduct on-the-spot inspections of such offices and buildings.

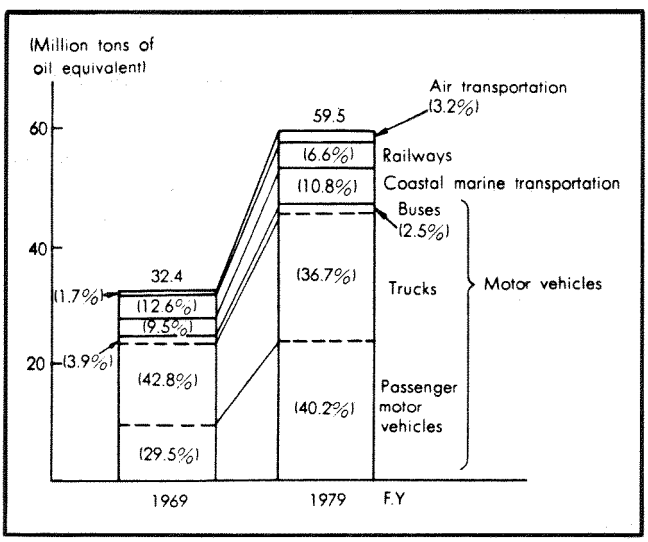


Figure 10. Shares of energy consumption by various domestic transportation means.

(ii) Enforcement Cabinet Order for Rationalization of Energy Consumption Law

This Cabinet Order designates special machines and equipment as type-designated gasoline-fueled passenger motor vehicles according to Rationalization of Energy Consumption Law.

(iii) Ministerial Ordinance Regarding Determination of Automobile Fuel Efficiency

This law provides that the motor vehicle fuel efficiency to be indicated by the manufacturers shall be the 10-mode fuel efficiency determined by the Minister of Transport at the time of type-designation.

(iv) Guidelines for Manufacturers and Others concerning Improvement of Motor Vehicle Performance (Ordinance of Ministry of International Trade and Industry and Ministry of Transport)

These guidelines for manufacturers set the targets of 10-mode fuel efficiency vehicle weight to be attained by

F.Y. 1985 concerning the passenger motor vehicles to be shipped to the domestic market.

Also, these guidelines provide for the contents and methods of indications to be made by manufacturers.

These matters will be explained in detail in the following section.

B. Fuel efficiency standard of motor vehicle and indication of fuel efficiency

Guidelines for manufacturers concerning the improvement of motor vehicle performance provide for the following standards and requirements concerning the indications:

a. Guidelines

As for the 10-mode fuel efficiencies of gasoline-fueled passenger motor vehicles falling under the categories of specified model classifications which will be shipped to the domestic market in F.Y. 1985 (in F.Y. 1988 for imported vehicles), manufacturers are required to ensure that the weighted harmonic averages of such 10-mode fuel efficiencies are better than the fuel efficiency standards shown in the following table.

Category / Item	A	B	C	D	(Reference) Overall average
Vehicle weight (kg)	less than 577.5	equal to or more than 577.5 less than 827.5	equal to or more than 827.5 less than 1265.5	equal to or more than 1265.5 less than 2015.5	
(A) Target (km/ℓ)	19.8	16.0	12.5	8.5	12.8

Remarks

In case any manufacturer ships passenger cars both of category 2 and of category 3 to the domestic market, category 2 and category 3 shall be combined into one category, and the target of energy efficiency for the combined category shall be 13.0 km/ℓ.

b. Matters to be indicated

Manufacturers are required to indicate the 10-mode fuel efficiencies and related matters (Type, engine displacement, type of transmission, etc.) clearly in the catalogs of their motor vehicles or on those for display from June 1st, 1980. The fuel efficiency in general is expected to be improved by 12.3% in F.Y. 1985 compared with F.Y. 1978 through the enforcement of the above-mentioned measures (see Fig. 12).

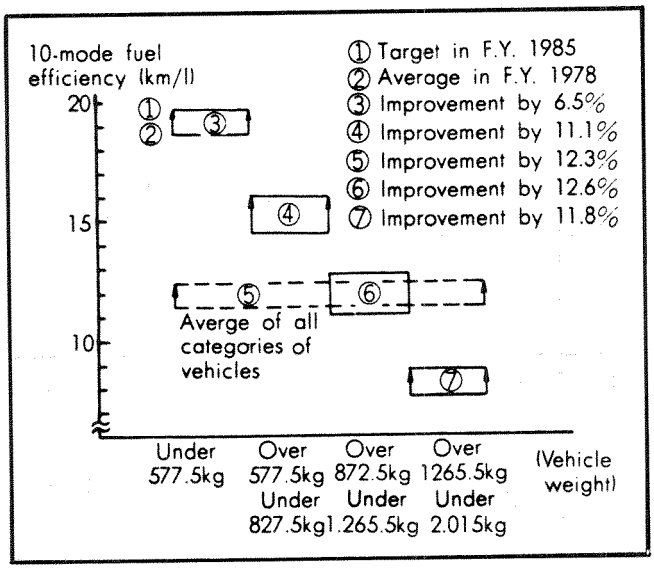


Figure 12. Fuel efficiency improvement target for passenger motor vehicles.

C. Other energy-saving measures for motor vehicles

In addition to promoting the technological development for improving fuel efficiency through the establishment of fuel efficiency standards and the introduction of the fuel efficiency indication system described above, the government is also promoting the energy-saving measures for motor vehicles by recommending the following:

(i) To refrain from abrupt acceleration and to maintain an economic running speed (Recommendations concerning the improvement of driving habits directed at drivers).

(ii) To carry out proper maintenance such as correct tire pressure and to keep ignition plugs clean (Recommendations concerning maintenance of motor vehicles directed at drivers).

(iii) To promote the establishment of car pooling and cooperative transportation systems in order to improve the load factor for passenger vehicles and trucks.

(iv) To encourage the use of public mass transport which is more efficient than individual motor vehicles.

Legal Systems of Japan on Motor Vehicles*

MASAKAZU KUME
Automobile Type Approval Test Division, Traffic Safety and Nuisance Research Institute, Ministry of Transport
HARUO OMORI
Engineering Division, Road Transport Bureau
KAZUSHIGE DAIKI
Environmental Pollution Control Division, Road Transport Bureau
KAZUYOSHI MATSUMOTO
Transport Department, Okinawa Development Agency Prime Minister's Office, Okinawa

Part 4: Type Approval System of Motor Vehicles

Outline of Type Approval System of Motor Vehicles

In Japan, before new types of motor vehicles are manufactured or sold, examination is conducted on each type of motor vehicle to determine whether it conforms to the safety requirements and antipollution standards as explained in previous issues. It is carried out as a part of the motor vehicle inspection system under the Road Vehicles Act in order that the inspection of new types of vehicles may be conducted accurately by a limited number of persons on many items in a short period of time. Particulars of the motor vehicle inspection system will be explained on another occasion, but the outline of the type approval system is as follows:

In Japan, every motor vehicle is obliged to undergo an inspection conducted by the Ministry of Transport. Only motor vehicles which, as a result of the inspection, conform with the Safety Regulations for Road Vehicles are allowed to be operated on the roads. The inspection is, in principle, carried out before the motor vehicles are first used on roads and at the time when effective term of motor vehicle inspection certificate expires on the motor vehicles submitted to the District Land Transport Offices located throughout Japan. However, it would be impossible to carry out a detailed technical inspection on all items under the Safety Regulations of Road Vehicles on each motor vehicle at the time of such inspection. Therefore, the type approval system of motor vehicles is established, under which the inspection of each type of motor vehicle is carried out collectively by the Road Transport Bureau and the Traffic Safety and Nuisance Research Institute, of the Ministry of Transport.

The type approval system is divided into two systems. One is the type designation system for vehicles produced and sold on a mass-production and uniform basis. The other is the type notification system for motor vehicles other than the above mass-production motor vehicles.

In addition to the above two types of approval systems for the motor vehicles as a whole, there is also the type approval system for devices of motor vehicles to ensure that the inspection is conducted efficiently.

Type Designation System

The type designation system is a system under Article 75 of the Road Vehicles Act which reads as follows:

Road Vehicles Act (extract)

Article 75 (Type Designation of Motor Vehicles)

(1) The Minister for Transport shall designate a motor vehicle as to the type upon receipt of application for the purpose of promotion of the safety of motor vehicles.
(2) The type designation provided for in the preceding paragraph shall be effected by judging whether the motor vehicle concerned conforms to the Safety Regulations, and besides, whether it has uniformity.
(3) Any person submitting the application provided for in paragraph 1 shall, in the case where he alienates the motor vehicle of the designated type, inspect whether the motor vehicle concerned conforms to the Safety Regulations, and when he judges that the vehicle conforms thereto, he shall issue a termination certificate of completion inspection and deliver it to the alienee.
(4) The Minister for Transport may, when the motor vehicle of the designated type has ceased to conform to the Safety Regulations or has ceased to have uniformity, cancel the designation thereof. In this case, the Minister for Transport may limit the effective scope of the cancellation as to the motor vehicles which have been manufactured up until the day of cancellation.

In this system, as provided for in Paragraph 2, it is required that the motor vehicle concerned not only conform to the Safety Regulations, but also that it have uniformity. Furthermore, as provided for in Paragraph 3, the system obligates the applicant to conduct the completion inspection on each type-designated motor vehicle and to deliver the termination certificate of completion

* Received 7th July 1981.

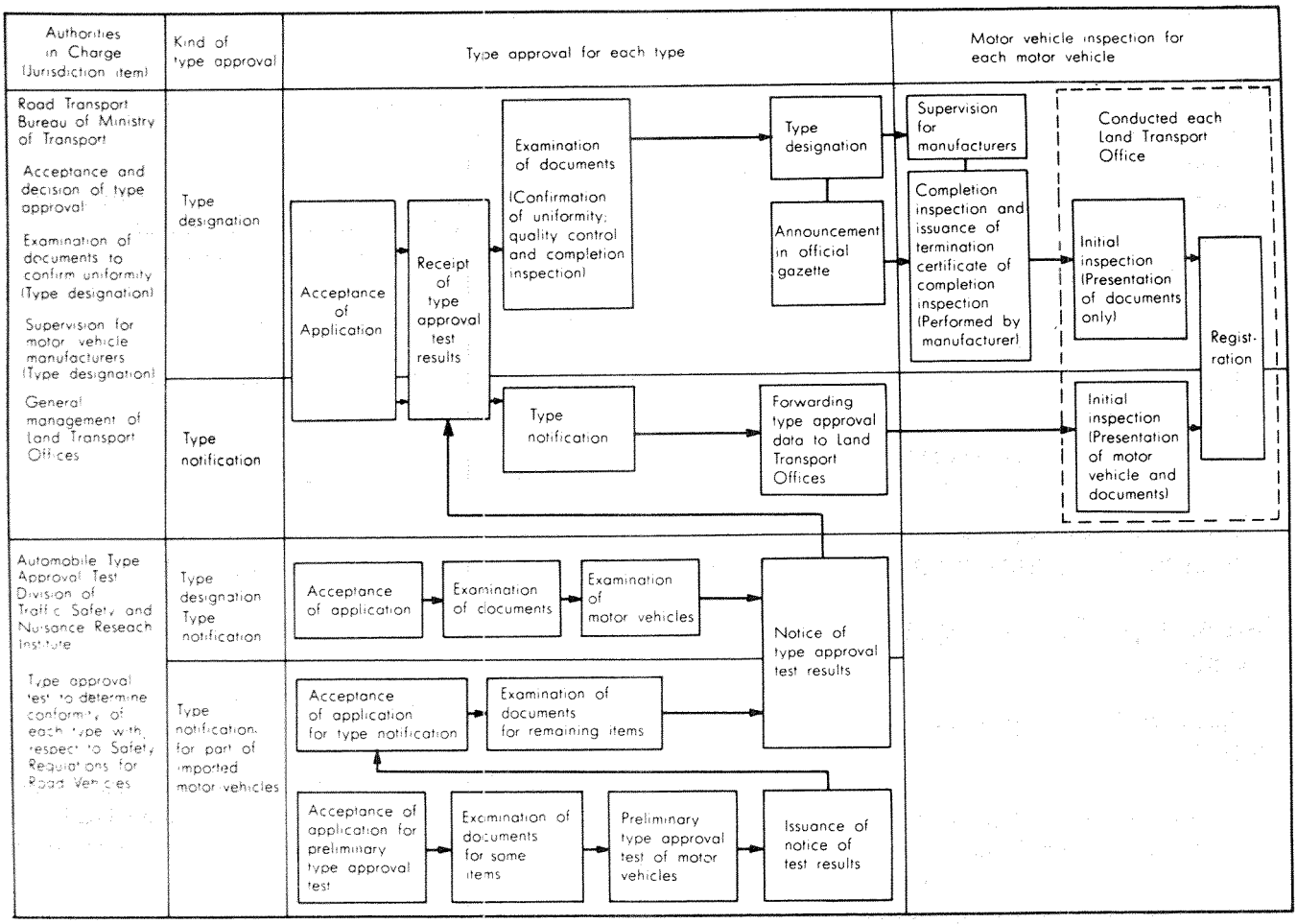


Figure 1. Flow chart of type approval and initial inspection.

inspection, so that the applicant is required to provide a system, facility and staffs to conduct the above inspection. Under the above conditions, there is an advantage that as to type-designated motor vehicles, if the termination certificate of completion inspection is presented at time of initial inspection at the land transport office, presentation of the motor vehicle concerned can be omitted. (Article 59 paragraph 4 of the Road Vehicles Act).

The application procedures under this type designation system, standards of completion inspection, form of termination certificate completion inspection, report on change, measures on defects caused by design or production process are provided by the Type Designation Regulations for Motor Vehicles (Ministry of Transport Ordinance No. 85 of 1951) and the particulars are provided by the Enforcement Procedure for Motor Vehicle Type Designation (Jisha No. 87 and Jisei No. 37 Circulars of 1970), etc. In this system, even after the designation is obtained, inspection of the manufacturer will be conducted on the uniformity of the type-designated motor vehicles, conformity to the Safety Regulations, situation of completion inspection, etc.

For your reference, Figure 1 shows the flow of process from application under the type designation system or the type notification system and the type designation or notification upon inspection to initial inspection and registration of each motor vehicle. After the application is received by the Road Transport Bureau of the Ministry of Transport, a technical examination is made by the Automobile Type Approval Test Division, Traffic Safety and Nuisance Research Institute of the Ministry. Furthermore, examination of the system for conducting quality control and completion inspection is carried out by the Road Transport Bureau. On the basis of these results, the type will be designated.

Incidentally, most of domestic passenger motor vehicles, small-sized trucks and buses have obtained designation of type. Two types of imported motor vehicles were given designation of type in August 1981 for the first time in recent years.

