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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.
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SECTION 1
CONFERENCE OPENING

Introduction of the Secretary

HOWARD DUGOFF
Associate Administrator for Research and Development
National Highway Traffic Safety Administration and Chairman of the Conference

Ladies and gentlemen, may I, on behalf of the National Highway Traffic Safety Administration, welcome you all to Washington, D.C. We hope that your stay will be a most pleasant one.

I will perform as your Chairman for this Sixth International Technical Conference on Experimental Safety Vehicles, and as my first official function, I have the great pleasure and indeed the honor of introducing our keynote speaker to officially open the conference.

May I present the Honorable William T. Coleman, Jr., the United States Secretary of Transportation. Secretary Coleman—

Keynote Address

SECRETARY WILLIAM T. COLEMAN, JR.
Department of Transportation
United States

I am pleased to keynote this Sixth International Conference, on Experimental Safety Vehicles. It is a particular pleasure for me to welcome our guests from the nine nations that, along with the United States, are participating in this joint effort to produce motor vehicles designed for the maximum safety of their passengers.

It is appropriate that we begin this 4-day conference in the auditorium of our State Department. We think of a nation’s foreign policy as being concerned almost exclusively with national security and threats to world peace, and these proved, indeed, to be the prevailing issues of last Wednesday’s television debate.

But as I heard Secretary Kissinger point out, when I had occasion to be on a program with him in Philadelphia recently, two of the permanent goals of American foreign policy are the strengthening of relations with our international friends, and the attainment of a safer, more progressive world. Certainly the alliance of nations represented here and the purposes of this conference serve those objectives.

The automobile is the preferred means of personal transportation in all the industrialized nations of the world, unsurpassed for comfort, convenience, and all-round utility. For many years we have paid a heavy price—unnecessarily high, we are finding—for the privilege of enjoying the motor vehicle’s advantages. While we have waged economic, scientific, technological, and legislative war against other forces that damage our environment or endanger our lives, we have treated the car with tolerance and equanimity—fearful that efforts to correct its faults might cost us some of its benefits.

That time is past. This confederation of concerned nations was founded 6 years ago in common dedication to the principle that a safer car can be a better car, and in the growing universal acceptance of passenger safety as not only a valid but a basic criterion of automotive design.
But our concern and our efforts go further. The motor vehicle has become a major cause of air pollution, a source of urban congestion, and a heavy consumer of scarce energy resources. The number of motor vehicles in worldwide use now exceeds 300 million. In the next 15 years, in our country alone, we expect to add about 36 million more vehicles, most of them private automobiles, to the 140 million now on our streets and highways.

This proliferation of motor vehicles, not only in the United States but throughout the world, underlines the necessity and the urgency of the business that brings us together.

Unless the automobile is transformed—unless it is made more fuel efficient, less deadly, and more socially acceptable—its future, and the extent of our dependence on it for our mobility, may indeed be in jeopardy.

Fortunately, that transformation is already underway. Today's cars pollute less and are equipped with more safety features than their predecessors of a few years ago. Current models deliver better mileage than the 1975 models, which were significantly better than the 1974 models.

Hydrocarbon and carbon monoxide emissions have been reduced by approximately 80 percent in the 10 model years since emission controls were required by the Clean Air Act.

The prospects for further reductions in air pollution caused by automobiles are excellent, but in moving toward the desired national standard for nitrogen oxide emissions some caution is in order. In transportation, as in other areas, we sometimes encounter a conflict of good intentions. Modifying the internal combustion engine to meet emission restrictions, for example, resulted in an 11-percent reduction in fuel economy—a loss that our industry's designers and engineers have been trying to recover. Clean air is something we all want, but with the era of cheap and plentiful energy now behind us we must pursue our environmental goals in tandem with our energy conservation and fuel-efficiency objectives.

On that subject, the report issued last month by the Motor Vehicle Task Force of President Ford's Energy Resources Council indicated that the introduction of lighter weight, more efficient automobiles would more than offset the historical increase in automobile fuel consumption.

By the 1990's such changes could lead to a net reduction of up to 1.3 million barrels of oil per day as compared to 1975, even though automobile use is projected to grow by nearly 50 percent in that time period.

The report pointed out, however, that such fuel savings might not be attainable without some trade-offs in carrying capacity or acceleration and some compromise in terms of acceptable levels of exhaust emissions and occupant protection.

One of the functions of this assembly, through its member nations and their technical resourcefulness, is to prove that report wrong—to demonstrate that good mileage, low emissions, and passenger safety can coexist in an automobile acceptable to the public's taste and responsive to their motoring needs.

When the U.S. Department of Transportation first began investigating the feasibility of a safe vehicle (one that would protect occupants from death or serious injury in accidents up to 50 miles an hour) the products that emerged were designed to insure the survival of their passengers, but only at heavy penalties in comfort and economy. Moreover, the weight of the experimental cars tested raised questions about the fate of anyone in a conventional car unfortunate enough to collide with them. Thanks to the technical expertise represented here today, we believe we have learned to design cars that are not aggressive in a collision, and that afford added protection for pedestrians as well as passengers.

That eventual solution, of course, and the route we are taking in this worldwide Auto Safety Development Program, is to further expand our integrated systems approach to safety, and to devise a motor vehicle that combines energy efficiency, operating economy, and environmental acceptability with occupant safety. We refer to this as our S3E concept.

This approach has led to the two advanced state-of-the-art research safety vehicles developed over the past 16 months, mockups of which were unveiled at the Sheraton Hotel.
earlier today and will be on display as a part of this conference. These vehicles are being developed by the Calspan Corporation, of Buffalo, and Minicars Incorporated, of Goleta, California, to meet the Department of Transportation (DOT) design specifications combining low weight and good fuel economy with occupant protection up to 50 miles per hour in frontal crashes.

While the mockups on display at the hotel represent the tangible results of our research, and the construction and subsequent testing of the vehicles will show how well they perform, our research program is perhaps equally valuable for its less visible contributions to the cause of motoring safety.

For example, as a part of our Research Safety Vehicle program we are gaining a better assessment of the full costs of present-day traffic accidents. We are projecting trends of automobile use and growth, along with accident frequencies and severities, to 1985. We are conducting cost/benefit analyses of safety features, examining advanced engineering models of automobile structures and restraint systems, and evaluating the practicality of various design innovations for greater safety, economy, and damage resistance.

Perhaps most significantly, we are learning together, pooling resources, sharing and exchanging knowledge. We have learned a great deal in recent years from our European and Japanese friends about the fuel economy and urban utility of the small car. I am confident that the same skills that made the small car more popular can contribute much toward making it increasingly safer.

We are gaining, too, from a growing public comprehension that safety on the highways is a public as well as a personal responsibility. Ten years ago, when our National Highway Traffic Safety Administration was established as an agency exclusively devoted to the cause of motoring safety, people were driving themselves to death by the tens of thousands. In 1966, 53,000 persons lost their lives in motor vehicle accidents, a rate equivalent to 5.7 fatalities per 100 million miles traveled.

As a result of government regulations and the industry's response, the safer cars since produced have substantially reduced deaths and injuries.

In addition to the protective benefits safer cars have brought, the 55-mile per hour speed limit, introduced nationwide for fuel-conservation purposes, has had a significant and welcome effect on highway fatalities. In the 2 full years the lower speed limit has been posted, the motor vehicle death toll has dropped 17 percent. We estimate that at least half of the 9,000 lives saved in each of the past 2 years can be attributed to the lower, more uniform speed. Today's rate of 3.5 deaths per 100 million miles, therefore, means that from the inception of the Highway Safety Program in 1966 until the present time our combined efforts and programs have yielded a 40-percent reduction in the fatality rate in the United States.

These achievements suggest that the highway does not have to be a place of sudden and violent death. We do not have to accept a particular highway death toll as inevitable, or any fatality rate as "acceptable." We must continue to treat death and injury on the highway as we would any other national affliction—through aggressive research into the best means of prevention and corrective treatment of the causes.

The best long-term prospects for increased safety of the vehicle itself lie with the work of this international coalition and the contributions of those involved. Most of the "easy" steps in vehicle safety have already been taken. Such things as radar brakes and stronger but lighter materials are still some years distant.

For the short term, the best prospects for greater passenger protection would seem to depend on the public's willingness to use overt or inert restraint systems. Experience indicates that today's three-point safety belts would be highly effective—if more people would use them. It is our estimate that the annual death toll in the United States could be reduced by 13,000 if 80 percent of the drivers and passengers would wear their belts faithfully.

As you may know, I am now considering what action to take with regard to future motor vehicle occupant crash protection policy. One alternative is to seek Federal or State
laws that would make the wearing of safety belts mandatory, as other countries already have done. I can, as another alternative, require passive restraint systems on all new cars.

In weighing these alternatives and other options open to me, I am faced with the responsibility not only of dealing with such complex matters as technical feasibility, system reliability, and safety benefits and costs, but I must also judge the public acceptability for each action. For while there is greater agreement today that highway safety entails public as well as individual responsibility, there can be no doubt that there are limits to public acceptance of government actions to increase individual safety.

I will, however, make my decision on this matter and announce my recommendations before the end of the year. In the meantime, I strongly urge the continued efforts of all the partners in this international safety consortium to seek out those technical, attitudinal, and motivational forces which will enhance the safety of our motor vehicles, of those who operate them, and of all those who ride in them. I also encourage your active participation as we work together on new initiatives to integrate safety, efficiency, and social acceptability into the total vehicle system.

This venture is indeed worthy of international cooperation and the combined resources of government and industry. I look forward to the status reports on experimental safety vehicle progress, and hope that our current accomplishments prove to be but a prelude to still greater gains in motoring safety.

I welcome you to this conference and wish you much success.
Status Report on Experimental Safety Vehicle Development Programme

J. W. FURNESS
Director/Chief Mechanical Engineer
Department of Environment, TRRL
United Kingdom

At the Fifth Experimental Safety Vehicle (ESV) Conference in 1974, the importance of low capital costs, economies of operation, and availability of energy resources, as well as vehicle safety and environmental matters, was rightly emphasised. The demand for relatively lightweight, low-cost vehicles that have low fuel consumption and low exhaust emissions was stressed not only for developing countries but for major European and North American markets as well.

The British Government's car safety programme began with the development of component systems that would be suitable for early incorporation in production cars. The programme followed many years of research work and took account of the need not to unduly increase the weight of vehicles and, hence, costs. It deliberately chose vehicles in the 860-1 300-kilogram (1 900-2 800-lb) weight range having engines of 1 000-1 800-cc capacity. Vehicles of these sizes are in common use throughout Europe and many other parts of the world. Such vehicles have a relatively low fuel consumption that is usually well within the proposed American target of 30 mi/gal. The British programme has not concerned itself with cars in the 1 360-1 800-kilogram (3 000-4 000-lb) category.

The British programme of work since the last ESV conference in 1974 has therefore continued primarily on safety matters. Papers to be presented at this conference indicate our latest studies. It will be noted that car occupant safety in side impacts and the need to design the fronts of cars to minimise injuries to pedestrians in the event of impact have been given prominence. In many countries of the world the number of pedestrians injured demands that urgent attention be given to both the above subjects. We believe that the front bumper should be below the current American legal requirements and at a height compatible with the height of car door sills; this would lead to front end designs in which impact injuries to pedestrians would be minimised and the severity of injuries to occupants of cars involved in side impacts would be lessened without the need for heavy reinforcement of car doors.

Accident investigations continue to play an important part in the British programme. Data are being collected and analysed, and efforts are being made to get more representative samples from different parts of the country. There is a general consensus that changes to the design of the steering and braking systems of European-type cars would play virtually no part in reducing accidents. Automatic levelling of headlights and improved performance from dipped headlights could possibly reduce dazzle and help driver convenience and comfort and may tend to reduce nighttime accidents. The number of injuries to car occupants involved in accidents in Britain has decreased in the past 2 years.