Type Notification System

The type notification system comes under the Handling Procedure for Motor Vehicle Type Notification (Jisha No. 375 and Jisei No. 86 Circulars of June 12, 1970). This

system obliges a manufacturer of motor vehicles or a person who has a sales contract with the manufacturer to notify the type with the Minister for Transport before he manufactures or sells new type motor vehicles, to carry out a detailed examination as to whether the motor vehicles notified conform to the collective Safety Regulations of the Road Transport Bureau of the Ministry of Transport and the Automobile Type Approval Test Division of the Traffic Safety and Nuisance Research Institute and to inform the result of inspection to the land transport offices throughout Japan together with relevant materials. Under this system, different from the type designation system, the initial inspection at the land transport office is conducted on motor vehicles submitted. However, since the result of the examination has already been sent to the land transport office together with the materials, it is possible to simplify the inspection to confirmation of uniformity of the vehicle, the content of notification and confirmation of enforcement of the modification items in order to efficiently perform the inspection. Further, the uniformity of motor vehicles is not required especially and the applicant is not required to provide any system, facility and staff for conducting the completion inspection. Moreover, no inspection of the applicant after the type is notified will be conducted. At the present time, type notification is made mainly on such motor vehicles whose production volume or number of sales per type is small such as imported motor vehicles, large-sized trucks, buses, etc.

Type Approval System Devices for Motor Vehicles

Under this system, manufacturers, etc. of motor vehicles can obtain type approval of vehicles on noise, exhaust emission control devices and other safety devices in accordance with the provisions of Articles 62-3-2, 62-4 and 63 of the Enforcement Regulations for Road Vehicles Act. The following is an explanation of the type approval on noise and type approval on exhaust emission.

As to the type approval of other devices for safety, explanation is omitted. Hereafter, explanation will be given on the type designation and type notification.

Type approval of motor vehicles on noise:

This is a system to give type approval on each type of motor vehicle in order to carry out effectively the control of noise of new type motor vehicles as provided for in the Safety Regulations for Road Vehicles.

Under the Enforcement Regulations for Road Vehicles Act, persons who are entitled to make an application for such approval are manufacturers of motor vehicles or the sales agent of such motor vehicles. In reality, as to domestic motor vehicles, the manufacturers make such an application and for imported motor vehicles the importer applies. Prior to application, the applicants must prepare data showing conformity to the noise standards set down in Article 30 of the Safety Regulations for Road Vehicles (as to motor vehicles for which type notification has been filed, the value so notified can be used). (Circular "Procedures for Type Approval of Motor Vehicles on Noise" (Jiko No. 162-2 of 1975)). Then, upon examination of documents, the type approval on noise will be given. At present, some domestic motor vehicles and almost all imported motor vehicles are using this system.

Type approval of exhaust emission control devices:

This is a system to issue type approval for each device (exhaust emission control device) to reduce the exhaust emission such as carbon monoxide, etc. (CO, HC, NOx and/or Diesel smoke) installed on motor vehicles in order to enforce the exhaust emission control of new type motor vehicles as provided for in the Safety Regulations for Road Vehicles.

The application procedures are the same as those for type approval on noise as mentioned above, but prior to application the applicants must prepare data showing conformity to the exhaust emissions standards as provided for in Article 31 of the Safety Regulations for Road Vehicles (as to motor vehicles for which type notification has been made, the value so notified can be used) and data concerning durability of exhaust emission control devices. (Handling Procedures of Type Approval for Exhaust Emission Control Devices (Jiko No. 115 of 1974)).

Obligations of persons obtaining type approval:

Persons who obtain type approval of motor vehicles on noise or type approval of exhaust emission control devices are subject to the following obligations:

A. Implementation of inspection:

Before transfer of motor vehicles to transferees, persons who obtained the type approval must carry out an inspection as to whether the motor vehicles conform to the noise and exhaust emission standards as provided for in the Safety Regulations pursuant to the provisions of the Enforcement Regulations for Road Vehicles Act. In implementing such an inspection, it is permitted that measuring of noise or exhaust emission for each motor vehicle be replaced by sampling test or quality control through test of pollution-control parts in the course of the process. If it is found that the motor vehicles conform to such standards, as to noise indication will be made by attaching plates to the motor vehicles and as to exhaust emission an approval certificate must be issued to the transferees. Incidentally, if false indication or certification is made, the type approval will be cancelled.

B. Securing uniformity:

Under the Enforcement Regulations for Road Vehicles Act, persons who acquire the type approval must endeavor to secure the uniformity of devices etc. by establishing quality control procedures in order to guarantee the quality of the noise prevention structures or exhaust emission control devices of motor vehicles and organize a system to perform such procedures. If it is found out that uniformity is not secured, the type approval will be cancelled.

C. Others:

Persons who have acquired type approval must establish an inspection and maintenance procedure and endeavor to publicize them to the users.

Type of Motor Vehicles

The motor vehicles are designated or notified by each type. The type in this case means that the fundamental constructions and devices of vehicles are almost the same, and the scope whereby motor vehicles are recognized as the same type is stipulated by the Judgment Criteria for Identity of Type of Motor Vehicles (Jisha Circular No. 151 of 1971). According to the Circular, if the following matters are different, they will be treated as variant:

(1) Category of motor vehicles (ordinary motor vehicles, small-sized motor vehicles, light motor vehicles, large-sized special motor vehicles, small-sized special motor vehicles) classified by constructions of vehicle, length, width, height and engine displacement pursuant to the provisions of Articles 1 and 2 of the Enforcement Regulations for Road Vehicles Act.

Vehicle classification by construction.

	Structure of motor vehicles			
	Length	Width	Height	Engine displacement
Ordinary motor vehicles	Motor vehicles not included in other categories			
Small-sized motor vehicles	4.7m or less	1.7m or less	2.0m or less	2.0ℓ or less (excluding Diesel engine)
Light motor vechicles	3.2m or less	1.4m or less	2.0m or less	0.55ℓ or less (0.25ℓ or less for two-wheeler)
Large-sized special motor vehicles	motor vehicles of special structure (vehicles with caterpillar track, etc.)			
Small-sized special motor vehicles	4.7m or less	1.7m or less	2.0m or less	1.5ℓ or less

Note: Maximum speed of small-sized special motor vehicles is less than 15 km/h.

(2) Use (Passenger motor vehicles, buses, trucks and special purpose motor vehicles).
(3) Shape of body (in case of passenger motor vehicles: sedan, station-wagon, convertible, etc.)
(4) Category and main construction of engine (gasoline engine, diesel engine, engine displacement, etc.), power transmission system (rear-wheel drive, front-wheel drive, four-wheel drive, etc.), running system (two-axle, three-axle, etc.), wheel suspension system (independent suspension, rigid axle suspension, etc.) and control system.
(5) Frame (frame type, frameless type, etc.)
(6) Wheel base
(7) Kinds of main brake system (oil pressure, air, mechanical, etc.)
(8) Difference in exhaust emission standard value cleared (1975 standard, 1976 standard, 1978 standard, etc.)
(9) Margin of length, width, height and vehicle weight exceeding the prescribed tolerance in the production.

Documents and Motor Vehicles To Be Submitted at Time of Application

Documents to be submitted:

In case of type designation, an applicant is required to submit the following materials together with the application:

a. Specifications.
b. External views and external photographs of motor vehicles.
c. Documents proving compliance with the Safety Regulations for Road Vehicles.
d. Brief description of constructions and devices.
e. Documents setting forth operational system and implementation procedures for completion inspection and maintenance procedures of machinery and equipment for inspection.
f. Documents setting forth operational system for the inspection of devices under the Safety Regulations and implementation procedures.
g. Documents setting forth procedures for issuing termination certificate of completion inspection.
h. Documents setting forth motor vehicle inspection and maintenance procedures conducted by user.
i. Documents setting forth production plan and monthly number of motor vehicles sold by the applicant during the past one year.
j. In case a person who enters into a sales contract with a manufacturer of motor vehicles applies, a copy of the sales contract.

In case of type notification, documents specified in preceding Items (e), (f), (g) and (i) may be omitted. As to Item (c), documents having more detailed contents will be required in case of type designation.

Motor vehicles to be submitted:

In case of type designation, new motor vehicles and motor vehicles that have been subjected to long distance running as required must be submitted for presentation in accordance with the provisions of the Announcement of Requirements on Durability Vehicles for Type Designation. (Ministry of Transport Announcement No. 356 of 1969). In case of type notification, only new motor vehicles will be submitted. The number of motor vehicles to be submitted will differ according to the variety of construction and devices, that is, one to several vehicles in the ordinary case of type notification or some tens of vehicles in case of series of type designation on large scale.

Judgment Criteria of Technical Examination and Method of Testing

In case application is made for type designation or type notification, a technical examination will be conducted on documents submitted, such as the applicant's test data, etc. and on motor vehicles submitted for presentation and it will be determined whether they conform to all provisions of the Safety Regulations and circulars under the Regulations. As a result, it will be judged whether the motor vehicles subject to the application conform to the Safety Regulations or not. The main circulars used for judgment in the examination are as follows:

- Technical standards:
  These circulars stipulate deliberately the application scope on the content, test method, requirement, etc. in case the provisions of the Safety Regulations do not specify concrete requirements. As of March 1981, there were 23 standards in total.
- Type Approval Testing Standards (Jisha No. 626 and Koshin No. 531 Circular of 1972):
  This circular stipulates more concretely necessary parts to be tested in order to determine whether motor vehicles of a new type conform to the Safety Regulations.
- Motor Vehicle Inspection Procedures (Jisha Circular No. 880 of 1961):
  This circular sets forth the standards for determining reasonably and efficiently whether motor vehicles including new type vehicles conform to the Safety Regulations at the time when the inspection is conducted.

In the meantime, as to the technical standards, in conducting tests relating to the type notification of imported motor vehicles, the following procedure is established. That is to say, if they are proved to conform to the foreign standards which are deemed to be equal to or more stringent than Japanese technical standards by prescribed documents, they are recognized as conforming to the Japanese technical standards. Eleven technical standards are presently recognized as being equal to FMVSS, 10 are recognized as being equal to ECE Regulations and 2 are recognized as being equal to EEC Directives, and 13 technical standards are recognized to be equal to FMVSS, ECE or EEC.

As the circulars providing in detail the test procedures for the official examination of motor vehicles and the test procedures for preparing intra-company data, there are the Type Approval Test Procedures (Koshin Circular No. 453 of 1971) (called "TRIAS").

These circulars are established and amended in consideration of the amendment to the Safety Regulations, appearance of new motor vehicle technology, improvement of measuring techniques, etc. In such cases, opinions are sought from the parties concerned such as motor vehicle manufacturers and importers as the need arises, and as to imported motor vehicles, opinions of foreign motor vehicle manufacturers are sought through the Japan Automobile Importers' Association, etc.

Test Items for Inspection of Submitted Motor Vehicles

Testing of motor vehicles for type approval is conducted on the following items by using motor vehicles submitted to the Automobile Type Approval Test Division.

Test of motor vehicles for type notification (in case of passenger motor vehicles):

- Measurement of specification weight
- Confirmation of construction, devices and function
- Front wheel alignment test
- Braking test
- Noise test (steady running noise level test, accelerated running noise level test, exhaust emission noise)
- Exhaust emission test 10-mode (Note 1) and 11-mode test (Note 1) of gasoline-fueled motor vehicles and fuel evaporation gas test (Note 1) and 6-mode test of Diesel-powered motor vehicles and Diesel engine smoke test
- Heat-damage test (Note 1)
- Lighting device (headlamp, number plate lamp, backup light, auxiliary headlamp) test and rear-view mirror visibility test
- Test of speed warning devices
- Test of brake fluid leakage warning devices
- Horn sound level test

Test of motor vehicles for type designation (in case of passenger motor vehicles):

In addition to the test items of motor vehicles for type notification as set forth in Item (1), tests will be conducted on the following items:

- Specification measurement
- Engine load test

- 10-mode fuel economy test of gasoline-fueled motor vehicles (Note 2)
- Service brake/parking brake systems efficiency test
- Various impact and strength tests such as steering impact test
- Windshield washing system test

Moreover, as to construction and device performance confirmation and exhaust emission test (in case of gasoline-fueled motor vehicles), for the type designation, tests are also conducted on motor vehicles which have run a long distance.

(Note 1) In case of type notification of imported motor vehicles whose annual number imported is 1200 or less, no test is carried out, but it is necessary to attach the test data by the Japan Automobile Transportation Technique Association as the official test institution in Japan to the application.

(Note 2) The test is carried out under the Rationalization of Energy Consumption Act.

Special Treatment of Test of Imported Motor Vehicles

As to the type notification of imported passenger motor vehicles, at the request of foreign countries which are exporting motor vehicles to Japan and from the viewpoint of geographical disadvantages and mutual benefits, favorable measures for carrying out actual tests are provided. One such measure is the use of test results of foreign official test organs and the other is the implementation of a preliminary test. Through the use of these systems, the number of days required to test imported passenger motor vehicles is shortened as much as possible and on average, the number of days is considerably less than that for domestic motor vehicles.

Use of test results of foreign official test organs:

This system is, in the case where a foreign government or official automobile test organ which is recognized by the Japanese Government carries out tests on the following six items under the Japanese test method and the test results are attached to the application together with the certificate, to use such results and has been operated since 1977:

a. Braking test
b. Noise test
c. 10-mode exhaust emission test for gasoline-fueled motor vehicles
d. 11-mode exhaust emission test for gasoline-fueled motor vehicles
e. Fuel evaporative emission test for gasoline-fueled motor vehicles
f. Heat damage test for motor vehicles with exhaust emission control devices

The foreign official test organs recognized by the Japanese Government are the following six organs of four countries

(1) France:
Union Technique de l'Automobile du Motocycle et du Cycle
(Test to be entrusted: All of the above six items.)

(2) Federal Republic of Germany:
Rheinsch-Westfälischer Technischer Überwachungs-Verein e.V.
(Test to be entrusted: Items a, c, d, e and f)
Technischer Überwachungs-Verein Bayern e.V.
(Test to be entrusted: Item b)

(3) United Kingdom:
Vehicle Engineering and Type Approval Centre, Department of Transport
(Tests to be entrusted: All of the above six items.)

(4) Italy:
Centro Superiore Ricerche e Prove Autoveicoli e Dispositive, di Roma Ministero dei Trasporti
(Tests to be entrusted: Items a and b)
Centro Prove Autoveicoli di Torino Ministero dei Trasporti
(Tests to be entrusted: Items c, d, e and f)

Implementation of preliminary test:

This system is, at the request of the applicant, to carry out the test of motor vehicles on all items normally implemented at the Automobile Type Approval Test Division by dispatching motor vehicle inspectors to overseas motor vehicle manufacturers prior to the application for type notification. Correctly observed, this system renders it unnecessary to bring the motor vehicle concerned for test in Japan. Furthermore, since there is a tendency for applications of notification of imported motor vehicles to be concentrated in the autumn, if the ordinary procedures are taken the tests in this season may tend to be delayed.

This system, on the other hand, makes it possible to handle a great number of types at one time efficiently. This system has been in effect since 1977, when the necessary budgetary allocation for dispatch overseas of inspectors was made. The overseas motor vehicle manufacturers for whom the preliminary type approval test had been carried out up until 1980 were as follows:

United States of America:
General Motors Co., Ford Motor Co., Chrysler Co.

Federal Republic of Germany:
Volkswagenwerk AG, Audi NSU, Auto Union AG, Ford Motor Co.

England:
Rolls-Royce Motors Ltd., British Leyland Ltd.

Sweden:
Volvo Car Co.

Table 1. Ratio of type-notified imported motor vehicles using preliminary test.

(Unit: %)

	Year	1977	1978	1979	1980
Ratio of number of tested types	U.S.	35	48	56	59
	Europe	20	16	14	34
	Total	29	34	29	47
Ratio of number of tested vehicles	U.S.	33	52	66	65
	Europe	40	23	25	48
	Total	36	38	40	57

The preliminary test occupies an important position in the test of imported motor vehicles. As shown in Table 1, from 1977 to 1979, on average, approx. 30% of tested types and approx. 40% of tested number of motor vehicles and in 1980 approx. 50% of the tested types and approx. 60% of the tested number of motor vehicles were dealt with by the preliminary test.

Incidentally, the preliminary test is rendered even more efficient when combined with the system of using the test results of foreign official test organs, described in Paragraph (1).

Test Facilities

The main facilities owned by the Automobile Type Approval Test Division for implementation of the type approval test of motor vehicles are as follows:

Kumagaya Proving Ground:

The construction of a proving ground for motor vehicle type approval test was commenced at Kumagaya City, Saitama Prefecture in 1976 for the purpose of strengthening the test system in conjunction with the regulations for safety and antipollution of motor vehicles which were made more strict and partly because no further expansion of the headquarters facilities in Mitaka District was possible. The proving ground covers an area of approx. 240,000 square meters part of which has been in use since 1978, and at present facilities are still being constructed one after another. The total amount expended for the test facilities up to 1981 was approx. 10 billion yen. The facilities presently being used are as follows:

a. Test course:
(Specifications) Total length: 1,350 meters; width of direct line course: 50 meters (maximum); 25 meters (minimum), asphalt-paved road, durable load: 40 tons (100 km/h); brake test course (21m × 100m; paved with reinforced-concrete)
(Main test items)
Brake test, noise test, road load measurement for exhaust emission test, speed warning device test, steering stability test, etc.

b. Motor vehicle confirmation laboratory:
(Main facilities) Surface plate (14m × 4m made of cast-iron, 13m × 7m made of concrete); side-slip tester, brake tester, speedometer tester, headlight tester, pit
(Main test items) Test for confirmation of construction, devices and functions, specification measurement, etc.

c. Measurement test laboratory:
(Main facilities) Weight-meter, brake tester, crane
(Main test items) Weight measurement, braking efficiency test, etc.

d. Exhaust emission test laboratory and fuel economy and large-sized motor vehicle exhaust emission test laboratory:
(Main facilities) 6 chassis-dynamometers (DC type or EC type; Absorption power: 110 ~ 220kw, diameter of roller: 1,590mm, maximum equivalent inertia weight: 3,500kg (25kg interval) ~ 7,000kg (125kg interval), 6 vehicle speed proportional blowers (maximum airflow: 1,680 ~ 3,900 m^3/min; maximum air speed: 80 ~ 100 km/h); 7 exhaust emission analyzers (5 sets for gasoline-fueled motor vehicles and 2 sets for Diesel-powered motor vehicles); 5 CVS devices (2 PDP type units and 3 CFV type units)
(Main test items) 10-mode and 11-mode exhaust emission test for gasoline-fueled motor vehicles, fuel evaporative emission test, 10-mode fuel economy test for gasoline-fueled motor vehicles, 6-mode exhaust emission test for Diesel-powered motor vehicles, Diesel smoke test, 6-mode exhaust emission test of gasoline-fueled motor vehicles.

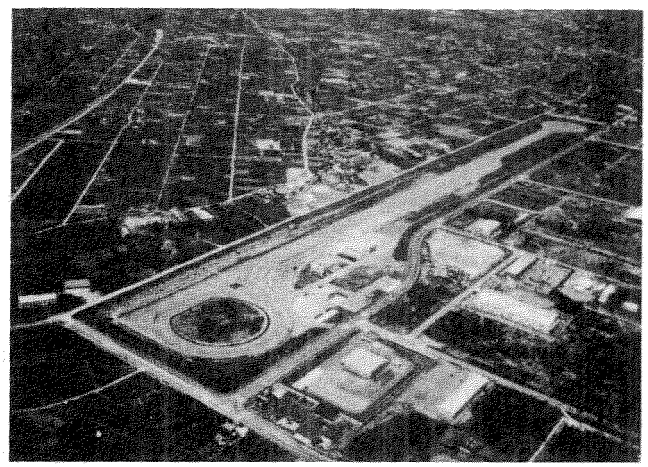


Figure 2. General view of Kumagaya District Motor Vehicle Proving Ground and neighboring area.

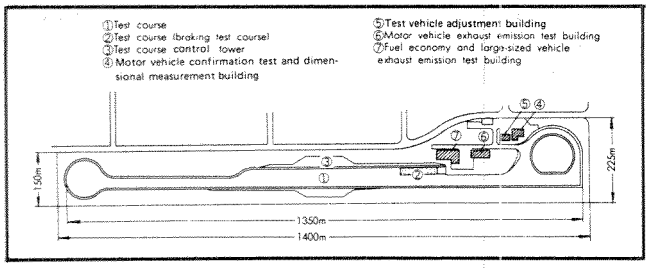


Figure 3. General drawing of Kumagaya District Motor Vehicle Proving Ground.

Mitaka District Headquarters Facilities:

The facilities of Mitaka District Headquarters have been used since 1970 and include, in addition to an administrative building, exhaust emission test facilities (4 chassis-dynamometers), constructions and devices confirmation facilities, and other facilities for specification weight and size measurement equipment, etc. The Mitaka District Headquarters also has the heat damage test facilities (one unit chassis-dynamometer and vehicle speed comparative blower), lighting equipment (head-lamp, etc.) test facilities and maximum inclination angle stability test facilities.

Test and Inspection on Uniformity, etc. of Motor Vehicles for Type Designation

Requirements for type designation are, as stated in Section 2, uniformity of motor vehicles, implementation of completion inspection and delivery of termination certificate of completion inspection in addition to their conformity to the Safety Regulations. Explanation will be made on the examination at time of application of these requirements and inspection of the manufacturer's facilities after the designation as below.

Examination of time of application:

At time of application, the examination including hearing from the applicant will be carried out based on the documents submitted to confirm that there is no problem on the following matters:

(i) Outline of motor vehicles:

Purpose of development of applied motor vehicles, technical features, newly adopted mechanism, new manufacturing process, variation, optional parts, etc.

(ii) Specification table:

If there arises any change in the specification table of motor vehicles which have obtained type designation, no motor vehicles after such change will be sold as type designated motor vehicles without obtaining disposition of approval of such change separately. The same shall apply to the exterior drawings of the motor vehicles. If they are changed, it will be considered as constituting a change in the uniformity.

(iii) Overall quality guarantee system:

Assignment of works and relationship of the respective divisions from product planning to development, approval of trial production of merchandise, trial production, experiment, evaluation, secondary trial production, evaluation, determination of commercial production, arrangement of parts, preparation of test procedures, application, commencement of production, feedback complaints in market, etc.

(iv) Warranty of parts manufactured by sub-contractors:

Assessment method of quality warranty system of sub-contractors, check of delivered quality (relationship of shipping test among sub-contractors and acceptance test by motor vehicle manufacturers), communication system and disposition method of defects, whether a system is well arranged so that changes in process and materials of sub-contractors are made correctly and accurately, and so on.

(v) Quality warranty and completed inspection of intra-manufactured parts and sub-assembly:

Test items and test procedures as sub-assembly in the course of processing and assembly. Items and procedures of completion inspection, layout of test places, disposition of personnel, training of assembly workers and inspection workers, administration of initial products and outbreak of sub-standard products, terms and conditions for suspension of shipment, maintenance and management procedures of test equipment, etc.

(vi) Others:

Sampling inspection of completed motor vehicles carried out for quality control (measurement of specifications, 10- and 11-mode exhaust emission test, etc., not included in items of completion test.)

On-the-spot inspection of manufacture after designation:

Ministry of Transport officials make on-the-spot inspection regularly of the designated motor vehicle manufacturers pursuant to the provisions of Article 100 of the Road Vehicles Act. The object of the inspection is to make on-the-spot inspection on the quality control of the type designated motor vehicles and on the points recognized as improper as a result of the inspection, guidance such as recommendation for improvement, etc. will be given. If the motor vehicles lose their uniformity or do not conform to the Safety Regulations, disposition to cancel the designation will be made. On-the-spot inspections will be made of more than 50 factories every year to inspect the following matters:

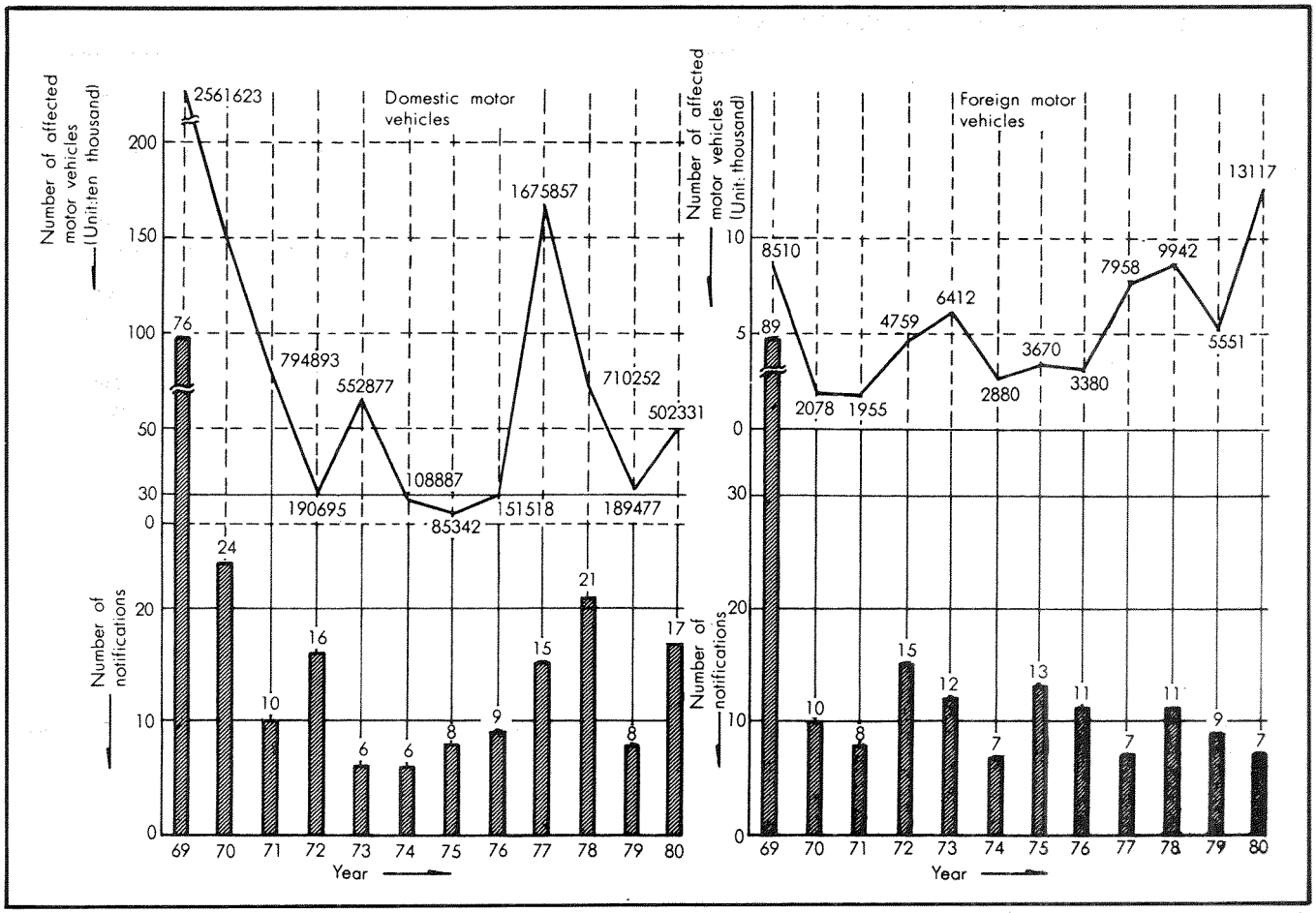


Figure 4. Number of notifications on defective motor vehicles and number of affected motor vehicles.

(i) Inspection of documents:

Situation of implementation of matters in Paragraph (1), (i) to (vi), completion of detailed application rules, records of various tests, records of sub-standard products, and record of training.

(ii) Plant inspection:

Inspection will be made on the following items:

- Production plan and procedures for issuing production directives, procedures for parts control (storing place and giving advice to carry parts near production line) and procedures for changing production methods when the order of production process is changed.
- Process control (process standard, work standard and arrangement of sub-standard products disposition system)
- Precision control (change of cutting tools, rationalization of workers' placement, method of recovering from work delay (placement of new workers, mistake in assembly work, parts shortage, etc.) placement of standard samples, model samples, etc.
- Inspection process (implementation of procedures from acceptance test to completion test of parts, and to sampling test of completed motor vehicles, filing and collection of test records, maintenance and management of machinery and equipment for inspection, such as regular tests)
- Stamping of chassis numbers and engine types and issue of termination certificate of completion inspection (prevention of erroneous stamping and occurrence of missing numbers, disposition of such incidents, etc.)
- Sampling of completed motor vehicles:
  Sampling will be made from among motor vehicles which have passed completion inspection for static test to confirm the quality.

Recall System

In the type designation, Article 13 of the Type Designation Regulations for Motor Vehicles under Article 75 paragraph 4 of the Road Vehicles Act provides that if a manufacturer of type-designated motor vehicles finds that the construction, devices or performance of certain type-

Table 2. Record of recalls relating to safety (100,000 or more affected motor vehicles).

Date of notification	Category and use	Number of affected motor vehicles	Condition of defect and its cause
1977	Small-sized Passenger car	142,119	Danger of carburetor screw coming off and throttle not returning
1977	Small-sized Passenger car	146,932	Weak carburetor cap which may cause leakage of fuel from the defective part.
1977	Ordinary and Small-sized Passenger car	300,147	A part of fuel hose is easily damaged by fuel, which may cause fuel leakage from the hose.
1977	Motorcycle	178,087	Danger of opening lever of fuel tank cap being accidentally touched by human body, which may cause opening of the cap.
1980	Light Truck	178,354	1. Steering devices: Nut of connecting metal of steering wheel axis can come loose, leading to possible loss of control. 2. Electrical devices: Contact with engine body will damage the wiring cover of electrical wiring, which may cause fire.

Table 3. Records of recalls relating to pollution (total number).