The use of seatbelts in cars has increased during recent years, and this has encouraged the development of better and more comfortable seatbelts. These belts are mostly of the three-point lap-and-diagonal type equipped with emergency locking retractors. No developments towards the fitting of airbags as possible restraint systems are contemplated. At the last conference we referred to a
new type of windscreen glass known as “Triplex Ten Twenty,” which has been developed with the intention of minimising the lacerative effects to car occupants caused by laminated screens if broken in accidents. This type of windscreen is now offered as standard equipment on at least one type of British vehicle. The “run flat” concept of tyre and wheel equipment was referred to in our presentation at the last conference. This development was intended to abolish the need for a spare wheel and tyre to be carried on each vehicle and to provide greater luggage space and less weight. The “run flat” tyre equipment is advantageous in minimising loss-of-control accidents in the event of a sudden puncture and is considered worthy of further attention. Run flat tyres, although expensive, are currently being offered as optional equipment on at least four different types of British vehicles.

Close collaboration between British and other European governments continues under the auspices of the European Experimental Vehicles Commission (EEVC). Work is about to commence on improved procedures for impact testing utilising performance standards that can be related to available biomechanical data and real-life accidents. The merits of angled or overlapping frontal impacts will be considered, as will the merits of utilising the British Occupant Protection Assessment Test (OPAT) and Transport Road Research Laboratory (TRRL) dummies for legislative test work. So far, this latter equipment has been used very satisfactorily for side impact tests.

The British car safety program has shown that worthwhile improvements in safety and convenience to car occupants are feasible without the need to significantly increase vehicle weight or costs and without lowering environmental standards. Demands for additional material and energy resources can be minimised or avoided if the demands for improved safety are kept at reasonable levels. The benefits or disbenefits of any safety feature cannot be effectively demonstrated until significant numbers of vehicles made to the new standards are in existence on the roads. Some vehicle manufacturers are already voluntarily meeting some of the levels of safety performance advocated in the ESV conferences, but legally agreed requirements are necessary in order to embrace all vehicles.

The United Kingdom is more concerned about getting realistic standards that relate to the real-life accident situation than to the achievement of technological breakthroughs. For instance, an important feature of impact testing for occupant protection is the question of the appropriate test speed and the selection of realistic human tolerance limits that together determine the safety performance. We believe the time has now come to attempt to agree on worldwide regulatory standards for vehicle safety. It is suggested that this might best be achieved through the auspices of the United Nations Economic Commission for Europe (ECE) Organisation. All the major vehicle-producing countries of the world participate in this forum. The United Kingdom’s first priority in such work would be to establish safety requirements for the front ends of cars to minimise pedestrian injuries and reduce the severity of injuries to car occupants in side impacts. As stated earlier, positioning the front bumpers where they would align with the heights of door sills seems to merit urgent consideration.
unquestionable merits for being a determinant stimulus in implementing safety studies and for giving life to a highly appreciable form of fruitful cooperation on an international level. It was also pointed out that the hypothesis of a constructionally safer vehicle would not necessarily provide the complete, final answer to the complex problem of effectively guaranteeing globally safer vehicular traffic. This, of course, implied the extension of investigations to other numerous and important fields.

Other views underlined on those occasions were the close relationship between the vehicle and its environment. No effort was to be spared in insuring an increasingly narrower margin of disturbance that the vehicle, especially when irrationally used, often causes through certain objectionable inherent manifestations such as noise or other polluting emissions.

Also stressed at that time was the existing interdependence between the study and the test plan prepared for the ESV program and the need for putting into practice the results obtained, once they could be suitably adapted to volume production requirements. It was then said, and factual confirmation is now at hand, that scoring such targets would be a task left to the international organizations involved, such as the Economic Commission for Europe (ECE), United Nations Organisation (UNO), and European Economic Community (EEC) agencies, whose terms of reference no doubt include the issuance of updated technical standards. The circumstances that came about and the subsequent developments confirm the substantial correspondence of such basic views and their doubtless effectiveness.

The significance of the aspects considered above imposes a deeper discussion. Before going into this, however, I will now briefly outline the results of the experiments and research work conducted by our national industries and the Ministry of Transport, either directly or through specialized agencies.

With regard to active safety, phase I of the life-sized model wind tunnel test program has been concluded. The program was aimed at determining the behaviour of vehicles with different body configurations when exposed to sidewind gusts. The target set for this task was the evaluation of the effects of this dangerous, perturbing factor on vehicle directional stability. Representative vehicle behaviour parameters were identified and measured. Road tests, further wind tunnel work, and the use of a suitable mathematical model will allow integration of the study.

Some information was released at the London ESV Conference on the advanced stage of the research and test work then being conducted on a stop light system featuring single intensity level and a variable illuminated surface area. This system, though non-dazzling at night, would be capable of providing an effective and safe daylight signal whose progressive lighting feature would be directly proportional to vehicle deceleration. One prototype device, installed on a series-produced car, was shown during an ECE meeting held in Rome in the fall of 1974. It is our intention to further investigate the matter and to determine the practical application of such a device.

During earlier conferences, reports were made on the investigations by Istituto Sperimentale Auto Motori (ISAM) on the effects of vehicle vibrations on the human body. These investigations were sponsored by the Ministry of Transport. A summary report was recently forwarded to all the European Experimental Vehicles Commission (EEVC) member countries and agencies (EEC) attending the committee meetings as observers.

Regarding research work on passive safety, the Ministry of Transport, in cooperation with Fiat, began work on the possibilities offered by an energy-absorbing, sliding seat. The technical specifications were illustrated in London, 1974. ISAM is now continuing those studies and is also engaged in the design and construction of a seat incorporating special physiological and safety features. Because this research effort is still in a preliminary stage, it is not yet possible to release any details, except that its primary final aims are:

- A structure that will allow for maximum comfort and correct limb position, even as a function of the reaction time needed in emergencies (active safety)
- A structure that, in case of collision, will effectively restrain the occupant in the
original position while at the same time absorb the largest possible amount of inertial energy released in the impact (passive safety).

With regard to the research work carried out by the industries on their own, I must mention that Alfa Romeo has further implemented its investigation of the behavioural performance, in front-end offset collisions against barriers, of some car types characterized by different mass, structure design, and crush rates, though still falling under the specification packages typical of European cars. During this research, the consequences to occupants were the object of a comprehensive analysis; also considered were the more suitable energy systems as well as the absorbing active/passive restraint systems (protective safety).

A study was also made of the effect of crosswind on vehicles. To this end, the actual behaviour of the driver-car system and the definition of a mathematical model that generalizes the experimental results were taken into account. The study covers driving on a straight course, cornering, and overtaking. The major car dynamic parameters are evaluated in relation to the different driving modes and driver's ability. The results obtained so far appear to provide appreciable indicative data to insure concrete vehicle improvement with regard to preventive safety. Fiat is carrying on the study on vehicle compatibility in the event of collisions, with due consideration being given to different vehicle size, mass, and shape. The purpose of the investigation is also to highlight the damage liability of a struck vehicle and the aggressiveness of the striking vehicle. It should, however, be pointed out that a reliable evaluation of such characteristics requires more sophisticated collision tests than those presently carried out. On this problem, Fiat has been developing a systematic analysis aimed, among other things, at correctly identifying the exact terms of the problem and the best evaluation methods.

At any rate, as far as progress achieved by the Italian industry in the specific area of research is concerned, more ample and in-depth information will be provided with the papers to be presented on Wednesday, October 13—and during the concurrent seminars. In this connection, in the course of the Biomechanics Seminar, a study will be presented whose scope is to assess the human tolerance data obtained from experience in sporting activities. Having exhausted this review, I think it is desirable to resume the considerations formulated earlier.

It has been stated that it is impossible to deny the influence that the ESV and Research Safety Vehicle (RSV) programs have had in the field of automotive safety.

Even those less concerned with the events in the automotive world cannot fail to realize the slow, almost unnoticed but at the same time growing consciousness regarding automotive safety problems among the users and manufacturers. Even advertising by motor companies repeatedly highlights those active and passive safety requirements that the public expects to find in marketed vehicles. As proof that 7 years of study and research have not been in vain, we can now see with satisfaction that the vehicles presently rolling off the assembly lines generally incorporated a great number of construction improvements.

Conversely, there is no doubt that this specific theme cannot be completely exhausted by simply assuming that the vehicle structure embodies the maximum safety potential offered by engineering advances. It has often been said that many factors must agree to reach a desired goal. This has been recognized by the members of the Committee of the Challenges of Modern Society (CCMS) program who have examined other important elements, such as pedestrian safety, accident analysis, and actions taken after an accident. In our opinion, it is from this general standpoint, of which the environment represents the major element, that the problem must be considered. Quite evidently, the advantages of safer mobility must not be offset by greater exhaust emissions, which would further deteriorate the environment.

By now we know that along with the violent deaths caused by many vehicle accidents there is a slow death from the deep disturbance of the environment caused by traffic pollution. It is for this reason that Italy promptly joined the ESV program, and was
ready to underwrite the multilateral agreement on polluting emissions that was later to include research on noise pollution. (It should be mentioned that the energy crisis has added another undesired element that has rendered the safety problem more complex inasmuch as it involves implications and repercussions that cannot always be dealt with along the same line.)

The philosophy behind the safe vehicle program has therefore broadened its boundaries and shifted the ideal acceptance index toward a type of vehicle whose performance meets many diversified and new requirements. Of these, the safety requirement is the most important.

It has already been pointed out that current auto production is taking advantage of the results obtained from the ESV and RSV programs. Some new models have incorporated structural solutions that, as research has shown, improve passive safety. Even more worthy of note is the influence exerted by such investigations in the past few years on national and international engineering regulations.

The ECE and several EEC directives have approved a number of international regulations. A high percentage of them are based on well-known concepts that, after having been tailored to the yearly output requirements of millions of vehicles, materialized thanks to the ESV and RSV programs.

The main target of the informative principle of the regulations is to keep pace with the technical evolution in safety without disregarding the likely economic consequences.

Among the EEC directives included in our own regulations, some concern active safety (steering wheels, rear view mirrors, braking systems, and so forth), while others cover protective safety (fuel tanks, interior and exterior fitting, doors, protection from impact against steering wheel, seat anchorage systems, and safetybelt attachment hardware). Other regulations relate to environmental protection and establish limits for noise levels, emissions, and radio disturbances caused by spark-ignited engines. Domestic legislation shortly will include requirements on safetybelt certification and their mandatory installation, tire certifi-
EXPERIMENTAL SAFETY VEHICLES

1. Identification of the more qualifying problems, based on the statistical analysis of accidents
2. Simulation by laboratory tests
3. Design, development, and experimentation of modifications to current construction criteria, based on test results
4. Evaluation of benefits obtainable through the adoption of relevant standards

With regard to point 1, it should be realized that no generalized, uniform system exists for the acquisition and correct interpretation of the data obtained from accident analysis; therefore, the exchange of information between countries and the various agencies dealing with the analysis appears to be difficult to accomplish.

An important pilot study by CCMS on road accident analysis has never found any practical application, in spite of the work done to arrive at a satisfactory, systematic approach to the problem. In our view, this pilot study deserves to be reconsidered.

Furthermore, it should be noted that, on the serious and important problem of the accidents involving pedestrians, remarkable uncertainties exist regarding what can actually be done for pedestrian protection. From the bibliography on this subject it still appears to be debatable whether a pedestrian would suffer more severe injuries from impact against a vehicle or against the ground.

It should also be noted that, while detailed and specific information on biomechanics is available, a basic approach and the formulation of clear guidance principles are lacking. Tolerance levels are still being discussed and their basic parameters and classes of subjects have yet to be defined.