Year	Category and use	Number of affected motor vehicles	Condition of defect and its cause
1974	Ordinary Passenger car	30	Defective temperature control valve of EGR devices may cause an increase in NOx emission.
1976	Ordinary Passenger car	25	Circulation of some pipes of devices for controlling fuel evaporating gas are defective which may cause insufficient performance of the devices.
1976	Ordinary Passenger car	403	Defective connection of vacuum hose of EGR devices may cause damage to hose.
1977	Small-sized and Ordinary Passenger car	388,758	Insufficient strength of BPT (back pressure transducer) valve of EGR devices will cause defective operation of valve and may increase NOx emission.
1977	Small-sized Passenger car	899,248	Insufficient heat resistance of temperature-sensor switch used in ignition-time control devices may damage the switch.
1978	Small-sized and Ordinary Passenger car	426,593	Insufficient strength of BPT valve of EGR devices may cause defective operation of valve and an increase of NOx emission.

Table 4. Record of recalls relating to tires (total number).

Year	Quantity	Condition of defect and its cause
1970	584	Larger-size tubes were inserted into tires by mistake, which may cause puncture.
1976	627	Defective materials, which may lead to puncture.
1976	459	Ditto
1978	20	Ditto
1978	16,000	Based on reports from overseas tire manufacturers.

designated motor vehicles are not in compliance with the requirements of the Safety Regulations for Road Vehicles or there is a possibility that they do not conform to such requirements, and when he recognizes the cause is derived from the design or production process, he shall report the following items to the Minister for Transport:

(1) Situation of the defect and its cause.
(2) Measures for improvement.
(3) Measures to inform the defect to the users and motor vehicle repair business operators.

As to the measures for improvement, the State (Minister for Transport) may direct the alteration and request that the situation concerning implementation of improvement measures be reported to the State. After the report, the person who obtained the designation shall recall the motor vehicle concerned by issuing public notice and conduct the repair to the motor vehicle concerned free of charge. These measures are usually taken by sending direct mail circulars to the users and by inserting a notice in periodicals of the association of motor vehicle disassembling repair business operators (Federation of Japan Associations of Automobile Repair and Maintenance). The State will also make notification through the mass media. Even on type-notified motor vehicles, the same procedures must be taken under the Handling Procedures for Motor Vehicle Type Notification. This recall system was established as a part of the type approval system in 1969.

The number of recall cases in Japan are shown in Figure 4.

These statistics include recalls of motor vehicles each of which obtained type approval and motor vehicles not subject to the motor vehicle inspection such as motor-driven cycles, etc. The number of subject motor vehicles includes those intended for export from Japan. Guidance is also given to exported motor vehicles to ensure recall whether there exists such a recall system or not in the country concerned. Even recall of parts and devices such as tires, etc. is made through the motor vehicle manufacturers. According to the figures by devices, the largest number of recalls out of the total number of recalls until March 1980 concerned brake devices accounting for approx. 25%. They were followed by engines with approx. 19%, steering devices with approx. 16% in that order, these three devices accounting for approx. 60% of all recalls.

Examples of recalls made recently are shown in Table 2, Table 3 and Table 4 classified by safety, pollution and tire recall groups.

The completion of recalls carried out under the foregoing system has been approx. 94% on average since 1969. This figure includes recalls of motor vehicles whose inspection and registration is not mandatory (motor driven cycles, etc.). Accordingly, the figures excluding the above vehicles indicate that the recall completion rate is nearly 100% in Japan.

Legal System of Japan on Motor Vehicles*

HIDEMI TOZAWA
Inspection and Safety Division, Road Transport Bureau, Ministry of Transport, Tokyo
HIDEYUKI KADONO
Registry Division

Part 5: Motor Vehicle Inspection and Registration System

MOTOR VEHICLE INSPECTION SYSTEM

In Japan, there were approximately 40 million motor vehicles as of the end of September, 1981 and motor vehicles are now indispensable for economic activities and improving the people's living standards. On the other hand, there have arisen such serious social problems as traffic accidents, and environmental pollution caused by exhaust gas, noise, etc. Therefore, there is now a strong need to ensure safety and prevent environmental pollution and various countermeasures are being taken. The inspection of motor vehicles also plays an important role as one of measures to solve these problems.

That is, all motor vehicles are obliged to undergo an inspection conducted by the Government under the Road Vehicles Act. This inspection is to check whether motor vehicles conform to the Safety Regulations for Road Vehicles (Ministry of Transport Ordinance No. 67 of 1951). The Safety Regulations for Road Vehicles are established

* Received 13th October, 1981.

on the structures and devices of motor vehicles for the purpose of securing the safety of motor vehicles and preventing pollution. Unless it is confirmed through this inspection that motor vehicles conform to the Safety Regulations for Road Vehicles, no motor vehicle is permitted to be operated on Japan's roads.

History of Inspection System

It was in 1919 that the inspection of motor vehicles was commenced in Japan. Before that year, the inspection of motor vehicles was conducted locally, but henceforth it was carried out on a nationwide basis. At the time, the number of motor vehicles was very small being approx. 7,000 and contents of inspection were simple compared with those nowadays. When the Road Vehicles Act was promulgated in 1951, the present legal system concerning the inspection was established. Thereafter, several amendments relating to the inspection of motor vehicles were made, including the following major items:

(1) **1952 Amendment**

Up until this time, the effective term of the inspection of motor vehicles was a uniform one year, but it was altered to 9 months for buses and taxis, one year for trucks and two years for other motor vehicles, respectively.

(2) **1963 Amendment**

a. A system of designated motor vehicle maintenance business was established, under which the Government designates maintenance business entrepreneurs who have good equipment, technology and management organization and the inspection equipment of the same level as the Government. Such establishments are entrusted with part of the administrative work of inspection otherwise conducted by the Government. (For details of the system of designated motor vehicle maintenance business, please refer to the maintenance of motor vehicles to be published in the later installment.)
b. The effective inspection term for buses and taxis was extended to one year and that for motor vehicles whose passenger capacity is 11 persons or more, school buses, rental cars and motor vehicles for private use which have been used for more than 10 years was shortened to one year.

(3) **1973 Amendment**

It was determined to conduct an inspection on light motor vehicles including four-wheelers with displacement of 0.55 ℓ or below as well as other motor vehicles and the effective term was fixed as two years. Then, the organization to conduct the inspection is the Light Motor Vehicle Inspection Association as a Government-recognized corporation and contents of inspection are almost the same as that conducted by the Government.

(4) Recommendation of Council for Transport Technics

In January 1982, the Council for Transport Technics made a recommendation to the Minister for Transport regarding the inspection of passenger motor vehicles. The Council recommended that the effective term of inspection certificate for new passenger motor vehicles be extended from two years to three years. In accordance with this recommendation, the Ministry of Transport expects to amend the Road Vehicles Act Soon.

Kinds of Inspection

The inspection of motor vehicles is divided into three major phases. They are the initial inspection which must be conducted when a motor vehicle is operated for the first time, continuation inspection which the vehicle must undergo every one or two years and modification inspection of which must be conducted whenever a major alteration or improvement is made. The record of the number of various inspections conducted is shown in Table 1 below:

(1) Initial inspection (Article 59 of the Road Vehicles Act):

This inspection is to be performed when a motor vehicle is operated for the first time or when a motor vehicle whose registration was cancelled because it was not intended to be used for a long period is to be used again, etc. The inspection is performed by submitting the motor vehicle to the Land Transport Offices in the prefectures, but new motor vehicles of which the manufacturer of the motor vehicles has obtained the type designation issued by the Minister for Transport are exempted from submitting the motor vehicles to the office, by presentation of the certificate of completion inspection. In case a motor vehicle has passed the inspection and completed registration, a motor vehicle inspection certificate and licence plate are issued. No motor vehicle may be operated without a motor vehicle inspection certificate.

(2) Continuation inspection (Article 62 of the Road Vehicles Act):

This inspection is conducted on motor vehicles which are registered upon initial inspection, and is performed at regular intervals thereafter. The inspection is made by submitting the motor vehicle to the Land Transport Office, but as for a motor vehicle which is handled by a designated maintenance business entrepreneur, it is exempt from the inspection if a certificate showing that the motor vehicle conforms to the Safety Regulations is submitted.

(3) Modification inspection (Article 67 of the Road Vehicles Act):

This inspection is to check whether a motor vehicle conforms to the Safety Regulations in case it is altered

Table 1. Number of inspected motor vehicles.

(Unit: 1,000 vehicles)

Items \ Fiscal year		1965	1970	1975	1980
Number of motor vehicles submitted for inspection		5,065	12,951	23,276	31,695
Continuation inspection	Conducted by Government	2,198	4,159	5,147	6,121
	Conducted by designated maintenance business	306	1,641	5,666	8,880
	Sub-total	2,504	5,800	10,813	15,001
Initial inspection	Conducted by Government	772	1,161	1,191	1,448
	Type designation	1,000	2,610	3,321	3,588
	Sub-total	1,772	3,771	4,512	5,036
Modification inspection		44	57	46	40
Number of vehicles which did not pass the inspection conducted by Government		555	747	960	1,046
Total number of inspected motor vehicles		4,875	10,375	16,331	21,123

or improved substantially. Alterations which require this inspection are as follows:

- Alteration of length, width or height
- Alteration of shape of body (for instance: Alteration of truck to tank car)
- Change of engine to another type engine
- Alteration of kind of fuel
- Alteration of passenger capacity or maximum loading capacity

Effective Term of Inspection

When a motor vehicle has been determined as conforming to the Safety Regulations upon inspection, a motor vehicle inspection certificate setting forth the date of the next inspection is issued for the motor vehicle. The period until the date of next inspection, that is, the effective term of inspection varies according to the categories of motor vehicles, being either two years or one year. Details are set forth in Table 2. During the term, no inspection is required, but for the purpose of securing safety, motor vehicles are subject to the periodical checking maintenance by the motor vehicle users. This must be undergone every six months for motor vehicles for private use and every month for motor vehicles for business use. However, it must be undergone every month for passenger motor vehicles for private use whose passenger capacity is 11 persons or more, large trucks for private use and rental cars.

Inspection Facilities

There were 83 inspection centers throughout Japan as of April 1981. This means one inspection facility for approx. 300,000 motor vehicles which are subject to inspection. The inspection center is divided into two: inspection line which conducts the inspection of motor

Table 2. Effective terms of inspection.

Categories of motor vehicles	Effective term of inspection
Trucks Buses Taxis Rental cars Motor vehicles for private use whose passenger capacity is 11 persons or more School buses Passenger motor vehicles for private use which have been used for more than 10 years	1 year
Passenger motor vehicles for private use which have been used for not more than 10 years Motorcycles	2 years

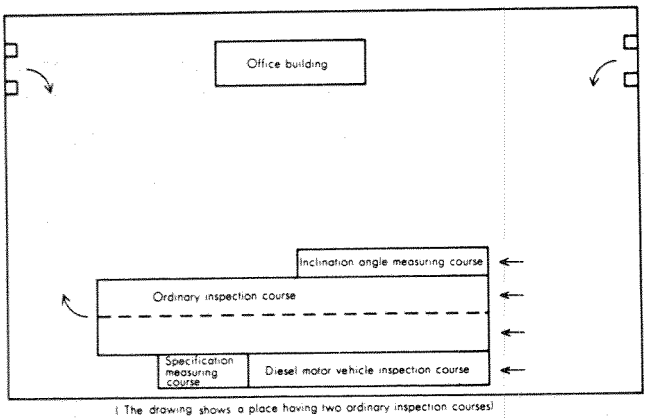


Figure 1. Motor vehicle inspection center.

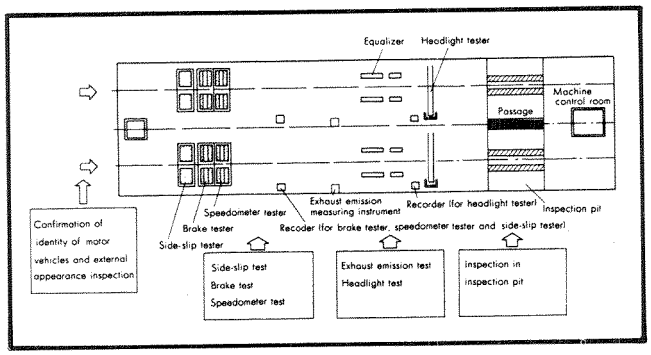


Figure 2. Ordinary inspection course.

vehicles and the office where the registration and other businesses are handled, as shown in Figure 1. The inspection line consists of an ordinary inspection course, Diesel motor vehicle inspection course, specification measuring course and inclination angle measuring course. The ordinary inspection course is used to inspect gasoline-fueled and LPG-fueled motor vehicles, Diesel motor vehicle inspection course conducts inspection of Diesel motor vehicles including smoke emission test, the specification inspection course for measuring length, weight, etc., and the inclination angle measuring course for measuring the stability against rollover. The ordinary inspection lines are provided with 1 to 8 courses in the inspection office according to the number of motor vehicles which are subject to inspection in the jurisdiction area. As of April, 1981, there were 266 ordinary inspection courses in the inspection centers throughout Japan, inspecting approx. 120 vehicles per course a day, and the number of government inspectors was 1,058.

Contents of Inspection

The inspection items and method are stipulated in detail by laws, orders and circular notices, so in this section only the outline will be described. In Japan, motor vehicles are obliged to undergo periodical checking maintenance, and motor vehicles which are to be inspected are brought to the inspection center after this periodical checking maintenance. The inspection is conducted by using machinery, equipment and test hammer and through observation of external appearance. The inspection machinery are automated and results of and procedures for the inspection are shown to the applicants. The applicants' vehicles undergo inspection according to directions shown by such indication devices. The ordinary inspection course is as shown in Figure 2.

Motor vehicles to be inspected, after completion of one inspection, proceed to another inspection in succession. The decision whether a motor vehicle passes the inspection or not is made according to the Safety Regulations for Road Vehicles and a motor vehicle which does not conform to the Regulations will be ordered to undergo repair and maintenance and must be inspected again. The causes of re-inspection by devices as of April, 1981 are shown in Table 3. The time required for inspection, though it varies with motor vehicles, is approx. 15 minutes in case of passenger motor vehicles.

The outline of inspection is as follows:

(1) Confirmation of identity of motor vehicle:
The chassis number, type of engine, etc. as set forth in the motor vehicle inspection certificate is confirmed.

(2) Examples of contents of inspection of external appearance:
- Lighting and attaching condition and break of lighting equipment
- Attaching condition and break of reflectors
- Break of rear-view mirrors
- Operating condition of wipers
- Attaching condition of seat-belts and head-restraints
- Wear of tires
- Play of brake pedal
- Play of steering wheel

(3) Contents of inspection by means of machinery
i) Side-slip test: The motor vehicle is made to travel

Table 3. Causes of re-inspection by devices as of April 1981.

	Engine	Power transmission	Steering	Brakes	Chassis	Head lights	Waste emissions	Markers and other lights	Others
Share (%)	5.8	7.5	6.3	9.7	7.8	34.6	8.1	7.5	12.7

in a straight line on the testing platform to measure the extent of side-slip. The standards are 5 millimeters or less when running one meter.

ii) Brake test: Wheels are placed on two spline-shaped rollers and the braking force is measured by rotating the rollers. The circumferential speed of rollers is 3 to 6 cm per second. The standards for determination are as follows:
- Total braking force of right and left wheels: 60% or more of axle load
- Difference between braking force of right wheels and that of left wheels: 8% or less of the axle load

iii) Speedometer test: The wheels of the motor vehicle are revolved at a fixed speed so that the motor vehicle's speedometer indicates 40 km/h and the error is measured with a tester. The standards are $+4.4 \sim -5.2$ km/h. For front-wheel-drive motor vehicles, a guide roller to prevent bodily swing of the vehicles is provided so that safe and correct inspection may be conducted. Moreover, in the Diesel motor vehicle inspection course, free-rollers are provided in parallel with the tester in order to allow inspection of two-axle rear wheels of large trucks.

iv) Exhaust emission test: NDIR-type tester is used to measure the density of emitted carbon monoxide and hydrocarbon at time of idling of engine. The standards are as follows:
CO is 4.5% or less and HC is 1,200 ppm or less for 4-stroke-engine vehicles, 7,800 ppm or less for 2-stroke-engine vehicles and 3,300 ppm or less for rotary-engine vehicles.
As to Diesel motor vehicles, a test is conducted for smoke emission at time of no-load acceleration and the standard is 50% or less of smoke emission.

v) Headlight test: Using a condenser type tester, the brightness and deviation of the optic axis of the headlights on main beam are measured. The standards are as follows:
- Luminous intensity:
  4 lights system: 12,000 cd or more
  2 lights system: 15,000 cd or more
- Deviation of optic axis:
  Right lamp: Up 0, down 2/100, left 2/100, right 1/100 or less
  Left lamp: Up 0, down 2/100, left 2/100, right 2/100 or less

(4) Inspection in the pit

The pit is generally 2.3 meters deep and provided with a table lift adjustable up or down enabling inspectors to make inspection in the most suitable posture. The top of the pit has a cover of acrylic resin and the bridge portion is provided with an air-curtain to prevent entry of exhaust emission to the pit. The inspection items are as follows:

- Brake fluid leakage from and damage to brake hoses and pipes
- Looseness and damage of steering devices
- Water leakage from radiator
- Oil leakage from transmission
- Play and distortion of propeller-shaft joint
- Oil leakage and distortion of shock-absorber
- Exhaust pipe damage
- Attachment and damage of catalyst equipment and heat insulation plate

Table 4. Fees of inspection.

Categories of motor vehicles	Fees for inspection
Small-sized motor vehicles (displacement: 2,000 cc or less)	¥1,200
Ordinary motor vehicles (displacement: Over 2,000 cc)	¥1,300

Fees for inspection

A charge is levied for the inspection and the income is used to defray the cost of operating the inspection centers. Fees for inspection vary according to the category of motor vehicles. (See Table 4.)

MOTOR VEHICLE REGISTRATION SYSTEM

Outline

The registration of motor vehicles under the provisions of the Road Vehicles Act (Law No. 185 of 1951) is an administrative requirement for the operation of motor vehicles and a civil requirement for establishing the ownership of motor vehicles against a third party.*

That is to say, the registration system of motor vehicles has two aspects, one termed "administrative registration" which is required to ascertain the actual situation, etc. of use of motor vehicles (Article 4 of the Road Vehicles Act) and the other is called "civil registration" required to confer the power to set up against a third party for the safety of transactions of motor vehicles (Article 5 of the Road Vehicles Act).

The Road Vehicles Act

(General effect of registration)

Article 4. Motor vehicles (excluding light motor vehicles, small-sized special motor vehicles and two-wheeled

*The term "to set up against a third party" means that a juridical relation which becomes effective between the parties is claimed against a third party. For instance, if Party X assigns a motor vehicle to Party A and Party B jointly, Party B who has not registered the ownership so assigned cannot claim any legal ownership of such motor vehicle against Party A who has registered the ownership.

small-sized motor vehicles; hereinafter the same in this Chapter, except Articles 29 to 32) shall not be operated unless they have been registered in the motor vehicle registration file.

Article 5. The acquisition or loss of ownership of motor vehicles which have registered shall not set up against a third party, unless it is registered.

2. The provisions in the preceding paragraph shall not apply to large sized-special motor vehicles as provided for in the proviso of Article 2 of the Motor Vehicle Mortgage Law (Law No. 187 of 1951).

The subject motor vehicles are ordinary motor vehicles, three-wheeled and four-wheeled small-sized motor vehicles and large-sized special motor vehicles (including motor vehicles with caterpillars, etc.). The registration is effected, upon application by owners of motor vehicles, by the Minister for Transport. However, at the present time, under the provisions of the Road Vehicles Act Enforcement Order (Cabinet Order No. 254 of 1951) the governors of prefectures having jurisdiction over the place where such motor vehicles are authorized to make registration and the business is handled by the Land Transport Offices (including branches and sub-branches located at 80 places throughout Japan).

Computer Registration Processing System

As mentioned in the introduction, the postwar growth of the number of motor vehicles in Japan has been outstanding, so that the registration business of motor vehicles expanded and became increasingly complicated year by year. To cope with such a tendency, the Ministry of Transport introduced a computer registration processing system in March 1970 for the purpose of rationalizing and modernizing the registration business. To handle the business accurately and speedily, the Land Transport Offices throughout Japan were linked by an on-line system to the motor vehicle registration center to centralizedly control the registration records of motor vehicles in the motor vehicle registration file.

Further, in January 1979, the Ministry of Transport changed the system by introducing larger and more highly efficient computers for further rationalization of the registration business and improvement of the administrative service.

(Reference 1) Growth of Holding Number of Motor Vehicles

(Unit: 1,000 vehicles)

As of the end of fiscal 1955	150.2
As of the end of fiscal 1960	340.4
As of the end of fiscal 1965	812.3
As of the end of fiscal 1970	18,919.0
As of the end of fiscal 1975	29,143.4
As of the end of fiscal 1980	38,992.0

Method of Application for Registration

The application for registration of a motor vehicle, in principle, is filed jointly by the person who is entitled to make the registration (the person who obtains the right of ownership upon registration—normally the purchaser) and the person who is obligated to make the registration (the person who relinquishes the right of ownership—ordinarily the dealer) or his attorney, who appears at the Land Transport Office.

However, joint application is required only for the registration of transfer of ownership and registration of creation of pledge.* Application for initial registration, registration of cancellation, etc. can be made alone by the person who is entitled to make the registration, while registration of alteration can be made alone by the owner (registered owner).

Kinds of Registration

As to the registration of motor vehicles, there are various registration procedures such as the initial registration in case where motor vehicles which have not previously been registered are registered, the registration of alteration in case where any registered matter has been altered, the registration of alteration in case where the ownership has changed, etc. However, the growth in the number of main items handled in various registration procedures is as shown in Reference 2 and the contents are briefly explained below:

(Reference 2) Growth in Number of Main Items Handled Relating to Registration

Items \ Fiscal year	1965	1970	1975	1980
Number of registered motor vehicles	5,017,155	12,779,069	23,018,860	31,249,900
Initial registration	1,747,307	3,693,353	4,466,734	4,850,288
Registration of alteration	484,626	1,278,085	1,230,743	1,613,723
Registration of transfer of ownership	722,559	1,607,312	2,616,039	3,366,115
Registration of cancellation	930,731	1,939,329	2,507,008	3,798,769

(1) Initial registration (Article 7 of the Road Vehicles Act)

This refers to the case where motor vehicles which have not previously been registered are registered, including

*This means that in case Party A lends money to Party X, in order to secure the repayment of such money, a motor vehicle owned by Party X can be provided as security by leaving the use of such motor vehicle to Party X. If no repayment is made, the ownership of the motor vehicle will be transferred from Party X to Party A.

the case where motor vehicles whose registration has been cancelled are registered again. The owner can use the motor vehicle concerned for operation upon registration and set up the ownership of the motor vehicle against a third party.

(2) Registration of alteration (Article 12 of the Road Vehicles Act)

This registration is to alter the former records when there occurs alteration in type of motor vehicle, chassis number, type of engine, locality of principal place of use, and the owner must apply for registration of alteration within 15 days from the day when such alteration is effected.

Incidentally, the alteration of ownership comes under the registration of transfer of ownership as stated below and is not included in the registration of alteration.

(3) Registration of transfer of ownership (Article 13 of the Law)

This registration is made when ownership of a motor vehicle which has been registered is changed, and the new owner must apply for registration of transfer of ownership within 15 days from the day when such transfer occurs. In case the registration is made thereby, the new owner will be able to set up the ownership of the motor vehicle against a third party.

(4) Registration of cancellation (Articles 15 and 16 of the Road Vehicles Act)

There are two categories of registration of cancellation: One is made by the owner of a registered motor vehicle when the motor vehicle is lost, disassembled or no longer used as a motor vehicle or when the chassis of the motor vehicle differs unidentical from that at time of initial registration due to alteration within 15 days from the day when such alteration occurs, and the other is made by the owner of a registered motor vehicle when he suspends use of the motor vehicle at his discretion. If registration is made of a motor vehicle which can be operated, the motor vehicle will be handled as a mere personal property under civil law and cannot be used unless the initial registration is made again.

(5) Registration of mortgage (Article 5 of the Motor Vehicle Mortgage Law) (Law No. 187 of 1951)

A registered motor vehicle can be used for mortgage and by registering the acquisition, loss or alteration of the mortgage in the motor vehicle registration file, the power to set up the ownership against a third party will be given. The recent trend has been toward a decline in use of the motor vehicle mortage system due to utilization of the ownership reservation system (this means that the ownership of the subject motor vehicle is reserved by the seller until the price is fully paid after the delivery of the said motor vehicle), comparative decline in the price of motor vehicles, etc.

(6) Other registrations

There are also registration through commission which is effected by authorities in case of attachment, etc. under laws and orders (Article 9 of the Order, Article 71 of the National Tax Collection Law, etc.), registration of correction to correct or supplement any mistake or omission in the registration (Articles 25 to 28 of the Order), etc.

Motor Vehicle Registration Number and Motor Vehicle Registration Number Plate (Article 11, etc. of the Road Vehicles Act)

The motor vehicle registration number specifies the motor vehicle which has been registered for administrative purpose and is determined for the motor vehicle at time of initial registration, and the motor vehicle registration number is indicated on the motor vehicle registration number plate.

The motor vehicle registration number is determined by combining the indication of location of Land Transport office or its branch, classification number according to the category of motor vehicle, Japanese hiragana syllable or capital letter of Roman alphabet and figures of four digits or less, in this order.

Moreover, the motor vehicle registration number plate is not only a means to facilitate confirmation of the identity of the motor vehicle, but also a sign to show that the motor vehicle has already been registered. Therefore, the delivery of number plates is performed by the Government, but it is a work requiring such discretion that it cannot be entrusted to the private sector. Accordingly, under Article 25 of the Road Vehicles Act a system of agents for delivery of motor vehicle registration number plates has been created to entrust a person appointed by the Director-General of District Land Transport Bureau having jurisdiction over his place of business with the delivery business of motor vehicle registration number plates.

Sealing of Motor Vehicle Registration Number Plates (Article 11 of the Road Vehicles Act)

This stipulates that the owner of a registered motor vehicle must confirm that the motor vehicle conforms with the motor vehicle registration number plate when the number plate is attached to the motor vehicle and that in order to prevent the number plate from being removed he must agree to its sealing thereof by the governor of the urban or rural prefecture, agent for delivering number plates entrusted by the governor of the urban or rural prefecture, etc. (Article 11 of the Road Vehicles Act).

However, if the motor vehicle registration number plate is lost, seal is removed and so on, the attachment of seal which becomes necessary for such reason will be con-

ducted by the governor of the urban or rural prefecture, because it is specially required to handle the matter strictly for the purpose of indicating the motor vehicle registration number plate setting forth the genuine motor vehicle registration number.

Temporary Operation and Forwarding Operation of Motor Vehicle

(1) Permission for temporary operation (Articles 34 to 36 of the Road Vehicles Act)

In case of test run of a motor vehicle or forwarding of motor vehicle to be submitted for the application for initial registration, initial inspection, etc. or other case of necessity, the Director-General of District Land Transport Bureau, etc. may give permission for temporary operation for an effective period not exceeding five days. Permission for temporary operation will be given only as an exceptional measure by specifying the object and route of such operation for the motor vehicle concerned and in case such permission is given, the certificate of permission for temporary operation will be delivered and the temporary operation permission number plate will be loaned.

A motor vehicle for which permission is given for temporary operation can be operated legally by anyone on condition that it is operated according to the object and route as set forth in the permission for temporary operation kept by the motor vehicle.

(2) Permission for forwarding operation (Article 36-2 of the Road Vehicle Act)

The Director-General of District Land Transport Bureau may give permission for forwarding operation of motor vehicles for the effective period not exceeding one year to a person who is engaged in the business of manufacture, land forwarding or sale of motor vehicles. The governor of each prefecture will deliver the certificate of permission for forwarding operation in the number deemed necessary upon application and at the same time loan a corresponding number of forwarding operation permission number plates. The certificate of permission for forwarding operation will set forth the object and route of forwarding and the effective period must not exceed one month.

The features of the permission for forwarding operation compared with the permission for temporary operation are that while the former is permission for an individual motor vehicle (permission to the subject item), the latter is permission to the operator (permission to the person). Accordingly, in case of permission for forwarding operation, the permission will be effective only in case where the person himself uses it.

(Reference 3) Holding number of motor vehicles (As of the end of October, 1981)

(Unit: vehicles)

Function	Categories of motor vehicles		Use	Number of vehicles
Trucks	Ordinary motor vehicles		Private use	1,072,521
			Business use	458,706
			Total	1,531,227
	Small-sized motor vehicles	4-wheeled	Private use	7,078,908
			Business use	87,107
			Total	7,166,015
		3-wheeled	Private use	10,115
			Business use	518
			Total	10,633
	Trailers		Private use	8,610
			Business use	49,803
			Total	58,413
	Light motor vehicles		4-wheeled	5,118,419
			3-wheeled	1,349
	Total trucks			13,886,056
Buses	Ordinary motor vehicles		Private use	22,383
			Business use	85,490
			Total	107,873
	Small-sized motor vehicles		Private use	119,830
			Business use	3,891
			Total	123,721
	Total buses			231,594
Passenger motor vehicles	Ordinary motor vehicles		Private use	520,475
			Business use	1,608
			Total	522,083
	Small-sized motor vehicles		Private use	21,499,658
			Business use	249,551
			Total	21,749,209
	Light 4-wheeled motor vehicles			2,107,665
	Total passenger cars			24,378,957
Special-purpose motor vehicles	Ordinary motor vehicles		Private use	319,689
			Business use	76,643
			Total	396,332
	Small-sized motor vehicles		Private use	117,947
			Business use	4,071
			Total	122,018
	Large-sized special motor vehicles		Private use	296,586
			Business use	3,791
			Total	300,377
	Total special purpose cars			818,727
Motor-cycles	Small-sized mopeds			510,165
	Light motorcycles			635,220
	Total mopeds/motorcycles			1,145,385
Grand Total				40,460,719

(Number of registered motor vehicles: 32,087,901)

Legal System of Japan on Motor Vehicles*

JUN MASUI
Engineering Division
Road Transport Bureau
Ministry of Transport
Tokyo
AKIO SASAKI
Inspection and Safety Transport Division
TOSHINORI URANO
Radioactive Materials Safety Transport Office
Inspection and Safety Transport Division

Part 6: Motor Vehicle Accident Prevention Measures and Research System of the Government

Motor Vehicle Accident Prevention Measures

Outline of accident prevention measures

To reduce motor vehicle accidents, it is necessary to adopt overall measures from various sides, and at the present time the Head Office for Traffic Policy of the Cabinet as the central organ is taking various measures for traffic safety in cooperation with the competent ministries.