As far as point 2 is concerned, legitimate questions have been raised regarding the representativeness of the frontal collision test (against a rigid, perpendicular barrier) versus actual accidents on the road. Also the reliability of the oblique barrier test is still being debated. On the other hand, the frontal, lateral, and pedestrian collision tests reveal the fundamental need of basing the tests on compatibility criteria. Unfortunately, this matter is still in the initial stage.

As regards point 3, the possibility of a correct evaluation of protective effectiveness lacks an essential element, namely, the availability of a suitable dummy. The difficulty lies in establishing the characteristics of a dummy that would permit the measurement of unknown tolerance levels for the different unknown parameters and yet be representative of human behaviour.

Finally, in regard to point 4, it must be stressed that the research accomplished to date, particularly with regard to test methods, does not allow for sound evaluations of the effectiveness of future regulations. This is especially true as our knowledge increases and previous assumptions are reevaluated, as also evidenced at the 1975 San Francisco Conference.

It should be clear that, although mention was made of some deficiencies in the setting up and development of the research program on safety, this should not detract from the merits of the program, inasmuch as the applied research it encouraged and aided considered every possible safety-related detail.

The data and valuable indications yielded by this effort were not shelved. Through practical application they have already exerted a positive influence on some major aspects of mass production and are considered a sound guideline for rulemaking. The work done so far is not flawless, but the unveiling of truth requires relentless, patient, and tenacious effort, particularly in the progressive field of science.

In conclusion, this conference should be the starting point for the formulation of a vehicle safety work program that would be viable for the cars of the 1980's and later, and reasonably compatible with current possibilities and especially with present difficulties. We think that some themes, though still within the boundaries of an organic and realistic development of the RSV program, deserve particular attention and should be treated preferentially. Among these, for instance, the problem of compatibility and biomechanics (although not yet clearly defined) must be included today in the larger scheme envisaged in the comprehensive S3E concept. It is in this direction that the future efforts of the RSV program should be aimed.
It seems that events have led us to the end of a cycle that, on the whole, was full of initiatives and intuitions and yielded good results. Another cycle has started in which the safety problem has taken on a position and size that go beyond the initial objective, focused essentially on the vehicle as if it were separate from its surroundings.

A short pause and some meditation would seem desirable as they would permit a careful and necessarily critical evaluation of past work; new targets could be set aimed at attaining more accessible goals. These would perhaps be less ambitious than the ones initially set; nevertheless they would meet the primary requirement of making available to man vehicles that are safe and not aggressive, reasonably priced, not damaging to the environment, and reasonably economical to operate. Any further research and development efforts should be responsibly backed. The present recession demonstrated—in spite of hasty and pessimistic predictions—that the automobile is far from being doomed, and that its instrumental role in societal progress and welfare goes beyond individual mobility. Hence, it must be rightly judged as irreplaceable and must not be condemned.

Status Report

MICHEL FRYBOURG
Directeur
Organisme l'National de Securite Routiere (ONSE R)

International cooperation in the field of highway safety includes many aspects. Its dynamism stems from the importance of the stakes involved and the broad circulation given to information on research results.

Public financing has made it possible not only to get university and government laboratories to work on this subject, but also to strengthen the research teams in industry in return for the publication of their results.

The Experimental Safety Vehicle (ESV) conferences allow for a review of research work conducted in the field of vehicle technology, with special attention to passenger protection.

In France, research topics are chosen after broad discussion and periodic calls for ideas, after which research contracts are drawn up, with shared financing whenever the contracting party is a business enterprise. A scientific committee assesses the proposals and evaluates the research results. These research activities are organized on the basis of priorities set by public officials, and are designated in France by the expression "programmed thematic actions." It is called "thematic" because the objectives for research or themes are set by the funding administrator, and "programmed" because the operation fits into a several-year program which guarantees the continuity of efforts leading to the objective being sought.

The objective in this case is to contribute to improving the safety performance of vehicles on the road. This implies, first of all, that such performance can be assessed objectively, and then that the additional cost for improvements can be borne economically without penalizing the car manufacturers who would include them in their products.

That is why we, in France, have always thought that an effective research policy would necessarily rely on three converging activities:

- An in-depth analysis of real accident data to be able to objectively assess the vehicle performance levels; this is the field of accidentology and biomechanics
- A systematic study of possible technological improvements in vehicles, dealing with both structure and restraint devices, as well as other safety equipment
- Traffic regulations that would gradually integrate the results acquired so that road users could benefit without delay from the progress achieved and treat manufacturers equally for competitive purposes

All time lags or discrepancies in the performance levels sought for can only result in waste or, even more serious, in the loss of credibility for this type of operation by
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public officials. It would be all the more regrettable inasmuch as the so-called ESV program elicited a great deal of international hope at the outset, as witnessed by the international consensus of opinion it led to.

It is indeed hard to see why one would seek to modify vehicle structures in ways that would not correspond to the most frequently encountered accident characteristics.

It is equally hard to see why one would strive to establish rules whose validity would not be supported by research in progress, or why one would postpone the possibility for the car manufacturers to make those vehicle modifications whose value had been proved.

To illustrate this statement while remaining in the field of research, we shall provide details on three operations connected to each of these activities—accident analysis, technological progress, and regulation support.

A photographic library has been called upon to complete the facilities available for accident analysis. It seemed to be the swiftest way to determine the violence of impact in real accidents.

The first priority in technological progress was oriented towards the improvement of vehicle structure for the protection of occupants in the event of frontal impact, and was based on the analysis of the behaviour of structures absorbing energy in an impact.

Finally, the design, construction, and testing of synthesis vehicles make it possible to back up regulation-making activities by demonstrating that it is feasible to make modest-sized vehicles, under acceptable economic conditions, that satisfy rules of the type suggested by the European Experimental Vehicles Committee (EEVC). France agrees with the work of the EEVC, and in July 1975 proposed that the European Economic Community (EEC), using this work, draw up as soon as possible the vehicle secondary safety regulations to be applied starting in the 1980's.

To complete this status report, the other research work in progress will be referred to briefly; whereas fuller details are provided in the biannual reports we publish as part of the cooperation agreement.

THE PHOTOGRAPHIC LIBRARY OPERATION

Knowing the nature and violence of the impacts to which vehicles and occupants are subjected during road accidents is a top priority objective for safety officials in charge of drafting vehicle regulations. The impact tests chosen for approval purposes must actually be sufficiently representative of real impacts and must cover a sufficient fraction of the cases involved for the safety of occupants to be assured under acceptable conditions.

Several approaches are possible to gather this information. One consists of using a "black box," an accident recorder that would be fitted onto a large number of vehicles, which could then be recovered and analyzed after an accident. Another approach is to establish what, in France, is called a photographic library of controlled impacts. This library is made available to specialized investigators who are part of teams devoted to in-depth studies of a sample of highway accidents.

The first approach is technically feasible even though it requires major perfections, but it appears, a priori, to be more expensive than the second one and requires that a considerable amount of time be spent in field observations. The second approach, albeit less accurate, has the advantage that it can be established progressively and at much less cost. More precisely, the photographic library allows a trained observer to note vehicle damage after a real accident by referring to a series of photographs showing damages caused by impacts against standard obstacles at known speeds for the same vehicle brand.

The standard obstacles used for the moment include walls, poles, or movable barriers struck in a limited number of configurations. When the vehicle has struck an undistortable obstacle in the real accident whose violence is to be determined, examination of the photographs in the library makes it possible to know directly by interpolation or extrapolation what was the speed at the moment of impact as well as the permanent deformation of the vehicle. From that, the two main parameters for the impact felt by
the occupants—the change of velocity and the average deceleration—can be easily deduced.

When a vehicle strikes an obstacle that can distort in a real accident, the estimation of these parameters necessitates having a relatively low amount of energy dissipated after the impact and knowing the amount of deflection of both participants in the impact. When a collision involves two vehicles, use of the photographic library makes it possible to know, for each vehicle, the equivalent speed for an impact against a stiff fixed obstacle with the same deflection as that observed in the field. Knowing the mass of the two vehicles and the closing rate of their centers of gravity after deflection makes it possible to go from this equivalent speed to the real speeds involved at the moment of impact, and hence to determine the change in velocity and the average deceleration for each vehicle.

This theoretical procedure has been tried out on a dozen real accident cases examined by five separate teams. The outcome shows that the method is satisfactory in its application to front-front or front-rear impacts. On the other hand, for side impacts, it appears that the reference impacts with movable barriers do not provide sufficiently realistic deflection data to be used at the present time. Consequently, the decision was made to set up a photographic library for frontal impacts and to look for new ways to handle side impacts.

**PROTECTION OF OCCUPANTS IN THE EVENT OF FRONTAL IMPACT**

**The Structures**

Research work has first of all dealt with the assessment of the behaviour of quite different existing structures during induced accidents by varying the impact conditions; that is, the type of obstacle, the incidence, and the velocity. Along with these studies, theoretical and experimental research has been carried out on the behaviour of materials and elementary structures at high deflection speeds.

The results of these studies have made it possible to move on to the next step, which is the most important one, involving the protection of occupants. Theoretical work has been done dealing with the relationship during an accident between the behaviour of the structure and the means of restraint.

The conclusion is that it is possible to build the front-end of private motor cars that can provide a satisfactory measure of protection for impact conditions that are representative of the largest number of real accidents, while keeping within acceptable price and weight increase ranges.

**The Means of Restraint**

This research has dealt with the theoretical analysis of the parameters that determine the effectiveness of various means of restraint, particularly seatbelts, such as the time lag between the beginning of a collision and restraint action, the stress increase law, and the way this stress is applied.

Technological progress has essentially emphasized seatbelts and padding materials. This progress is allied to that achieved in structures, and the potential for further improvement of seatbelts enables one to expect that this means of restraint may prove yet more effective under impact conditions more severe than those used by the EEVC.

**Impact Speed and Angle**

In France we think we have acquired a good understanding of frontal impact, so the test conditions that we recommend in support of vehicle regulations, especially the impact speed and angle for frontal impacts, are not determined by technological limitations.

If they are less strict than the specifications for ESV, it is not because we do not know how to go about it but rather because we are looking for the right level of representivity of accidents and the best cost/effectiveness ratio.

**THE NEED FOR A SYNTHESIS VEHICLE**

Private research with experimental vehicles has already been carried out—there is the V.S.S. Peugeot and the B.R.V. Renault. The latter has been tested in America within the
framework of the bilateral agreements. The results of these tests will be given during the seminar on vehicle structure; however, none of the test requirements complied with the guidelines set forth by the EEVC. They were conducted as feasibility studies of the highest possible performance levels without any concern for rulemaking. The vehicles are therefore heavy and expensive, and consequently have a debatable cost/efficiency ratio. In addition, the vehicle performance levels were not connected to the statistical weight of each risk, especially for rear impact, and the vehicles were built to fit into the middle or upper weight category.

The French will, therefore, try to make sure that all the quantitative performance objectives for secondary safety indicated by the EEVC in London in 1974 are achievable in their synthesis vehicle despite cost increases and performance losses in the other fields (noise, pollution, fuel consumption, acceleration, road adherence, and so forth) that are relatively acceptable.

Two contracting parties have been chosen: one is working on the strict objectives of the EEVC while the other is using somewhat higher goals. This will make it possible to set figures for the differences in the weight, price, and evolution of the automobile as a product and as a function of the performances offered.

This type of program is worthwhile only if it seems to demonstrate the value of regulation proposals that are socially effective and economically justified.

The analysis work is not yet finished. Some progress has been achieved, but further research must be carried out. The problem is a complex one since many parameters are involved. A method identical to that for frontal impact is being used.

Work is currently at the following stages of development:

- Structure: It is likely that structures will have to be reinforced, but at the present time nobody knows with sufficient accuracy just where (floor or door) or for what performance level.
- Protection of vehicle occupants: It is certain that padding will be required to limit occupant acceleration, but it would be premature to take a stand as to the performance level required for the compromise that would be desirable between the resistance of the structure and the padding dimensions.

Protection of Vehicle Occupants in Urban Impacts

A study underway is examining the protection of occupants in urban impacts by using passive protection devices that would offer a valid alternative in city traffic to wearing safety belts. In view of the lesser severity of such impacts, the wise use of packing and inside refinements should provide notable improvements. Protection is provided by:

- The floorboard, which will be adjusted in packing, form, and inside finishing to protect the lower limbs
- A deflectable windshield, which resists jagged breaking and absorbs energy for head restraint
- A protection device built into the car shell for the rear passengers

One solution demonstrating this device was fitted onto a vehicle that may now be viewed in Washington, and it would be acceptable for speeds still higher than those reached in urban impacts.

Vehicle Aggressiveness: Pedestrians and Children

Research has been conducted on difficult topics such as the protection of struck pedestrians, the compatibility amongst vehicles, and the protection of child vehicle occupants. On this last point, the work has resulted in a proposal for a control test method, a French quality label of a new type, and in the design of a safety seat for children under 4 years of age.

The programmed thematic action entitled Vehicle Safety has progressively been extended to the problems of trucks and then to two-wheeled vehicles, which we shall not mention here.

To conclude this status report, the following remarks may be made:
The research approach being used appears to be fruitful and the results are numerous and promising.

International cooperation and the publication of results meet with the objectives that were set at the beginning of this program: encouraging emulation to help the community of motorists rather than competition based on commercial arguments without scientific bases. To be sure, automobile manufacturers do not have the means to set up separately the database required to acquaint them with real accident circumstances and human tolerance levels.

But the promising results achieved will yield a final concrete form only if policies and rules adjust rapidly to take account of the knowledge acquired.

The indispensable dialectic between action and thought gives action the support that puts it at the service of the general welfare, and gives thought the outlet that supplies it with meaning.

**Status Report of the Federal Republic of Germany**

H. PROF. DR. HEINRICH H. PRAXENTHALER
President
Federal Highway Research Institute
Federal Republic of Germany

I have the honour to present to you, on behalf of the Federal Republic of Germany, the status report of the Government.

By way of introduction let me point out to you that, in the Federal Republic of Germany, a pronounced consciousness of safety in automotive engineering developed rather early. It originated both from the industry's fully realising its responsibility and from the system of statutory uniform technical inspection of motor vehicles that had already been introduced in the early stages of mass motorising. In the late sixties, when technology in the United States was urged to considerably improve car safety—we still look with admiration upon that uncompromising course of action despite all resistance and attacks—the obvious thing for the Federal Republic to do was also to respond to that appeal and early on take an active part in the development of safety vehicles. The results of these efforts have been described and discussed in detail at the previous Experimental Safety Vehicle (ESV) conferences.

On the basis of the experience gained, specifications were drawn up in the course of continuing development, and lesser requirements, particularly regarding impact speeds, were formulated. The second ESV generation built according to these specifications was presented, as you all know, during the last conference in London.

In our opinion, what has been accomplished so far may be summarized as follows:

While the prototypes have impressively demonstrated the technical possibilities of accident protection, there is, on the other hand, general agreement that this conception goes beyond commercial boundaries and, in the end, exceeds national economic possibilities. The term "Experimental Safety Vehicle" is valid because the real gain of the major program lies not in the construction of prototypes but in the results of exhaustive experiments carried out with great effort. A great many extremely valuable findings were and still are being perceivably or imperceptably incorporated in the design work of motor car manufacturers as well as into the work of administrative bodies. On the other hand, the gaps of knowledge have become apparent; we know the areas in which crucially important fundamentals are still lacking and where intense research must be carried out. But this complex of problems has also gained two new dimensions: the question of the use of raw materials and energy in view of the world energy market and the worldwide endeavor towards the maintenance of a livable environment. We therefore consider the project of the Research Safety Vehicle (RSV), which was initiated quite some time ago, to be the consistent continuation of the ESV idea. In
the first phase of this project, which ended in 1975, a German contribution was provided. It is with great expectation that we are now looking forward to the outcome of the second phase of this project, to be presented at this conference.

In connection with the ESV activities, the German Federal Government has again and again emphasized that, in its opinion, the appalling accident rate cannot be reduced without a well-balanced package of counter-measures in the areas of engineering, education, and enforcement. Along these lines, in 1973 the Federal Government presented its comprehensive traffic safety programme, which summarises the numerous and manifold efforts made to improve highway traffic safety. Based on the relatively favourable trend in accidents during the past 3 years—the number of fatalities fell from 19,193 in 1970 to 14,849 in 1975—the Federal Government finds the encouragement to pursue this course of action with determination.

Therefore, may I ask you to bear with me while I briefly report on recent measures and activities in the field of traffic safety in our country.

Apart from the wide range of emphasised activities in the field of traffic education and traffic information, the following measures, provisions, and regulations should be mentioned:

- Since January 1, 1976, every front seat occupant has been obliged, by law, to use seatbelts. In taking this measure, the Federal Government fully recognised the globally acknowledged fact that seatbelts provide effective accident protection. A major topic in the discussions that preceded this decision was whether a requirement to use the belt would be consistent with constitutionally guaranteed personal freedom. One weighty point in favor of statutory obligation was the fact that in case of accident, the belt would serve not only for self-protection but also for the protection of other road users. However, not using the belt is not punishable by law in the Federal Republic. The reason for this regulation is mainly that older passenger vehicles at present do not have to be equipped with belts; furthermore, there is also a general principle guiding us in our endeavours toward achieving traffic safety, which allows as much latitude as possible without threatening or imposing penalties so that the citizen may develop the greatest possible sense of responsibility.

Present belt-use rates (related to vehicles equipped with belts) are: about 75 percent for motorways (Autobahn), about 60 percent for rural highways, and 40 percent for urban areas. Continuing efforts are aimed especially at increasing these belt-use rates and technically improving the seatbelt systems; in this respect, the emphasis is on correct functioning and comfortable handling.

- As the result of a large-scale experiment lasting over 3 years, a speed limit of 100 km/h was introduced on January 1, 1976, for all roads with less than two traffic lanes in each direction. The results indicate that there had been an apparent relationship between the speed limit and the decline in accidents without detecting any major deterioration in the level of service.

- In March 1974, a general 130-km/h recommended speed limit on motorways was introduced by regulation. In conjunction with this, a large-scale experiment on selected sections of motorways is now being carried out to study the effects of a strict 130-km/h speed limit. The comprehensive research concept is to examine the differences between a recommended speed limit and a strict speed limit in terms of accidents and traffic flow. The results are expected to be available in 1977. They ought to provide a decisionmaking aid as to whether or not a general maximum motorway speed limit should be introduced.

- Effective as of January 1, 1976, the following provisions have come into force:

  - obligation to use the turn signal at the end of an overtaking maneuver
  - obligation to use the hazard warning signal for school buses when children are alighting or boarding
  - prohibition against children under 12 years of age on the front seats of passenger motor vehicles
— the gradual equipping of all passenger motor vehicles registered after April 1, 1970, with seatbelts
— obligation for motorcyclists and passengers to wear protective helmets

Finally, we should also mention that the Federal Government, in a comprehensive study, is looking into the question of whether a general obligation to install headrests on the front seats of passenger motor vehicles should be provided by law. According to the results obtained so far, there is no controversy about the protective effect of headrests; on the other hand, headrests of current design do show, at least in a number of present-day motor vehicle types, various disadvantages. Consequently, an obligation to install them is not being considered for the time being.

As to the most suitable type of glass for windscreens, laminated safety glass is being compared with tempered safety glass. So far it appears that—especially in view of the obligation to use seatbelts—neither of the two types of windscreens show such crucial disadvantages that installing them would have to be banned.

Related to the objectives of the RSV project are efforts made by the Federal Government to reduce the environmental impact produced by motor vehicle traffic. By 1980, the pollution emissions by motor vehicles with Otto (controlled ignition) engines is to be reduced to one-tenth of the 1969 mean values; diesel engine measures are also to be initiated. The following specific steps are being implemented or planned:

- Reduction of currently applicable emission limit values for carbon monoxide (CO) and unburned hydrocarbon (HC)
- Introduction of nitrogen oxide (NO\_x) limits
- Limitation of evaporation losses from the fuel systems of controlled ignition engines
- Limitation of the lead content in gasoline to 0.15 g lead per liter. (This limit became law as of January 1, 1976, and it has decreased the emission of lead substantially.)
- Limitation of gaseous pollutant emission (CO, HC, and NO\_x) as well as particulate mass emission (soot) in diesel engines

International harmonisation of measuring and testing methods is being aimed at. No lesser importance is attached to emission controls for vehicles already in circulation than to limiting the emissions of prototypes and new vehicles. For this purpose, suitable control methods are to be devised.

In the field of vehicle noise, the Federal Government is having research programmes carried out to study whether the motor vehicle emission values determined according to the European Community measuring technique are directly related to the noise emission generated in city operation. Part of this programme is also to ascertain the present state-of-the-art. Pertinent legal measures applicable to new measuring and evaluating methods, introduction of no-entry areas for noisy motor vehicles, and so forth, cannot be taken until these studies are completed.

It has been possible to strongly intensify traffic safety research in the Federal Republic in recent years. The Federal Highway Research Institute (Bundesanstalt für Strassenwesen), upon a request made by the German parliament, was appointed the central agency for road accident research. It has since been considerably enlarged for that purpose. The central agency's primary task is the coordination of the numerous research activities. It arranges for research projects to be carried out by universities and other research institutions on the basis of a framework plan. In areas of special importance it carries out research of its own and, in particular, it centrally evaluates the results of accident research. It is directly attached to the Federal Ministry of Transport and, consequently, works in close contact with the appropriate departments of the Federal Government as well as performing certain international duties on its own behalf. For instance, it represents the Federal Republic of Germany in the working groups of the European Experimental Vehicles Committee (EEVC).

The ideas and experiences of the German Traffic Safety Council, to which institutes and experts from all sectors involved with the traffic safety belong, are being incorporated into the planning framework for research. The special research efforts made by German industry are described in the status report of
the industry. Out of the great number of bodies that carry out accident research in the Federal Republic, the German motor vehicle insurers (united in the HUK association) should be mentioned in particular. They have continued and even extended their accident research activities. Up to now, with approximately 50,000 passenger vehicle accidents with injuries to occupants, this research represents one of the most comprehensive studies in the world. Through an acceleration of collection and evaluation, more than 15,000 accidents of the years 1974-75 have already been evaluated by engineers so that their results are available. The main objective of a reality-oriented analysis of accidents must be to reduce to a minimum the time delay between the actual event and representative results; this is where the HUK association sees a major focus of its work and will, in future activities, further reduce that problem.

In addition to the above-mentioned research, the German insurance companies have carried out, and to a large extent completed, studies of accidents between passenger cars and heavy vehicles as well as motorcycle accidents. Characteristic features of accidents involving bicycles have been examined as well. Also, a study of 30,000 pedestrian accidents from the years 1975-76 has been launched; for the first time, it will combine automotive engineering aspects, injury criteria, psychological aspects of poor traffic behaviour, and road-building measures. The HUK association's accident research efforts will from now on cover not only, as in the past, safety issues of passenger vehicles but, in addition, the safety risks of all groups of traffic participants, providing better evaluation based on concrete results.