The Ministry of Transport is no exception. It is the fundamental mission of the transportation administration to ensure safety of transportation facilities, and for the purpose of promoting motor vehicle accident prevention measures, the following measures are taken: (1) Improvement of Inspection system and Maintenance and repair system of motor vehicles, (2) Strengthening of guidance and supervision from the side of safety of motor vehicle transportation business, (3) Establishment of regulations concerning the construction and equipment of motor vehicles and (4) Improvement of test and research system.

The above measures are shown in Figure 1 and efforts are exerted so that these systems work effectively and are improved by coping with changes in traffic environments and improvement of structures of motor vehicles.

Some of these systems and measures have been already explained in detail and some others will be explained in this part or the next part. The outlines of the measures will be enumerated and explained as follows:

(i) Motor vehicle inspection system (details were already explained in Part 5):

For the purpose of preventing accidents due to mechanical troubles of motor vehicles, the periodical inspection system is provided for motor vehicles and in order to improve such system, by creating special accounts for motor vehicle inspection and registration since fiscal 1964, the inspection facilities and personnel have been increased in keeping with the growth of the number of motor vehicles. Furthermore, in order to make the activities smooth and to cover a shortage in the number of personnel, the enlargement of the designated motor vehicle repair business system (inspection system by private repair shops) and rationalization of business through introduction of computers are being promoted.

(ii) Motor vehicle type designation system (details were already explained in Part 4):

New model motor vehicles must be examined before marketing to determine whether they conform to the Safety Regulations for Road Vehicles and have uniformity of production. The motor vehicles whose type was designated are exempted from submission of each vehicle at the time of initial inspection. In addition, supervision is extended for manufacturers of motor vehicles whose type has been designated.

In the meantime, a policy to strengthen the examination of motor vehicles against the problem of defective motor vehicles in 1969 was determined, and according to such policy the Type Designation Regulations for Motor Vehicles were amended. Since then, the type examination system has been reinforced year by year.

(iii) Approval system of motor vehicle maintenance and repair business (details to be explained in Part 7):

In order to upgrade the maintenance and repair motor vehicle maintenance and repair business, an approval system of maintenance and repair shops is employed. Since most of maintenance and repair businesses are smaller enterprises, they are designated as businesses under the Small and Medium Enterprise Modernization Promotion Law and their modernization is being promoted.

(iv) Authorization system of motor vehicle maintenance and repair mechanics (details to be explained in Part 7):

In order to upgrade the maintenance and repair techniques of motor vehicles, examination of skills of motor vehicle maintenance and repair mechanics and designation of training facilities of such mechanics are made.

Number of applicants for the examination:	193,019 persons (fiscal year 1979)
Number of training facilities:	383 facilities (as of the end of March 1980)

* Received 19th April, 1982

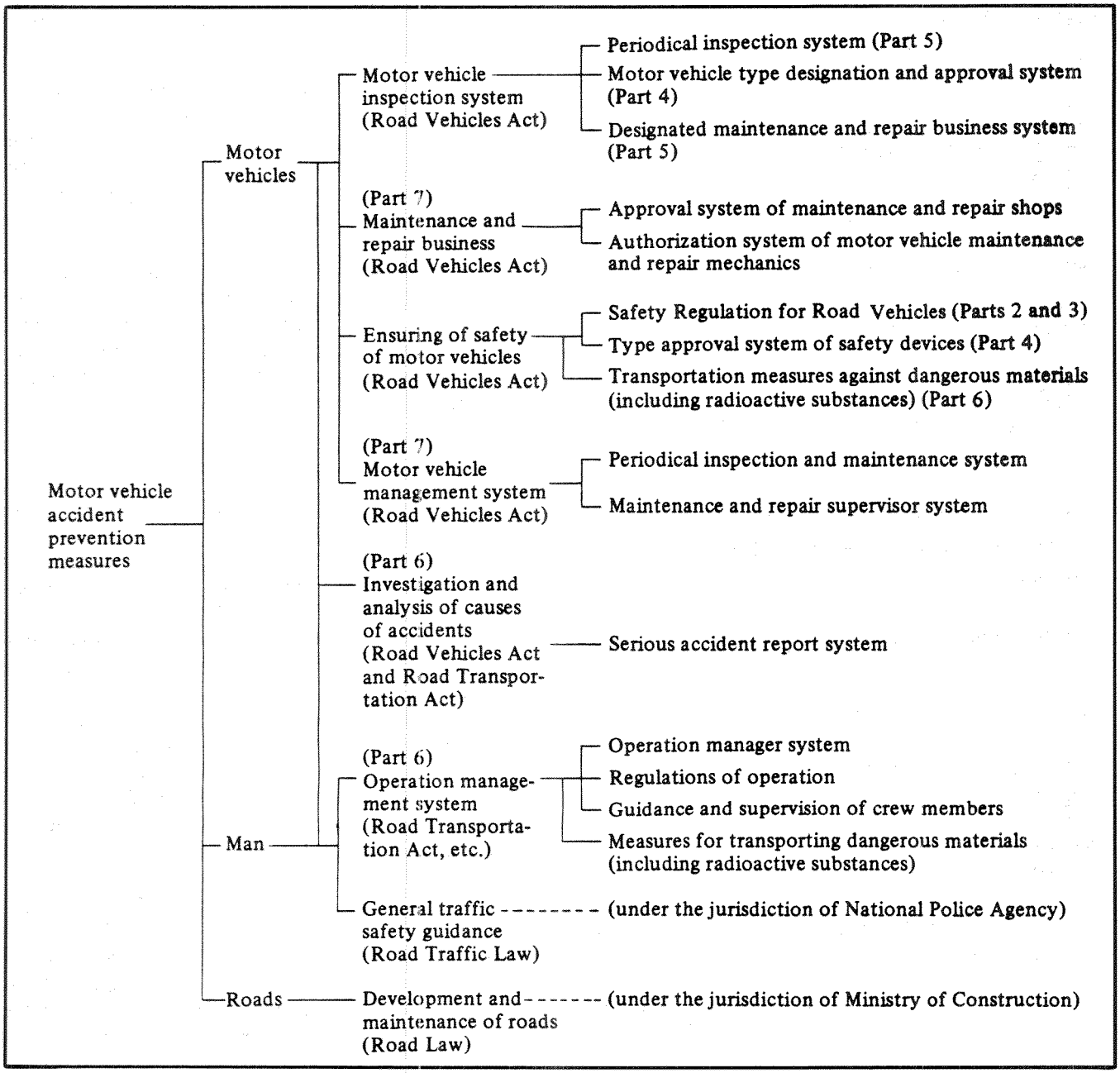


Figure 1. Motor vehicle accident prevention measures.

(v) Safety regulations for motor vehicles (details were already given in Parts 2 and 3):

Under the Safety Regulations for Road Vehicles established in 1951, the size, weight, braking system, lamps, meters, exhaust emission, noise, etc. are stipulated. These Safety Regulations have been amended one by one according to changes, etc. in the traffic environment, actual situation of use, etc. since their promulgation.

(vi) Periodical inspection and maintenance system (details to be explained in Part 7):

The users of motor vehicles are obligated to make daily inspection before driving and the periodical inspection and maintenance every month or every six months.

(vii) Maintenance and repair supervisor system (details to be explained in Part 7):

In order to ensure that the periodical inspection and maintenance are conducted without fail, a person who uses a large number of motor vehicles is obligated to appoint a qualified person as a maintenance and repair supervisor.

Number of maintenance and repair supervisors:	232,393 persons (as of the end of March, 1980)

(viii) Others:

In addition to the above measures under the Road Vehicles Act, for the purpose of ensuring safety from the side of motor vehicle transportation business operators, (a) establishment of operation management system and investigation and analysis of serious accidents are made under the Road Vehicles Act and the Road Transportation Act, which will be explained in Section (2) below.

Furthermore, safety measures for transporting dangerous materials such as gasoline, explosives, high-pressure gas, radioactive materials, etc. are adopted pursuant to the Road Vehicles Act, etc., which will be explained in Section (3) below.

Ensuring safety in motor vehicle transportation business:

Operation management:

(i) System of operation managers:

The mission of motor vehicle transportation business is to transport passengers or goods safely, surely and rapidly. From the viewpoint of public importance of motor vehicle transportation business, a responsible system to ensure the safety of transportation must be established in the organization of the motor vehicle transportation business.

Accordingly, it is necessary that all business affairs relating to the safety of daily operations be carried out by a responsible person. Furthermore, the responsible person must conduct his duties at all times during the operation of motor vehicles at each place of business.

However, sometimes it will be difficult for an operator to perform operation management directly by himself because of the operational scale of the business.

For that reason, a responsible person who disposes matters relating to safety of transportation must be designated under the Road Transportation Act (Law No. 183 of 1951; hereinafter referred to as the "Transportation Act") to appoint an operation manager.

(ii) Appointment of operation managers:

a. Place of business where the appointment of operation managers is required:

The place of business where the motor vehicle transportation business operators must appoint operation managers is stipulated according to the number of motor vehicles for business use as set forth in Table 1 under the Transportation Regulations for Motor Vehicles Transportation Business, etc. (Ministry of Transport Ordinance No. 44 of 1956; hereinafter referred to as the "Transportation Regulations").

b. Requirements for operation managers:

The operation manager has an important obligation to ensure the safety of operation of motor vehicles for business use on behalf of the operator. Accordingly, the operation manager is required to perform his duties with responsibility and to have sufficient specialized knowledge and experience for disposing affairs relating to safety.

Table 1. Place of business where operation managers are required.

Kind of business	Number of motor vehicles operated
(1) Passenger motor vehicle transportation business:	
Bus	1 or more
Taxi	5 or more
Specific passenger and free passenger transportation	1 or more (in case passenger capacity is 11 persons or more) 5 or more (in case passenger capacity is not more than 11 persons)
(2) Truck transportation business:	
General route	1 or more (in case of motor vehicles operating on specific routes) 5 or more (delivery motor vehicles excluding light motor vehicles)
General area	5 or more (excluding light motor vehicles)
Specific goods and free goods	5 or more (excluding light motor vehicles)

Requirements for the operation manager as provided for in the Transportation Regulations are having experience in any of the following items:

① A person who has business experience of one year or more in the operation management of motor vehicles for business use or a person who has business experience of three years or more in driving motor vehicles for business use, who has finished the training given by the Director-General of the District Land Transport Bureau.

② A person who has business experience of three years or more in the operation of motor vehicles for the same kind of business.

③ A person who has business experience of seven years or more in the driving of motor vehicles for the same kind of business.

④ A person who is recognized by the Director-General of District Land Transport Bureau to have an ability equivalent or superior to the person of Item ①, ② or ③ above in the management of operation of motor vehicles.

c. Notification on appointment of operation managers:

The motor vehicle transportation business operator

must, if an operation manager is appointed or any matter already notified is altered, notify the Director-General of District Land Transport Bureau not later than 15 days from the date of such appointment or alteration.

d. Discharge of operation manager:

If any operation manager does not conform to the Transportation Act or the Transportation Regulations, the Director-General of the District Land Transport Bureau may order the motor vehicle transportation business operator concerned to discharge such operation manager.

(iii) Operation management rules and safety service rules:

The motor vehicle transportation business operator must establish standards on matters relating to the service and authority of the operation manager and ensuring of the safety of motor vehicles for business use, that is, the "operation management rules" and submit them to the Director-General of the District Land Transport Bureau.

Table 2 shows the minimum extent of matters to be disposed of by the operation manager. It is stipulated that the operation manager must perform his duties to dispose those matters surely under the Operation Management Rules.

Moreover, passenger motor vehicle transportation businesses and general route truck transportation businesses are operating motor vehicles systematically by employing many crew members. Since the crew members perform most of their operations in places where direct supervision by supervisors is not possible, it is necessary to thoroughly educate them concerning standards for safe and sure performance of their daily operation. For this reason, they are obligated to establish safety operation guidelines on matters to be observed by such crew members and their services under the Transportation Regulations.

In the meantime, motor vehicle transportation business operators must give adequate guidance and supervision for the observance of the operation management rules to the operation managers and at the same time it is necessary to guide and supervise crew members under the safety service rules.

(iv) Operation management services:

The principal matters of operation management services are the management of drivers. In order to perform the management of drivers properly, it is necessary to complete the acceptance system inside the enterprises which can maintain a good level of driver proficiency. At the same time, necessary measures must be taken to upgrade drivers and to ensure that safety operation can be maintained at all times under all circumstances. For that purpose, it is required that a system to effect the operation management be established in the motor vehicle transportation businesses.

The operation management services are divided into three main categories as listed in Figure 2, (a) personnel management, (b) data management and (c) driving management. The personnel management referred to in this part includes that conducted in ordinary business companies, but it does not aim at merely raising the productivity, but means the special personnel management to those who are engaged in the special duties of driving motor vehicles.

The main purpose of data management is to obtain effective data for performing better personnel management. Such data will be indispensable for drawing up a rational operation plan and accident prevention measures, because it can be checked whether the daily operation is carried out as scheduled and it becomes possible to seize the actual record of operation.

Driving management is viewed as a measure to ensure that the respective drivers are in their best condition in different working places by taking the necessary measures before the commencement of daily operation. Unless any harmony exists between a motor vehicle and a driver, it cannot be expected to secure the safety of transportation in traffic, so that no matter how adequately training of drivers is made, the safety of transportation cannot be ensured without proper management of the driving. Besides, it is necessary as pre-conditions for proper execution of driving management that the personnel management and data management be carried out properly.

(v) Training of operation managers:

The Transportation Regulations stipulate as a series of measures for preventing accidents that motor vehicle transportation business operators must have their operation managers receive training executed by the Director-General of District Land Transport Bureau as to practices, techniques, etc. required for the management of operation. Through this training, the operation managers obtain the knowledge and improve the skill required for the performance of their duties in consideration of the public nature of their business which involves the transportation of lives and property.

Investigation and analysis of serious accidents:

(i) Report system of serious accidents:

In order for the Ministry of Transport to grasp the actual situation of motor vehicle accidents caused by motor vehicle transportation businesses and analyze it to prevent the recurrence of such accidents, the Transportation Act stipulates that a "report of accidents" be made and the Motor Vehicle Accident Report Regulations (Ministry of Transport Ordinance No. 104 of 1951; hereinafter referred to as the "Accident Report Regulations") stipulates in concrete detail how to make the report, etc.

Table 2. Minimum extent of matters to be disposed of by the operation manager.