Among important general priority targets of research in the field of accident prevention and mitigation of the consequences of accidents, we should now mention the following with respect to the motor vehicle sector:

- Analysis of the driver's behaviour interacting with road and vehicle
- Determination of coefficients for the intensity of collisions
- Improvement of accident simulation methods
- Injury and protection criteria, especially concerning restraint equipment
- Continuing development of uniform test dummies
- Problems of vehicle compatibility, such as endeavouring toward more or less equal probability of survival for all vehicle occupants involved in an accident
- Protection for pedestrians
- Cost/effectiveness calculation for safety measures

Of equal standing with accident research is the search for new technologies. The problems of motor vehicle traffic—safety risk, environmental impact, energy needs or dependence on oil, and land requirements—although they cannot be solved once and for all by continuing technological development, can be mitigated perceptably.

Consequently, the Federal Government is supporting the further technological development of the total system of motor vehicle and road traffic as a public responsibility. This promotion by the State is to help ensure that solutions may be achieved which would not otherwise become available, at least not in sufficient detail or in reasonable time. Specifically, this includes:

- Systematic studies of the fundamentals of new technological approaches to motor vehicles
- Development of technical alternatives of individual components and subsystems as well as evaluation in the framework of total traffic
- Laboratory specimens and demonstration models of promising variants (such as propulsion systems)
- The study and testing of system components in prototypes under realistic operating conditions

The main areas of current development are:

- Propulsion systems
- Fuels and other sources of energy
Underlying the continuing efforts on the part of Government and industry is the common belief that future problems cannot be solved properly except by harmonising, in a meaningful way, the components of traffic safety, environmental protection, and the saving of energy and raw materials. This is the right step for the future.

Status Report of the European Experimental Vehicles Committee

H. TAYLOR
Chairman
European Experimental Vehicles Committee

It is a great honour for me to speak as Chairman of the European Experimental Vehicles Committee (EEVC) and to do so in this historic city in the bicentennial year of the United States.

It has only been 4 years since the Experimental Safety Vehicle (ESV) Conference was last held in the United States, but there have been many major developments in that time. Considerable progress has been made in finding solutions to the technical problems that confront us, but the progress made has by no means been limited to individual technical activities. Substantial progress has been made in pooling the knowledge developed in various countries and in collaborating in selected research fields. Techniques have been developed in Europe for achieving a consensus of research views by several countries without prejudicing the freedom of any of them to negotiate nationally when it comes to questions of harmonisation of standards or of international legislation.

I am very happy to report that the growing European activity expressed through the EEVC has met with encouragement and a warm response from the United States Department of Transportation. I would like, on behalf of the committee, to express our appreciation for the consideration that has been given to our views in the international programme piloted by the United States.

The EEVC was formed in 1970 as a committee of government representatives and has therefore existed throughout the period of the development of experimental safety vehicles. The Governments of France, the Federal Republic of Germany, Italy, Netherlands, Sweden, and the United Kingdom are represented on the EEVC, and representatives from the Commission of the European Communities attend as observers. The committee maintains liaison between European national research and development activities to increase safety and abate noise and pollution; it also provides a forum for clarifying views on the various technical options and on the response that should be made to various international initiatives.

The EEVC has no executive or legislative function and it is not aligned with any other international body; however, it does have the full support of participating governments and their industries. It is thus able to draw on the best available expertise in many fields and this includes appropriate inputs from administrators and legislators in addition to scientific and technical experts.

In order to tackle, in detail, subjects of particular importance, specialised working groups of the EEVC have been set up to deal with:

- Data sources
- Human tolerance and road-user protection
- Order of priority and major requirements for safer vehicles
- Cost/benefit and cost/effectiveness techniques

These groups have well-defined terms of reference and reporting deadlines and the
groups are terminated when their stated tasks have been completed.

A major EEVC report, entitled The Future for Car Safety in Europe, was presented to the Fifth ESV Conference in 1974 and two further reports are being presented today. One of them is concerned with biomechanics and the other with "the use of cost/effectiveness and cost/benefit studies for the selection of vehicle safety measures."

Two important factors in international relations have emerged from these EEVC activities. First, because the committee is not directly aligned with regulation activities, all the government and industry participants felt themselves free to contribute fully to the work; and second, the reports, while not being acceptable to all the participants in every detail, do represent stepping stones in international understanding. It has thus proved possible to move forward from established positions to reach further understandings as more information becomes available; furthermore, the process of carrying out this work often serves to clarify research needs. Our paper to this conference on biomechanics illustrates these points.

A developing aspect of the committee's work is progress towards outlining and assessing the available options and quantifying the costs and benefits of various courses of action. Surprisingly, views as to whether a given safety measure is worthwhile can vary markedly between different countries even when the effects of it on accidents are agreed upon, and this can have considerable significance when it comes to harmonising standards internationally.

Our paper to this conference on the use of cost/effectiveness and cost/benefit studies is possibly the first attempt to compare, in detail, practices in different countries in relation to car safety measures.

In addition to the activities presented today, the EEVC has in progress working groups under the chairmanship of Dr. Pocci of Italy. This working group is charged with advising on suitable impact test procedures that could form a basis for assessment of car safety in Europe for the 1980's, using the EEVC Report of 1974 as a foundation. To round off the EEVC status report we have two brief presentations of the EEVC reports that I have already mentioned. The first, on biomechanics, will be presented by M. Halpern-Herla of France, and this will be followed by a summary of the report on the use of cost/effectiveness and cost/benefit studies for the selection of vehicle safety measures given by Professor Friedel of the Federal Republic of Germany.

Report of a Working Group on Biomechanics (EEVC)

Presented by MARC HALPERN-HERLA
Director
Organisme National de Securité Routière (ONSER)

TERMS OF REFERENCE ON THE GROUP

In June 1974, the European Experimental Vehicle Committee (EEVC) took the initiative in sending in a report, entitled The Future for Car Safety in Europe, whose aim was to put forth common views about vehicles to be produced in the early 1980's. The EEVC especially recommends judging new kinds of vehicles, in a limited number of impact tests, on the seriousness of injuries received by occupants—or people outside the vehicle involved in the accident.

In order to do this, having criteria of human tolerance levels and their transposition in measurements applicable to dummies is indispensable. The EEVC has gathered the data already established, or still subject to caution, in the annex written by the ad hoc working group (known as working group 3). This report discussed (with good reason) the difficulty in being very accurate because of the problem complexity and insufficient knowledge in certain areas. Nevertheless, acceptable human tolerance levels must be determined, at least temporarily, to carry the EEVC’s recommendations into effect.
SECTION 2: GOVERNMENT STATUS REPORTS

This is why the ad hoc group has been asked to propose a set of criteria applicable to controlled collision tests for use by the EEVC in order to judge secondary vehicle safety and the equivalent measurements applicable to dummies. The group should also state how equivalent loads on one dummy should be deduced from loads measured on another.

It should propose, if possible, what dummy should be produced for test purposes in the 1980’s. If there is not a sufficient consensus, the group should present elements for a dossier, so that representatives of qualified administrations can decide on a common viewpoint on this subject. The ad hoc group will begin by studying the situation in which front-seat occupants (simulated by dummies) wear seatbelts, while the vehicle undergoes impact tests as defined by the EEVC. The group will possibly study the case of unrestrained front-seat occupants in low-speed accidents. The EEVC working group 3’s review of current research in biomechanics will be completed, if necessary, especially in the field of accidents involving child occupants and pedestrians. Recommendations will be made, if possible, about research needs in this field. The group might consult experts from national or private scientific organizations and from different branches of the car industry.

WORKING APPROACH

Protection of Restrained Car Occupants

The basic information was drawn from the data of accident statistics. For every main body location, the frequency of injuries as well as their severity were taken into account. For both frontal and side impact configurations, it was then possible to classify injuries as “very important,” “important,” and “not important.”

For each injury, the following aspects have been studied: type of loading, relevant parameter, possible measurement on dummies, and tolerance level when known. Then, when possible, a requirement level was recommended.

In some cases, the group proposed easily adoptable design recommendations and research needs were pointed out. To establish recommended requirement levels, it was necessary to investigate the possibility of measuring the parameters relevant to the tolerance levels on standard dummies and the validity of such measurements. Current dummies were reviewed and their main failures discussed. Tolerance levels were examined for the possibility of measuring them on these dummies. Sometimes, the group judged measurements possible; at other times, the group had to point out the need for improvements in the design of future dummies. In these cases, recommendations could not be established.

Protection of Nonrestrained Car Occupants

While waiting for the evaluation of the first effects of the recent compulsory use of seatbelts in some countries, the group could not reach a full agreement on the need to protect unrestrained occupants. Nevertheless, the problem was examined and the need to protect nonrestrained occupants was considered.

Review of the Pedestrian Problem

Essentially the group had to estimate the importance of the pedestrian injury problem. Using accident statistics, the injuries were assessed by their frequency according to age (adults and children) and for two ranks of severity (AIS ≥ 3 and AIS <3). In addition, data from experimental studies, research in progress, and the results of studies on vehicle technology were reviewed.

CONCLUSIONS OF THE GROUP REGARDING INJURY CRITERIA AND RECOMMENDED REQUIREMENT LEVELS

The text is, for the main part, the result of an agreement between the different national delegations. The group recognized the fact that knowledge of the biomechanics of impact is still scarce, particularly regarding the distribution of injury tolerance levels among the car occupant population. This depends on many factors, including age, sex, and size.
Most of the group, however, believe that the recommended levels put forward are the best available at present. In accidents where they are not exceeded, it is expected that many of the adult car occupants involved would escape serious injury. Thus a very significant advance in car safety should be achieved by designing to these protection levels.

However, the Italian delegation did not fully agree and made some suggestions. They joined in the statement that the most advanced tolerance levels indicated represent a synthesis of the present knowledge. They nevertheless consider the belief optimistic that such levels, if applied to vehicle design, might signify a significant advance in car safety. On the contrary, Italy believes a design trend based on tolerance levels not sufficiently corroborated by the experimental research and therefore susceptible of being corrected, or even based on parameters that might be varied in the future, will eventually result in a certain cost burden without a compensation in terms of improved and certain passenger protection levels.

Nonsymmetrical Frontal Impact

Although the group agreed on general principles for occupant protection, it was sometimes difficult to reach full agreement on the numerical values of certain relevant parameters. Therefore, in some cases, alternative values are indicated.

In order to prevent injuries caused by localized high pressures, the group recommended that protrusions with an area of less than the small impactors that have been used in experimental works (that is, 1 in² or approximately 6.5 cm²) should not be placed or created where they could be contacted by restrained occupants.

Injuries to the Head. This type of injury was considered to be very important by the group.

Brain Injury. The parameter to be measured is linear acceleration as a function of time.

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1 The tolerance levels for nonsymmetrical frontal impact would also apply to symmetrical frontal impact.

If there is head contact, a value of the head injury criterion (HIC) 1000 or 80 gravity (g) for more than 3 ms should be considered as a tolerance level until further data become available and, when both values are combined, whichever is exceeded first is recommended as the requirement level for the resultant acceleration.

The group felt that, if there is no head contact, with present safetybelt restraint, accident data indicate there is no need for a requirement level; in particular, a HIC value above 1000 should not be considered as dangerous.

Skull Fracture. Although the relevant parameter that is not yet measurable is contact force or contact pressure, the group felt that, if the preceding requirement regarding automobile protrusions is fulfilled, the recommended requirement level for brain injury might possibly prevent skull fractures.

Face Fracture. As force measurement are not yet possible with the dummies currently available, the group was unable to recommend any requirement level to guard against face fracture in an in-vehicle test.

In case of head contact, the usefulness of a subsidiary test with a head form was discussed, but some members of the group were of the opinion that such a subsidiary test should not be recommended now because further research is needed in this area.

Facial Laceration. The group felt unable to recommend any method for the assessment of facial lacerations.

Injuries to the Neck. The group felt that injury to the neck by direct impact is very rare and did not consider a requirement level necessary. The group felt that other types of injuries were more important.

They were unable to recommend any requirement limit for flexion of the neck and felt that a survey of accident statistics and experimental research are needed to determine whether flexion is a more important cause of injury than extension.

For extension of the neck in frontal impact, the group did not think a requirement is needed at present.

Injuries to the Clavicle. This type of injury was considered to be not important by the group.
SECTION 2: GOVERNMENT STATUS REPORTS

Injuries to the Thorax. The group felt that injuries to the thorax were very important.

They decided that the parameter that should be measured in tests of this kind is chest deflection. This would be measured as displacement of the sternum relative to the spine. The tolerance level suggested in this type of loading would be 45 mm of deflection, and this value could be used as a requirement level provided the dummy has the same force-deflection characteristics as a person. If not, the level of 45 mm will have to be transformed into corresponding levels for other types of dummies.

If it is not possible to measure chest deflection in the near future, then, as an interim measure, acceleration levels exceeded for at least 3 ms could be used. The recommended levels will have to be different for dummies with different load-deflection characteristics.

Different acceleration values, either as components or as resultants, were proposed by the different delegations as indicated in appendix 1.

The steering wheel impact could be measured as force using a load cell and force distribution, but the group could not agree on any recommended level.

The group felt that protection against thoracic fracture at a given severity of impact would, at least with present belt systems of restraint, protect against most cases of intrathoracic injuries. Therefore the group did not propose any requirement limit.

Injuries to the Spine. The group was unable to recommend any particular requirement level. It would like to advise car manufacturers and the authorities that this type of injury could probably be avoided to a great extent by securing loads in the rear of the vehicle, using seatbelts for rear-seat passengers, and also by strengthening the backrest of the front seats.

Injuries to the Abdomen. The group considered injuries to the abdomen to be very important.

For injuries caused by loading from the lap portion of the restraint system, the group proposed that the requirement be that the lap part of the seatbelt shall be below the iliac crests in a normal sitting position and shall not slide up off the iliac crests during the loading phase of the impact. The means to do this for current dummies need to be developed.

Injuries to the upper abdomen might be caused by loading from the shoulder strap of the restraint system. The group felt that this type of loading could be avoided if the specifications for thorax protection were respected, and proposed that the position of the anchorage points of the seatbelts be carefully studied.

Injuries to the Knee, Femur, and Hip. The group agreed that injuries to this part of the body were very important.

A fracture to the femur may be caused by the bending component of loads and posterior dislocation of the hip joint by the compressive component of loads in the femur.

It is possible to measure compressive force, but the tolerance levels quoted in the literature vary considerably, probably owing to the exact loading direction. However, the majority of the group agreed that the requirement level of 4 kN for each femur should be used as long as it is not quite clear that the loadings will take place in a straight anterior-posterior direction. The German delegation, however, proposed a value of 7.6 kN.

The group did not recommend any requirement level for bending loads.

Injuries to the Lower Leg and Foot. The group considered these injuries to be not important. However, the group would recommend the requirement that no trapping of the feet occurs.

Lateral Impact

The group discussed the test situation and the problem of side impacts very carefully and found that very little is known about these accident situations.

The group agreed that for most injuries, measuring the force on a standard dummy would appear to be the best method of assessment if it is practical. This is not possible at present. There was no agreement concerning the validity of other methods such as the use of a special side-impact dummy, the measurement of vehicle intrusion, or the measurement of dummy accelerations.
As a solution, most of the group hoped that it would be possible to develop a practical universal dummy for front and side impacts, but some members thought that a more practical solution might be the use of two types of special dummies.

As for frontal impact, the group recommends that protrusions with an area of less than the small impactors which have been used in experimental works (that is, 1 in² or approximately 6.5 cm²) should neither be placed nor created where they could be contracted by restrained occupants.

Injuries to the Head. The group considered this type of injury very important.

Brain Injury. The parameter of interest would be linear acceleration as a function of time.

The HIC value has not been scientifically founded for side impacts. Until further research has been carried out, the group proposes the following as a requirement: if head contact occurs, a HIC level of not more than 1 000 and a resultant acceleration of 80 gravity for not more than 3 ms should be considered as a tolerance level.

Skull Fracture. Apart from the general design recommendation concerning small protrusions, the group could not propose any other requirement until force measurements are possible.

Face Fracture. This type of injury was considered not important in side impacts.

Injuries to the Neck. The group found injuries to the neck to be important.

Because of the lack of valid tolerance levels available in the literature, the group does not recommend any requirement level.

Injuries to the Clavicle. The group felt that injuries to the clavicle were not important.

Injuries to the Thorax. The group felt that injuries to the thorax were very important.

They could not agree on any specific tolerance level to be used here and could not recommend any requirement level.

Concerning the injuries of intrathoracic organs, the group felt that if some requirements to prevent thoracic fracture could be recommended and respected, there was little chance of an intrathoracic injury problem, but the accident situation should be monitored.

Injuries to the Hip and Pelvis. The group felt that injuries to these organs were important. The group was not able to reach an agreement on requirement levels for force, acceleration, and intrusion.

Injuries to the Abdomen. The group considered injuries to the abdomen very important.

They felt that the recommendations for hip and pelvic injuries should also take care of injuries to intra-abdominal organs as long as the recommendation to monitor the position of the lap portion of the restraint system is carried out.

Injuries to the Femur. The group considered injuries to the femur important; however, they could not agree on any requirement level.

General Remarks

These conclusions show that in many cases it was not possible to recommend any requirement level, and it appears that there is a great need of research. Indeed, research is wanted in the following fields:

- Investigation on human tolerance for a better understanding of the relevant parameters and criteria, and of the tolerance levels of these criteria (particularly for head injury tolerance and side impact tolerance)
- Research to determine methods of measuring force and its distribution, thorax deflection, belt strap displacements, and so forth, and improvements of dummies to make these measurements more meaningful

CONCLUSIONS OF THE GROUP REGARDING DUMMIES

At present, current dummies are only approximate substitutes for the human being, particularly in their dynamic behaviour. A number of problems occur when using standard dummies to assess injury criteria.

To obtain valid data from tests, a very careful calibration of the dummy according to the tolerance data is needed.

Measurements with test dummies are usually associated with a great deal of scatter in
the results. A statistical approach would seem to be the best method to reduce the scatter, but it would destroy too many cars for full-scale approval testing. Therefore it might be desirable to use another method, perhaps simulating the actual car impact deceleration pulse on a dynamic sled or using requirement limits that take into account both the expected value and the expected scatter, or requiring the manufacturer to take into account his expected scatter when designing to the requirement limits as he does now.

No existing dummy allows the measurement of all the parameters the group thinks necessary. Some parameters, however, are now measurable, and the group recommends the measurements of:

- Linear acceleration at the centre of gravity of the head in three separate axes
- Thorax acceleration on the spine in three separate axes, approximately at the centre of gravity of the parts of the dummy above the pelvis (such as the head and neck, the upper limbs, and the torso)
- The femur compressive load

Other parameters that the group felt should be measured were:

- Femur bending moment
- Chest deflection
- Lap strap displacement
- More generally, measurement of forces and their distribution, especially (but not only) for lateral impacts

The measurements of some of the preceding parameters imply an improvement of the dummies. Improvement of their dynamic behaviour for a realistic estimate of some injury potentials is necessary; this is particularly desirable for neck injury assessment.

Is it preferable to use a single dummy for all the crash configurations, or to have different dummies for frontal impact and for side impact? The group could not agree on an answer to this question. The two possibilities involve both advantages and drawbacks.

The group discussed the question of dummy size and recommended the use of the 50th-percentile dummy, but pointed out the need to consider the problem of other sizes.

**REVIEW OF THE UNRESTRAINED CAR OCCUPANT PROBLEM**

Even with a compulsory wearing of seatbelts in all European countries in a few years’ time, it can be assumed that unrestrained occupants will still represent a proportion of seriously injured car occupants (refusal to wear the belt and exemptions to the legislation). Thus, protection for unrestrained occupants needs to be considered. Because several European countries are just in the initial phase of introducing compulsory seatbelt wearing, it is too early to reach firm conclusions on this point.

If they are adopted, protective measures for nonrestrained occupants may need to be at a lower level of protection and should not lessen the protection afforded for restrained occupants.

**REVIEW OF THE PEDESTRIAN SAFETY PROBLEM**

The present synthesis was developed using data from each national delegation and from the analysis of American, Australian, and Japanese reports of studies in this field.

**Accident Statistics**

Pedestrian accidents are an important problem of traffic safety, especially in urban areas, although the injury severity is much higher in rural areas, probably because of higher speeds of impact. The frequency of pedestrian accidents is especially high for children and elderly people, but the severity is greater for adults.

Head injuries are both frequent and severe. Injuries to the lower limbs are also frequent but not so severe. Thoracic injuries are less numerous but tend to be more severe than those to the lower limbs.

Injuries result either from the first impact on the vehicle or from the subsequent impact on the ground.

**Data from Experimental Studies**

From experimental works, it appears that many parameters, such as posture, impact
EXPERIMENTAL SAFETY VEHICLES

speed, precrash and postcrash braking, car shape and struck area, have an influence on pedestrian kinematics. Thus, the results from studies performed in different conditions are not easily comparable.

Mathematical modelling is a new approach that seems to corroborate some experimental data.

Current and Future Studies

Whereas accident statistics will be developed, especially to gain knowledge of injury mechanisms, experimental studies are needed to determine the effects on children of the protective measures proposed for adult pedestrians.

With better knowledge of the real accident situation, it will be possible to study measures intended to lessen the severity of vehicle-pedestrian collisions using mathematical modelling techniques.

Results of Studies on Vehicle Technology

These studies deal with both the vehicle shapes and the materials used to reduce the severity of the pedestrian impact on the vehicle and the development of devices intended for avoiding pedestrian impact with the ground.

From present knowledge, it appears that little protection can be given in high speed impacts.

APPENDIX 1. INJURY CRITERIA FOR RESTRAINED CAR OCCUPANTS

Background

Scope. The scope of this document is to give relevant injury criteria for restrained adult front-seat car occupants in nonsymmetrical frontal and side impact test procedures proposed by working group 2 of the EEVC. The criteria and recommended requirement levels proposed for nonsymmetrical frontal impact would also apply to symmetrical frontal impact.

Such injury criteria should preferably be given in terms technically applicable to the design of motor cars. Where such criteria are not generally accepted at present, the authorities, as well as the car manufacturers, should be advised about trends in current research and possible areas where future studies may produce new and better knowledge.

In order to arrive at relevant parameters to be measured and limiting values to be used as requirement levels in approval tests, it was necessary for the group to take into account the present state of knowledge regarding the kinematics of accidents, human impact tolerance, and human substitutes used in similar types of tests. The group has recognised the fact that the knowledge in these fields is yet rather scarce, and that this is the case for side impacts in particular.

Kinematics of Accidents. Most of the research and development work on the kinematics of accidents has so far been related to the symmetrical frontal impact situation, which is considered more easily dealt with in studies of real accidents, as well as in simulation experiments. Although the kinematics of car occupants—unrestrained as well as under the influence of a number of different restraint systems—is fairly well known in symmetrical frontal impacts, this knowledge is not easily transferred to the more complex nonsymmetrical front or nonorthogonal side impact situations. The group has considered, however, that the kinematics of restrained front-seat occupants in the proposed nonsymmetrical frontal impact will differ very little from that resulting from a symmetrical frontal impact during the main part of the impact sequence.

Human Tolerance. Present knowledge of the tolerance of the human body indicates an age variation where the skeleton and the connective tissues of young adult males have higher breaking strength than those of children, females, and elderly people. As children are not taken into account in this document, the tolerance of the musculoskeletal system can here be considered as decreasing with age [1]. Accident studies indicate a very remarkable decrease in the breaking strength of the female skeleton above 50 years of age. There are, however, also some indications in the
literature that the tolerance for some very specific types of injury may well increase as a function of age. As an example of this, the tolerance against rupture of veins bridging the gap between the inside of the cranial vault and the brain can be mentioned [2].