No.	Transportation regulations	Contents of matters to be disposed of	Kinds of motor vehicle transportation business	
			Motor vehicles for passengers	Motor vehicles for cargoes
1	Article 15 paragraph 1	Boarding service of a conductor	Bus, chartered bus, specific and free passenger transportation (passenger capacity of 11 or more)	—
2	Article 20	Measures to be taken at time of extraordinary weather conditions, etc.	○	○
3	Article 21 paragraph 1	Prevention of overwork (working hours and boarding hours)	○	○
4	Article 21 paragraph 3	Ditto (the health condition of drivers)	○	○
5	Article 21 paragraph 4	Ditto (for long-distance or night driving, arrangement of relief drivers, etc.)	Bus and chartered bus	Route and area truck
6	Article 22	Roll-call, etc.	○	○
7	Article 22-2	Boarding record	○	○
8	Article 22-3 Article 44-4	Recording by tachograph	Bus, chartered bus, specific and free passenger transportation (in case of bus, operation routes of 100km or more)	○
9	Article 45-3 paragraph 3 item 3	Placement of motor vehicles with tachographs	Ditto	○
10	Article 23 paragraph 1	Standard driving chart manual, etc.	Bus	—
11	Article 23 paragraph 2	Operation schedule	Ditto	—
12	Article 24	Investigation, etc. of routes	Chartered bus	—
13	Article 25-6 Article 45-2	Appointment of drivers	○	○
14	Article 25-8 paragraph 2	Certificate of boarding crew member	Taxi	—
15	—	Indication of certificate of driver (Article 13 of the Taxi Business Rationalization Temporary Measures Law)	Ditto	—
16	Article 26	Supervision of crew members	○	○
17	Article 29 paragraph 2	Provision of emergency signal equipment, etc.	○	○
18	—	Limitation of drivers (Article 27 of the Road Transportation Act)	○	—
19	—	Warning of accident (Article 5 of the Regulations of Reporting Motor Vehicle Accidents)	○	○
20	Article 45-3 paragraph 1	Prohibition of operation of over-loaded motor vehicles	—	○
21	Article 44-3	Standards for boarding service	—	Route truck (applicable to operation route of 100km or more)

Note: Mark "○" is applicable to all motor vehicle transportation businesses.

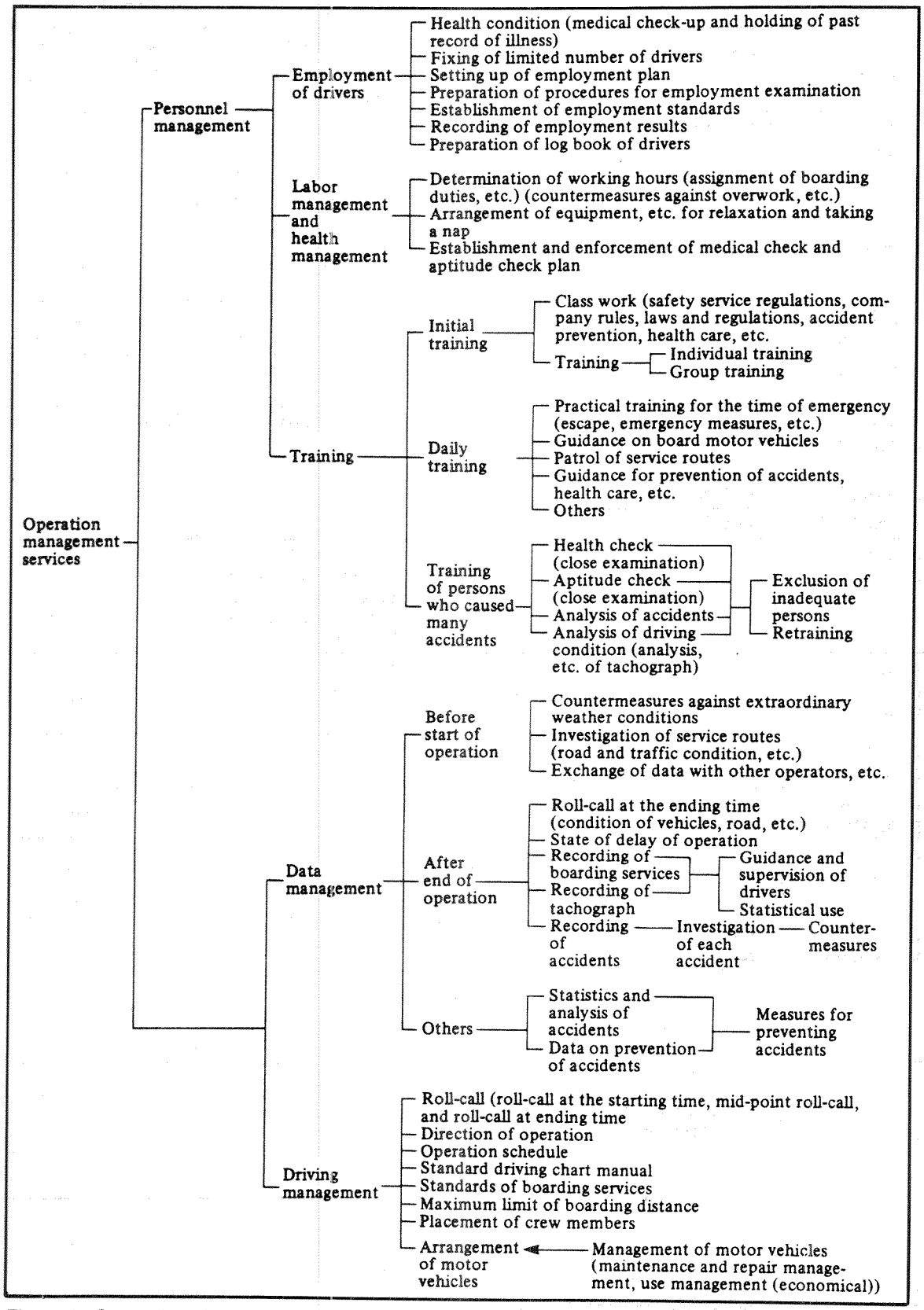


Figure 2. Categories of operation management services.

(ii) Report of serious accidents:

It is stipulated that motor vehicle transportation business operators must, if their motor vehicles have caused any accident which comes under any of the following items (hereinafter referred to as for "serious accident"), report such accident to the Minister for Transport through the Land Transport Office concerned in the prescribed form within ten days from the day of the accident in accordance with the provisions of the Transportation Act and the Accident Report Regulations.

Furthermore, the Minister for Transport or the Director-General of the District Land Transport Bureau assesses the circumstances of accidents and trend of accidents, etc. through such accident reports and the prompt report stated below and takes measures to prevent accidents through warnings, etc.

Kinds of serious accidents:

a. Roll-over accident
b. Fall-down accident
c. Fire accident
d. Grade-crossing accident
e. Death or serious injury accident
f. Accident whose damage exceeds 500,000 yen in total
g. Accident causing immobilization of the motor vehicle due to breakdown

(iii) Prompt report of accidents:

Motor vehicle transportation business operators must, if there occurs any accident in the above categories of serious accidents which causes roll-over, fall-down, fire and grade-crossing collision, with resultant fatalities and seriously injured cases, promptly report the outline of such accident to the competent Land Transport Office within 24 hours by telephone, telegram or other proper means.

In addition, the outline of any accident other than the above which causes conspicuously large numbers of fatalities and injured or which is considered to have a very serious influence on the society, will be reported promptly, too.

Safety measures for transportation of dangerous materials

Related laws

Safety measures for the transportation of so-called dangerous materials such as gasoline, liquefied petroleum gas, explosives, poisonous substances, powerful poisonous substances, cobalt 60, plutonium, etc. by motor vehicles are adopted on the basis of the related laws.

The general requirements concerning the handling of dangerous materials such as storage, transportation, containers to be used, etc. are prescribed by each of the following laws:

(i) As for dangerous materials such as gasoline, ether, acetone, etc., the Fire Prevention Act (Law No. 186 of 1948) stipulates that the quality of containers, loading method and transportation method be in conformity with the technical standards prescribed by the related cabinet order.

Furthermore, as for the transportation of dangerous materials by mobile tanks (such as tank lorries), the presence of a certified dangerous materials handler in the transportation vehicle together with the driver, his technical ability being in conformity with the standard prescribed by the related cabinet order, and his possession of the certificate with him in performing his duty are also provided by the above-mentioned law.

(ii) As for the handling of high-pressure gases such as methane, hydrogen, oxygen, liquefied petroleum gas, etc., the High-Pressure Gas Control Act (Law No. 204 of 1951) stipulates that the quality of containers, loading method and transportation method for the transportation of high-pressure gases be in conformity with the technical standards prescribed by the ordinance of the Ministry of International Trade and Industry. Furthermore, the standard concerning a container fixed on a vehicle (such as that of a tank lorry) that is established to supplement the requirements of such ordinance requires a) the warning mark of dangerous materials to be indicated at a readily visible place on the container, b) the contents of the gas in the container not to exceed 18,000 litres in the case of inflammable gases such as oxygen, and 8,000 litres in the case of poisonous gases, and c) in the case of containers other than those whose discharging outlets are provided at their rear, a container to be fixed on a vehicle so that the horizontal distance between its rear and the rear of the bumper will not become shorter than 30 cm.

(iii) Explosives

As for the transportation of explosives, the Gunpowder Control Act (Law No. 149 of 1950) stipulates that the carrier of the explosive must notify the competent prefectural public safety commission to obtain a certificate proving that the necessary notification has been submitted, and shall carry such certificate during the transportation of the explosive. Furthermore, the transportation route, loading method, indication of the warning mark and transportation method are stipulated to be in conformity with the technical standards prescribed by the ordinance of the Prime Minister's Office.

(iv) Poisonous substances and powerful poisonous substances.

As for the transportation of poisonous substances or powerful poisonous substances such as mercury, sulfuric acid, etc., the condition of the container, loading method,

transportation method, the conditions concerning the presence of the shift driver and helper in the transportation vehicle, indications of the sign on the vehicle must be in conformity with the Enforcement Order and the Enforcement Regulations of the Poisonous Substances and Powerful Poisonous Substances Control Law (Law No. 303 of 1950).

(v) As for the transportation of radio isotopes (such as cobalt 60) and nuclear fuel materials (such as uranium, plutonium, etc.), the conditions of the transportation are regulated by the Law Concerning the Prevention of Radiation Hazards due to Radioactive Isotopes, etc. (Law No. 167 of 1957) and the Law Concerning Regulation of Nuclear Source Materials, Nuclear Fuel Materials and Reactors (Law No. 166 of 1957). The outline of the regulations provided by these laws will be explained later in C.

Road Vehicles Act

As for the constructions and equipments of motor vehicles to be used for the transportation of dangerous materials, the following standards have been established in conformity with the Safety Regulations for Road Vehicles (Ministry of Transport ordinance already explained in Parts 2 and 3) based on the Road Vehicles Act, in order to enforce the inspection of vehicles (already explained in Part 5) for ensuring safety during the transportation of dangerous materials by preventing the occurrence of fire or explosion.

(i) Vehicles to transport any of the following dangerous materials, etc. are required to have a fire extinguisher installed.
* Dangerous materials such as gasoline (when the quantity exceeds the designated quantity)
* High-pressure gas (when the quantity is over 150 kg, and it is flammable)
* Explosive (5 kg or more)
* Radioactive and nuclear fuel materials

(ii) Any motor vehicle used to carry such dangerous materials must meet the following standards:
* The electric system shall be insulated properly.
* The rear body and engine shall be separated by non-inflammable partition walls.
* The parts of the exhaust pipes and silencers within the range of 200 mm respectively from the surface of the tank shall be covered with appropriate-heat prevention fittings.
* The rear of the frame shall be provided with a bumper and other buffer system in order to protect the tank and its accessories from being damaged in the event of collision.
* Others.

(iii) Any motor vehicles with gas-transporting containers (high-pressure gas) shall meet the following standards:
* The rear of the frame shall be provided with a bumper and other buffer system in order to protect the gas container and its accessories from being damaged in the event of collision.
* The buffer system shall be located sufficiently away from the rear side of the container and its accessories.
* Others.

(iv) Any motor vehicles carrying explosives shall meet the following standards:
* The rear body and engine shall be separated with non-inflammable partition walls.
* The electric system shall be insulated properly.
* Others.

Radioactive materials (radio isotopes, nuclear fuel materials, etc.)

The technical standards for the transportation of radioactive materials have been established in conformity with the "Regulations for the Safe Transport of Radioactive Materials" (1973 Revised edition) of IAEA (International Atomic Energy Agency), the "Techniques for the Transportation of Radioactive Materials" published by the Atomic Energy Commission in January, 1975, and the "Report on the Amendment of the Standard for the Transportation of Radioactive Materials or Substances Contaminated by Radioactive Materials" recommended by the Council for Radiation in August 1977. As a result, this standard has become one of the most stringent standards in the world.

(i) Standard for transported goods

The quantity of transported goods is specified by an ordinance of Prime Minister's Office in consideration of the kinds of transported goods. On this basis, radioactive materials are classified into type L, type A, type B(M) and type B(U).

type L: Substance to be transported in the least dangerous quantity.

type A: Substance whose radioactivity is less than the specified level.

type B(M) or type B(U): Substance whose radioactivity is higher than the specified level.

Of the above classifications, the least dangerous quantity means less than one thousandth of the specified quantity. Also, the transported goods are required to meet the technical standards applicable to type L, type A, type B(M) and type B(U) respectively, shown in Table 3.

(ii) Standard for transportation method

In order to ensure the safety during transportation, the ordinance of the Ministry of Transport stipulates that the

Table 3. Technical standards to be met by the categories of the transported goods.

Standard	Type L	Type A	Type B(M)	Type B(U)
1. All the sides of the container should be longer than 10cm.	○	○	○	○
2. Handling should be easy and safe.	○	○	○	○
3. Container should be free of cracks or damage during transportation.	○	○	○	○
4. Container should be sealed.	○	○	○	○
5. Surface contamination should be lower than permissible concentration.	○	○	○	○
6. Radiation leakage level should be lower than the standard value.				
(1) Surface (m rem/h)	0.5	200	200	200
(2) 1m from surface (m rem/h)	–	10	10	10
7. Unnecessary articles should not be put in the container.	–	○	○	○
8. Under normal testing conditions:				
(1) Maximum permissible radiation level on the surface (m rem/h)	–	200	200	200
(2) Permissible leakage of radioactive substances (1h)	–	No leakage permitted	$A_2\times10^{-6}$	$A_2\times10^{-6}$
(3) Surface temperature should be under 50°C.	–	–	○	○
(4) Surface contamination should be under permissible concentration.	–	–	○	○
9. Under special testing conditions:				
(1) Maximum permissible radiation level 1m from surface (m rem)	–	–	1,000	1,000
(2) Permissible leakage of radioactive substance (1W)	–	–	A_2	$A_2\times10^{-3}$
(3) −40°C test.	–	–	–	○
10. Use of filter and mechanical cooling equipment shall be prohibited.	–	–	–	○
11. Internal pressure should be under 7kg/cm^2(G).	–	–	–	○

(Note) Besides the standards listed in the above table, as for the fissionable materials, the standards for preventing such materials from reaching the critical state must also be observed.

place of handling, loading method, method of indication, etc. must be in conformity with the standards listed in the following Table 3.