In accidents represented by the test situations prescribed, the population at risk would probably not be the same in different types of cars or in different countries. This means that requirement levels should take into proper account the most vulnerable adult occupants in cars. These problems are to some extent taken care of if requirement levels are derived from representative samples of accident data from several countries. As only a very limited number of studies have been carried out on the kinematics and tolerance of the human body in side impacts, the knowledge about injury criteria in this situation is very scarce.

Test Dummies. The standard test dummies currently used in experimental impacts have been designed to remain unchanged during a large number of tests. This implies that the structure does not fail in the same manner as it would in a living human body under the same conditions. The kinematics of these dummies are, for this reason, not necessarily the same as those of human beings, and this is particularly the case in later phases of complex impact situations. These dummies also have—for obvious reasons—been designed and used mainly in frontal impacts and there is hardly any information about their feasibility for use in side impacts.

Interpretation of Results. Measurements of head and chest accelerations as well as of femur loads—for which test dummies have been used—are usually associated with a great deal of scatter in the results. This would make either a statistical approach, or some alternative method to reduce the scatter, desirable. A statistical approach could imply the use of several cars for full-scale approval testing. This would probably not be practical in economic terms. One possibility is to require a limit that takes into account both the expected value and the expected scatter, or to require the manufacturer to take into account his expected scatter when designing to the requirement limits as he does now. Another possibility would be to reduce as much as possible the degrees of freedom of the system undergoing approval testing. The current normal procedure, in research and development work as well as in approval tests for restraints, is to simulate the actual car impact deceleration pulse on a trolley or sled where parameters of interest can be recorded more easily. It therefore seems possible as an alternative to limit the number of parameters to be measured in the full-scale car impact to what is necessary as a basis for further component testing. The experience from this field indicates, however, that there would still be a number of problems to overcome in order to obtain repeatable results from this kind of testing. The influence and hence the importance of minor variations in different parameters is yet not fully understood.

The group has recognized these difficulties in the test situations prescribed and reached the conclusion that it would be misleading not to point out very strongly the great uncertainty in many of its recommendations, and that the results of further investigations in a few years may lead to a desire to change several requirement levels and even some of the parameters to be measured. The group has felt great pressure to reach an agreement on as many points as possible and—where this has not been possible—to indicate the reasons for the various opinions. Most of the group, however, believes that the levels put forward are the best available at the present time. In accidents where they are not exceeded, it is expected that many of the adult car occupants involved would escape serious injury. Thus a very significant advance in car safety should be achieved by designing to these protection levels.

The Italian delegation joins in the statement that the most advanced tolerance levels indicated represent a synthesis of the present knowledge. It nevertheless considers the belief optimistic that such levels, if applied to vehicle design, might indicate a significant advance in car safety. On the contrary, Italy believes a design trend based on tolerance levels not sufficiently corroborated by experimental research and therefore susceptible to correction, or even based on parameters that might be varied in the future, will eventually result in a certain cost burden without a
compensation in terms of improved and certain passenger protection levels.

Injury Criteria and Recommended Requirement Levels

Nonsymmetrical Frontal Impact

The Test Situation. The test car is supposed to decelerate mainly in a frontal direction and any rotation in the horizontal plane is supposed to begin at a relatively late phase of the car frontal linear deceleration sequence. Restraint front-seat dummies will decelerate under forward displacement relative to the ground. The relative displacement between the dummies and the car will depend mainly upon the characteristics of the car and the restraint system. "Normal" slack in current 3-point inertia reel belts will probably delay the linear deceleration of the dummies towards the end of the car linear deceleration sequence when a possible rotation begins. The relative displacement between the dummies and the car will therefore probably take place at a small angle with the longitudinal axis of the car and this angle may increase as a function of time. Any rebound of the dummies may therefore not bring them back to the center of the seat.

Injuries to the Head. This type of injury was considered very important by the group.

Brain Injury: The brain will be subjected to inertial loading during the forward deceleration of the body, but in current restraint systems this does not seem dangerous unless the head impacts against car interior structures. It is therefore important that a possible head impact can be detected.

Linear acceleration of the center of gravity of the head is the parameter to be measured. It should be measured in three directions and each of these should be recorded as a function of time. Human tolerance levels for this type of loading are supposed to vary with amplitude and duration of the center of gravity deceleration. However, peaks shorter than 3 ms are not supposed to be of significance in this situation.

It is considered that any head deceleration below 80 g and within the time duration applicable here does not cause brain injury. However, some studies indicate that pulses of long duration even below this value may be hazardous and, in order to take this into consideration, the head injury criterion (HIC) has been developed and a value of 1 000 [3] is, at present, the most widely applied as a tolerance limit, although higher values have been recorded in situations where no injury is supposed to have occurred, such as in forward deceleration with no head contact. The group has considered this situation and recommends that any head contact be recorded very carefully. If there is contact, a value of HIC 1 000 or 80 g for more than 3 ms should be considered as a tolerance level until further data become available. When both values are combined, whichever is exceeded first is recommended as the requirement level for the resultant acceleration. The group felt that if there is no head contact, with present safetybelt restraint, accident data indicate there is no need for a requirement level; in particular, a HIC value above 1 000 should not be considered as dangerous.

The group (in line with the car industry) felt that there was a great need for increased research into brain injury mechanisms, tolerance levels, and assessment methods. Studies on the effect of filters on measurements of this kind are also needed.

Rotational acceleration of the head has in some studies been considered to have a deleterious influence on the brain, especially in combination with linear impact accelerations. Various figures have been suggested as tolerance levels, for example, 1 800 rad/s² [4], but the group felt that there was need for further research to confirm this value. Some improvement of the necks of the dummies will probably also be needed before measurements of rotational acceleration would be meaningful in standard tests. Consequently, neither tolerance nor requirement levels are suggested for this type of loading.

Skull Fracture: In the case of head contact with interior car structures, localized force against the cranial vault may result in a skull fracture. Experimental studies indicate that a force of more than 2.5 kN [5] over an area of less than approximately 6.5 cm² may lead to skull fracture. If the area is larger than this limit, a force of more than 4 kN is required to produce skeletal damage [6].
At present, contact force cannot be measured on the head of standard dummies. The group felt that research and development is needed to make such measurements possible in the future. In the meantime, the group felt unable to recommend definitive requirement levels, but would advise that interior details in the head impact zone should have an area of at least 6.5 cm². If this requirement is fulfilled, it was felt that the recommended requirement level for brain injury might possibly prevent skull fractures, though the genuine relevant parameter, not yet measurable, is contact force or contact pressure.

Face Fracture: Fractures to facial bones seem to occur in about 10 percent of the seriously injured front-seat occupants and thus in a much lower proportion of all injury-producing accidents. However, the group felt that this type of injury, if it is accompanied by concussion, may occasionally become a very serious complication when the inhalation of blood from the nasopharynx and the consequent possibility of asphyxia occurs. Current restraint systems do not seem capable of preventing all facial contacts with the steering wheel. For these reasons, a requirement is desirable but not easily realised.

As force measurements are not yet possible with present dummies, the group was unable to recommend any requirement level for the in-vehicle test. If the test indicated that head contact occurred with the 50th-percentile dummy, or was likely to occur with sizes of occupants other than the 50th percentile, a subsidiary test with a head form might be performed if the object struck was capable of producing localized loading of the face. The group felt that in such a test, a tolerance level of 0.7 kN for small impactors [5] would perhaps correspond to an acceleration of 15 gravity for 3 ms measured on a suitable head form. Some members of the group were of the opinion that such a subsidiary test should not be recommended now because further research is needed in this area.

Facial Laceration: The group felt unable to recommend any method for the assessment of facial laceration but would recommend that research be carried out in this field. Investigations to determine the frequency of face laceration, and that of eye injuries in particular, are of great importance. If this should appear to be a problem of grave dimension, further development will also be needed on possible test methods.

Injuries to the Neck. The group felt that injury by direct impact is very rare and did not consider a requirement level necessary. The other types of injury (that is, fracture and dislocation of the cervical spine and spinal cord injury) were considered more important.

Possible types of loading are, in the first place, extension, flexion, rotation, lateral flexion, and shear force. Possible parameters would then be angular movements of the head where head angles versus the torso line should be measured.

The group felt unable to recommend any tolerance limits for flexion of the neck, and felt that a survey of the accident statistics and experimental research are needed to know if flexion is a more important cause of injury than extension. For extension of the neck, the group agreed that 80 degrees of angular movement of the head relative to the torso could be considered as a tolerance level [7], but did not think a requirement is needed in frontal impacts.

Another possibility will be to determine relative head-to-thorax acceleration in three directions and calculate the load on the neck. However, the group felt that there were not yet enough results from such calculations. Other types of loading such as traction, compression, and bending may be of importance for the development of neck injury in some situations, and tolerance levels of 1.6 to 2.2 kN of traction have been suggested in the literature [8], but the group was unable to give any recommendation at this stage. It felt that improvement of the dummy neck behaviour is necessary if such measurements should be considered.

Clavicle. This type of injury was considered by the group to be not important, especially compared with injuries to the thorax.

A clavicle fracture might result from bending caused by a shoulder strap. The parameters of importance here would be strap angle and strap tension. It was shown in the United Kingdom that, for an angle of 35 degrees, the
limiting tension observed was 8 kN measured on an OPAT dummy [9]; but these conditions are not enough for the group to accept them. The group would advise, however, that the upper anchorages of straps should be placed to minimize the load on both the clavicle and the spine without increasing the risk of injury to the thorax.

**Thorax.** The group felt that injuries to the thorax were very important.

Thorax fracture is considered to be caused by either shoulder strap load or steering wheel impact or a combination of both. The group considered that the parameter of interest would be strap tension and this could be measured by a load cell; the tolerance levels would then be between 6 and 8 kN in most current restraints [8]. However, the group could not agree to recommend a level for this type of loading at present.

Another parameter that the group recommended be measured in tests of this kind is chest deflection. This would be measured as displacement of the sternum relative to the spine. The tolerance level suggested in this type of loading would be 45 mm of deflection [9], and this value could be used as a recommended level provided the dummy has the same force-deflection characteristics as man. If not, the level of 45 mm will have to be transformed into corresponding levels for other types of dummies. To keep the error resulting from such a transformation as slight as possible, it is important that the chest stiffness and damping of the dummy approximate as closely as possible that of the human.

If it is not possible to measure chest deflection in the near future, then, as an interim measure, acceleration levels could be used. The recommended levels will have to be different for dummies with different load-deflection characteristics:

- The United Kingdom suggested that 35 g for the OPAT dummy would probably correspond to between 35 and 60 g measured in other dummies.
- France suggested the value of 50 g as resultant acceleration for HYBRID II dummy.
- Germany suggested 60 g resultant acceleration.
- Sweden suggested 45 g in $g_x$ direction, combined with 20 g in $g_z$ direction.
- Italy and the Netherlands were unable to support any fixed value.

These figures will have to be measured for a duration of at least 3 ms.

The steering-wheel impact could be measured as force in a load cell, and tolerance levels between 5 and 6.5 kN are mentioned in the literature [10]. The group felt that such values are probably not sufficient and that it would perhaps be necessary to measure the force distribution. The group could not agree on any recommended level here. It felt, however, that improvement of the dummy to allow measurements of force and pressure would probably be needed in the future.