(iii) Approval for the transportation of radioactive materials

When transporting transported goods (such as type B(M) or B(U) transported goods) for which special care for the prevention of radiation leakage and the critical state is required, the transported goods to be transported must be approved by the prime minister or the general director of the Science and Technology Agency, and the method of transportation by the Minister for Transport respectively in order to confirm that both the transported goods to be transported and the method of transportation are in conformity with the related technical standards, respectively. Also, when transporting the transported goods, the user of such materials is required to notify the competent prefectural public safety commission to that effect.

(iv) Measures to be taken at time of accident during transportation

When an accident has occurred during transportation of radioactive materials, the carrier who is responsible for the transportation of such materials not only shall immediately take the necessary measures such as preventing the general public from approaching the vehicle but also shall immediately notify all the related parties to that effect.

Testing and Research Systems by the Government

Outline of the traffic safety and nuisance research institute:

The increase of traffic accidents, air pollution by exhaust gas from motor vehicles and so forth have gradually

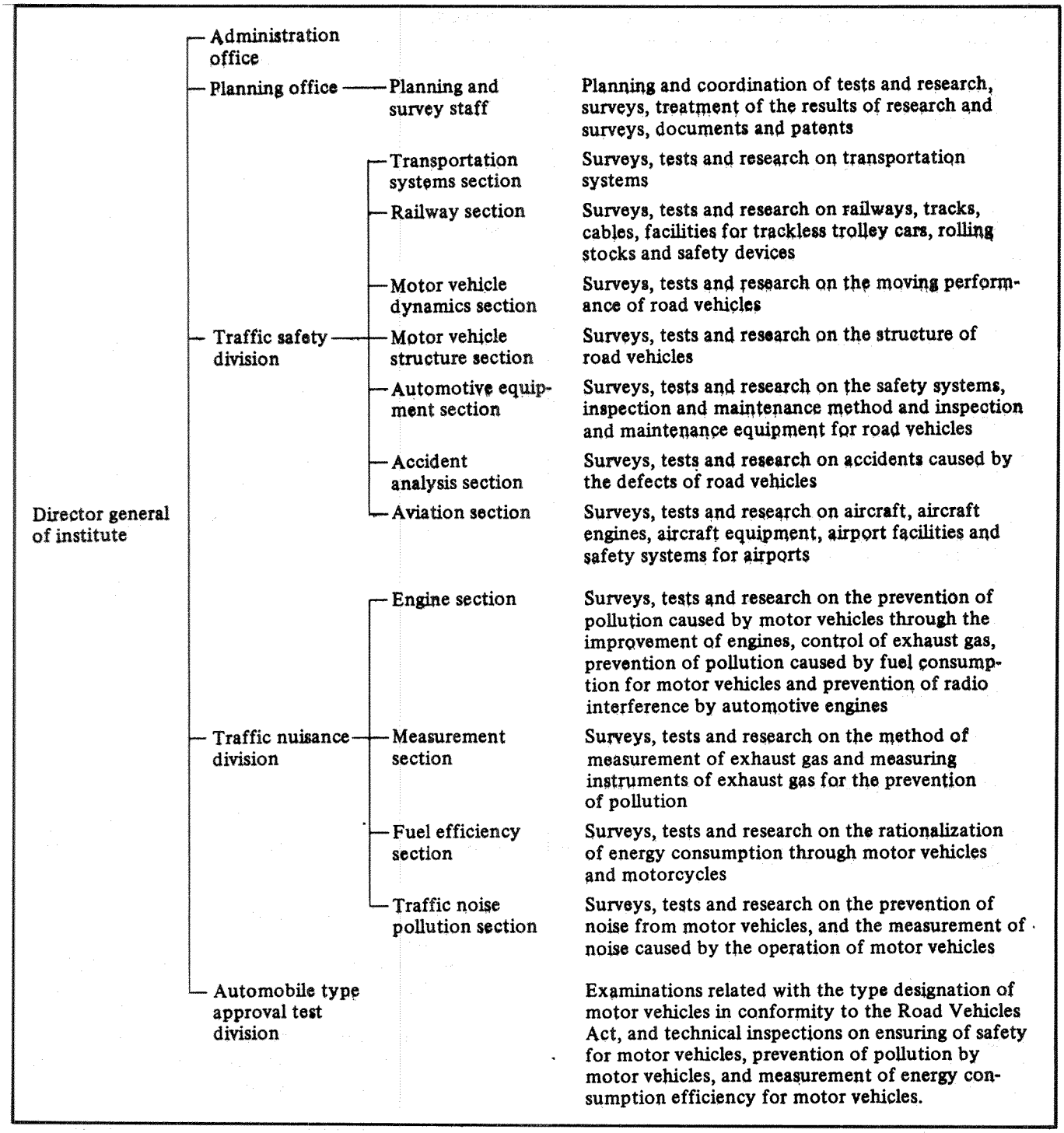


Figure 3. Organization and duties in traffic safety and nuisance research institute.

come to the fore as social problems from about 1965 along with the progress of the motorization in this country. Besides, the existence of defective motor vehicles had become another social problem by 1969. In order to cope effectively with the problems of increasing traffic accidents, public nuisances caused by vehicles and the existence of defective vehicles, the traffic safety and nuisance research institute was founded in 1970 as a subsidiary organ of the Ministry of Transport to undertake tests and research that can be utilized for traffic administration.

This institute also includes the Automobile Type Approval Test Division as already explained in Part 4 and the research section for railway traffic and air navigation. In this part, however, we are going to take up only the section concerned with safety for motor vehicles, prevention of pollution and energy saving.

Organization and duties in the traffic safety and nuisance research institute:

The organization and duties in this institute are as shown in Figure 3. The traffic safety division is responsible for the research on the safety of motor vehicles.

A. The traffic safety division comprises the four research sections for motor vehicles, and these research sections are currently engaged in the following principal research projects respectively.

(i) The motor vehicle dynamics section is now engaged in researches on the controllability and stability of motor vehicles based on the technical data obtained through experiments using models and actual motor vehicles.

(ii) The motor vehicle structure section is now conducting research on improving the brake performance of motor vehicles based on the technical data obtained not only through experiments using individual brakes and braking systems for high-speed vehicles but also through experiments using actual motor vehicles.

(iii) The automotive equipment section is now undertaking research on how to make the optimum vision available for drivers of motor vehicles based on the technical data concerning the running speed, locus and the scope of driver's eyes obtained through the experiments using actual motor vehicles.

(iv) The accident analysis section is now carrying out research on how to reduce the damage to vehicle and driver at the time of collision and the strengths of the structure and equipment of motor vehicles based on the technical data obtained through the collision experiments.

B. On the other hand, research on the prevention of pollution caused by motor vehicles and energy-saving systems for motor vehicles are undertaken by the traffic nuisance division. This division comprises the four research sections for motor vehicles, and these research sections are engaged in the following principal research projects respectively.

(i) The engine section is now engaged in research on how to measure the characteristics of exhaust gas from gasoline engines in use, measurement of the performance of exhaust gas control systems for motor vehicles, and generation and prevention of toxic substances from engines and exhaust systems based on technical data obtained through experiments using actual motor vehicles and individual engines.

(ii) The measurement section is engaged in research on the measurement of NOx emitted from large diesel-engined motor vehicles based on technical data obtained through experiments using actual motor vehicles.

(iii) The fuel efficiency section is conducting research on how to measure the fuel efficiency of motor vehicles, how to mix fuel with alcohol for practical use, and how to reduce fuel consumption while motor vehicles are running, based on technical data obtained through experiments using actual motor vehicles and individual engines.

(iv) The traffic noise pollution section is responsible for research on the method of measurement and estimate of noise from motor vehicles based on technical data obtained through experiments using actual motor vehicles and anechoic chamber.

C. The traffic safety and nuisance research institute is also conducting research entrusted by other parties, providing technical guidance to other parties, and cooperating with the police and judicial authorities by providing them with the technical data that they need in performing their duties, in addition to its own research activities.

Remark: Originally scheduled for this issue, the 6th installment of "Maintenance and Repair of Motor Vehicles" has been postponed to the next issue No. 9, since partial revision of the law pertaining to it is now being made.

For further information, please contact:

In Japan;
Engineering Division, Motor Vehicles Department, Road Transport Bureau, Ministry of Transport, 1-3, 2-Chome, Kasumigaseki, Chiyoda-ku, Tokyo, 100, Japan

Phone: (03) 580-3111 Ext. 3112
Fax: (03) 581-1454

In Europe;
Takashi SHIMODAIRA
Ambassade du Japon
58, Avenue des Arts, 1040 Bruxelles, Belgique

Phone: 513-9200

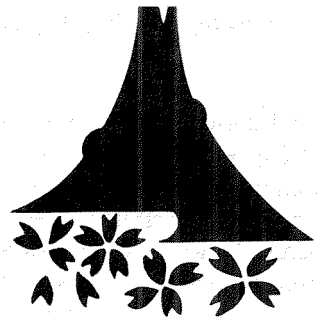
In the United States;
Sakae KOBAYASHI
Automobile Department, Japan Trade Center
1221, Avenue of the Americas, New York 10020

Phone: 212-997-0437/840-0267

Table 4. Standard for transportation method.

Item	Requirements
Place of handling	Handling in any place that is readily acccessible by outsiders should be prohibited.
Loading method	Loading and unloading should be done with adequate attention to safety. Loading operation in any place that is readily accessible by outsiders should be prohibited.
Prevention of critical state (Applicable only to nuclear fuel materials)	Under no circumstances should the radioactive substance be allowed to reach its critical state during transportation.
Restriction of mixed loading	Mixed loading of explosives and high-pressure gases should be restricted. Any material whose heat-radiating rate is higher than $15\,W/m^2$ should not be loaded together with other materials unless special measures are taken.
Limitation of radiation level for the container	Surface: Under 200 m rem/h; 1 m from surface: Under 10 m rem/h; Permissible surface density should be restricted.
Transport index	Calculation method of transport index should be specified.
Labeling or indication	Labeling for transported goods, indication of "Full load", indication of type (such as type A or type B), indication of the "Full load" for type B material should be specified.
Limitation of load	Total transport index per vehicle should be under 50.
Permissible radiation level for vehicle	Surface of vehicle: under 200 m rem/h, 1 m from surface of vehicle: under 10 m rem/h, driver's cabin: under 2 m rem/h.
Labeling related with vehicle	Vehicle labeling should be indicated on both sides and rear of the vehicle.
Documents concerning the handling to accompany the material to be transported	Documents indicating the kind, quantity, handling method, cautions and measures to be taken at the time of accident should accompany the material to be transported.
Shift driver	In case the material has to be transported over a long distance or during nighttime, a shift driver should be provided in order to prevent driver fatigue.
Guard	Parked vehicle should be watched by a guard.
Measures to be taken in transporting type B(M) transported goods	In transporting type B(M) transported goods, radiation detector, protective devices and specialist should accompany the material to be transported.

CONFERENCE CLOSING



Closing Remarks by the Head of the Japanese and American Delegations at the Ninth ESV Conference

NORIYOSHI UNO
Director-General of Traffic Safety and Nuisance Research Institute, Ministry of Transport

The Ninth ESV International Technical Conference is about to come to a close. The Conference has been a great success, and, as the representative of the sponsoring country, I should now like to add a few words of my own.

This is the second time that the ESV conference has been held in Japan. The first was in March 1973. All Japanese involved in automobile safety technology have been most happy to sponsor these two conferences. The technical results brought about in the context of ESV Programs to date have become the common property of the automobile industry, research laboratories, and government organizations throughout the world. Some of them have been incorporated into the design of mass-produced automobiles, with the result that mankind now enjoys the benefits of the motor car with increasing safety. Accompanying the development of motorization, the safety and anti-pollution requirements made on automobiles are growing ever greater; particularly noticeable is the development of technical innovation in the automobile industry with both specific safety technology and testing methods becoming ever more complex and advanced. Indeed, I believe that it would be no exaggeration to say that without international cooperation it would be virtually impossible for any individual country to carry out such research and to establish regulations entirely on its own. The purpose of this conference is to allow experts in the field of automobile safety technology from throughout the world to gather in a single place and exchange their various studies and findings in order to create a common awareness of the problems involved. This should make it possible to create an international concensus regarding the results of safety research and the fundamental data used in the establishment of regulations.

Technical sessions on a wide variety of themes have been held at this conference. In the field of biomechanics and dummy development, meaningful results have been obtained from new concepts. A significant exchange of opinions has occurred in such essential areas of research as the collection and analysis of accident survey data. A technical session was newly set up at this conference for the purpose of discussing automobile safety ratings. Problems from previous ESV conferences were discussed, and new points for discussion were identified.

I should like to express my warmest feelings of gratitude to the United States government, which has contributed so much to the sponsorship and success of this Conference. May I also take this opportunity to offer my thanks to all of you for coming to Kyoto and participating in this Conference.

Thanks must also go to the interpreters who have put so much effort into conquering the language barriers, and to those involved on the Japanese side in ensuring the smooth flow of conference proceedings.

Participants in this Conference will have had the opportunity to come into contact with the culture and customs of Japan, and I hope that this experience will have helped towards ever greater understanding of Japan. As I am sure you are aware, Kyoto is both the ancient capital of Japan and, at the same time, a modern city. It is an ideal city for coming into contact with the culture and customs of Japan. I should like to conclude these remarks by saying how much I hope that you will be able to find the time after the closing of this Conference to appreciate for yourselves the beauty of this city, in which the autumnal tints are now at their peak.

Lastly, the next ESV meeting is going to be held in the Spring of 1985 in the U.K. at the kind invitation of the government of the United Kingdom. I would like now to declare the Ninth International Technical Conference on ESV closed. I look forward to meeting all of you again at the next meeting.

Michael M. FINKELSTEIN
National Highway Traffic Safety Administration

As this Ninth International Technical Conference on Experimental Safety Vehicles comes to a close, we in the auto safety community again have tangible evidence of the benefit gained from our effort to seek solutions to our common problems. As we progress beyond the development of Experimental Safety Vehicles to the examination of the full range of vehicle safety problems facing us all, it is clear that our success to date in the ESV program must serve as a model for future cooperation.

Here in Kyoto, we have had four days of wide-ranging discussions of vehicle safety. We've heard and discussed papers of the highest quality; papers whose importance will grow as we have time to study them and incorporate these new findings into our own future research.

We would be remiss if we did not take this opportunity on behalf of Deputy Secretary Trent, Administrator Peck, and the entire United States delegation—I am sure I can say without fear of contradiction, on behalf of all of the conference participants—to express our gratitude for the generosity, hospitality, and remarkable efficiency of our Japanese hosts: the Government of Japan, the Japanese Auto Manufacturer's Association, and the Japanese Automobile Research Institute. Thank you all.