The loading of internal thoracic organs would be the result of inertia, and parameters to be measured would be spine acceleration in three directions. The tolerance levels found in the literature are very confusing, and the group felt that this, to a large extent, depends on the type of human substitute that has been used for measurements. The group felt that protection against thoracic fracture at a given severity of impact would, with present belt systems of restraint at least, protect against most cases of intrathoracic injuries. Therefore, for this kind of injury, the group did not propose any requirement limit. If, however, the restraint systems are improved to reduce the risk of rib fracture, intrathoracic injuries may become relatively more important. For these reasons, the group recommends research in this topic, particularly on the effect of the $g_z$ component on the intrathoracic organs as well as on the spine in car accidents.

**Spine.** The group has considered the question of spine injuries very carefully. This is thought to be a type of injury that could be caused by loading from the rear and, as the group was unable to recommend any particular kind of measurement, it would like to advise car manufacturers and the authorities that this type of injury could probably be avoided to a great extent by securing loads in the rear of the vehicle, by using seatbelts for rear-seat passengers, and also by strengthening the backrest of the front seats. The group also would like to propose research in the form of a survey of accidents to define the importance
of this kind of injury and to study the injury mechanisms. Experimental studies are also needed for determining human tolerance levels.

Abdomen. The group considered injuries to the abdomen to be very important.

Injuries to the lower abdomen are probably caused by loading from the lap portion of the restraint system. The parameter would be deformation of the lower abdomen, and the measurements should aim at detecting any submarining tendency or contact with the steering wheel. It was felt that human tolerance levels were always liable to be exceeded if the lap portion of the restraint was moved upwards onto the abdomen. The group therefore proposed that the requirement be that the lap part of the belt shall be below the iliac crests in the normal sitting position and shall not slide up off the iliac crests during the loading phase of the impact. The means to do this for current dummies need to be developed. The group also recognized that the risk of intra-abdominal injury increases if hard components of the seatbelts can get in contact with the soft abdominal wall and cause rupture of intra-abdominal viscera, and would therefore recommend that hard parts of the restraint system such as buckles be positioned in such a way that they could not get into contact with the abdominal wall. The group also felt the need for research on the dynamic behaviour of various dummies and their ability to disclose any tendency to submarining.

Injuries to the upper abdomen are probably caused by loading from the shoulder strap of the restraint system. The deformation of the abdomen in general and consecutive to the deflection of the lower ribs was considered as a parameter of interest. The group also felt that this type of loading could be avoided if the specifications for thorax protection were respected, and would like to propose that the position of the anchorage points of the seatbelts be carefully studied.

Knee, Femur, and Hip. The group agreed that injuries to this part of the body were very important.

One injury to this complex could be a kneecap fracture. The group felt that the probability of the occurrence of such fractures could be decreased if protruding objects with an area less than those of the small impactors used in experimental works (that is, 1 in² or approximately 6.5 cm²) be avoided in the knee impact zone. Fracture to the femur and compressive components may cause posterior hip dislocation.

Compressive force can be measured, but the tolerance levels quoted in the literature vary considerably. The United Kingdom delegate mentioned that accident investigations indicated that hip injuries could occur at thigh compressive loads as low as 2 kN, but a more realistic level would be 4 kN [10]. On the other hand, experimental tests carried out mainly on cadavers indicate tolerance levels of 7 or even 10 kN if the thighs are in a straight-ahead position at the time of the impact. The majority of the group agreed that a recommended level of 4 kN should be used as long as it is not quite clear that the loadings will take place in a straight anterior-posterior direction. The German delegation, however, would like a value of 7.6 kN [11]. As an additional item of information, it is reported that the Swedish and French car industries let their respective national working group 4 delegates know that they would prefer the value of 7.6 kN.

Bending load is a more difficult measurement and not yet in current use in standard dummies. The group did not recommend any requirement level for this type of loading.

Lower Leg and Foot. The group considered injuries to the lower leg and foot not important, and could not prescribe any measurements or tolerance levels. However, the group recommended a requirement of no trapping for the feet, because it is necessary for an injured accident victim to be extracted from the car easily. The group also recommended studies on the design of pedals.

Lateral Impact

The Test Situation. The group discussed the test situation and the problems of side impacts very carefully, and found that very little is known about this accident situation. It is apparent that the intrusion of the side of the car might at present be used as a measurement of accident severity, but a requirement of limitation of the intrusion in the test situation would not necessarily lead to
EXPERIMENTAL SAFETY VEHICLES

less severe situations for the occupants. The stiffening of the lateral structure of the vehicle might lead to higher acceleration levels of the struck car.

The group also agreed that ultimately one might wish to aim at measuring forces on a standard dummy if this is practical. It is not possible at present. Because the use of a special side impact dummy was not accepted by all, the only parameters now available with which to assess injury potential were dummy accelerations and vehicle intrusion.

The group, however, would like to warn that the use of such parameters might result in a misleading conclusion, and they strongly urged that research be conducted into the measurement of loads on dummies in side impacts. At the same time, the acceptability of the current side impact dummy should be investigated. Most of the group hoped that it would be possible to develop a practical universal dummy for front and side impacts, but some members supposed that a more practical solution might be the use of two types of special dummies.

The group agreed that, for side impact as for frontal impact, the 50th-percentile dummies were adequate for assessing occupant protection, but attention needs to be given to the problems likely to be raised by other adult sizes.

Injuries to the Head

Brain Injury: The group considered this type of injury very important.

The loading would be inertial with or without head impact. The parameters of interest would be acceleration and its duration, and the measurements should be linear acceleration in three directions. The only tolerance level referring to this situation in the literature is the Mean Strain Criterion of 0.0061 cm/cm [12], while the HIC has no scientific foundation for side impacts. In this situation, however, the group would propose a level of HIC 1 000 or 80 g for 3 ms as a requirement if head contact occurs, until further research has been carried out in this area.

Skull Fracture: It was agreed that protrusions with a surface area of less than the small impactors that have been used in experimental works (that is, 1 in² or approximately 6.5 cm²) should neither be placed nor created in the zones likely to be impacted by the head in the lateral impact situation. It is not yet quite clear if this will protect the occupants against skull fracture, but the group could not propose any other requirement until force measurements are possible.

Face Fracture: This type of injury was considered to be not important for side impacts, but the group proposed that further research in this field be carried out.

Neck. The group found injuries to the neck to be important.

The type of injuries would be fracture, dislocation, and spinal cord injuries, and the type of loading would be side flexion, rotation, flexion traction, compression, bending, and shear force. The parameters to be measured would be angular movements to the head, relative head accelerations, and forces. As far as angular measurements are concerned, the group would like to give a tolerance level of 60 degrees for pure side flexion [13]. For all the other parameters, there are no tolerance levels available in the literature, and the group felt the need for research to define the tolerance levels in order to set up requirement levels and to improve the dummy neck behaviour to allow angular measurements. Therefore, at present, the group does not recommend any requirement level.

Clavicle. The group felt that injuries to the clavicle were not important and could be dealt with in connection with the thorax.

Thorax. The group felt that injuries to the thorax were very important.

Thoracic fracture in side impacts can be caused by transversal force—deflection or acceleration—and the limitation of intrusion could be discussed, as mentioned earlier. The group could not agree on any specific requirement level to be used here and would like to point out the need for further research and development studies.

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2The U.K. delegation proposed the use of a side impact dummy on which a force of 6 kN at shoulder level, 2 kN at each of the four rib stations, and 5 kN total at the hip and pelvic levels would be considered as injury criteria.

3The Swedish delegation proposed 20 gz acceleration as a requirement level.
As far as the intrathoracic organs are concerned, the group felt that if the requirement to prevent thorax fracture was respected, there was little chance of an intrathoracic injury problem, but the accident situation should be monitored. It is also recalled that Zoborowski mentioned a 14-g tolerance level for volunteers [14].

Abdomen. The group considered injuries to the abdomen to be very important.

The side impact load from the straps or from the intruding structures would cause compression and shearing of the abdomen or transverse force. Forces or accelerations can be measured at the pelvic level. The group felt that the recommendations for hip and pelvis injuries should also guard against injuries to the intra-abdominal organs as long as the recommendation to monitor the position of the lap portion of the restraint system is carried out.

Hip and Pelvis. The group felt that these injuries are important.

The type of injury would be a fracture of the pelvis or fracture-dislocation of the hip and the type of loading would be side impact causing transversal load or acceleration. Measurements should be made of forces on the pelvis and hip joint if possible or maximum resultant acceleration. The group could not agree on the use of a side impact dummy, but strongly advocate research in this field to find tolerance levels and to clarify the effects of intrusion. Improvements of the dummy to measure forces easily in this region are also urgent. In the meantime, the group was not able to reach agreement on recommended levels for force, acceleration, or intrusion.

Femur. The group considered the injury to the femur to be important.

The type of injury would be a fracture caused by the side impact, and the parameter should be bending load or bending moment. This would require the use of force load cells, and the tolerance levels found in the literature reached from 2 to 3.2 kN and 200 to 400 Nm, respectively [15]. The group could not agree on any recommended level here, but would strongly suggest research in order to measure force, and a survey of the accident statistics is needed to establish a connection between intrusion and femur injury.

References


APPENDIX 2. DUMMIES AND RELEVANT PARAMETERS FOR STANDARD TESTS

To transform the human tolerance levels into recommended levels on the dummy, the group had to examine the different existing dummies and, if necessary, propose improvements for the measurements of injury criteria parameters.

General Remarks

Dummies are approximate substitutes for human beings, and a number of shortcomings can be demonstrated among the different types. The main ones are thought to be lack of reproducibility, poor dynamic behaviour, and poor reliability. Though some recent dummies, especially the HYBRID II, seem to be improved, they still leave something to be desired. Their poor dynamic behaviour is particularly marked at some anatomical locations such as the neck, thorax, and pelvis. These deficiencies, though they have been recognized and steps have been taken to rectify them in new dummies (as, for instance, the OPAT dummy), lead the group to question the value of measurements at those locations. In some cases, these deficiencies may make a valid assessment of injury potential impossible.

The group points out that, assuming dummy behaviour is good enough in other respects to express human tolerance, the strength required to enable the dummy to remain unchanged during a large number of tests make it difficult to obtain an accurate representation of human behaviour (a comparison of the thorax force-deflection characteristics of man and dummy can be cited as an example). (It seems that this aspect has received special attention in the design of the new dummies. Nevertheless, a careful calibration of the dummy needs to be carried out in order to transform the human values of parameters into corresponding levels for the dummy. Similarly, for reasons of reliability, all the variable parts of the dummy (especially the joints) have to be adjusted before each test by a method defined according to the response characteristics in connection with the human tolerance data.

The dummy size is another problem discussed by the group. Indeed, 50th-percentile dummies cannot take into account the protection of the whole population: The risk of impact may be increased for the tallest people and bad fitting of the seatbelt may be more likely when the size increases or decreases from the median one. Nevertheless, the group recommends the use of the 50th-percentile dummy, but points out the problem of protecting other sizes of occupants.

The parameters to be measured on the dummy are, in fact, the chief problem. On the one hand, most of the available human tolerance data are force levels required to produce the bone fracture because they are the easiest ones to be determined. On the other hand, current standard dummies (HYBRID II, for instance) were not designed to measure forces at some locations of interest with regard to tolerance data, but they enable acceleration measurements. From a general point of view, two ways are possible to solve this question. Either force data may be changed into acceleration levels and stand-
ard dummies can be used, or force measurements may be kept as recommended levels. This needs the use of special dummies. The choice between these two options gave rise to discussion in the group and no general agreement could be reached for the moment. This question will be examined more precisely later in this paper with parameters to be measured at every body location.

Analysis of the Different Parameters According to the Body Locations

The group has to classify the different possible parameters in terms of their utility and feasibility of measurement on the dummy. So, it must determine:

- Parameters of little or no interest
- Parameters that can be measured at present
- Parameters that it is desirable to measure on the dummy in the near future
- Interesting but less useful parameters that could be measured later on

The main body locations were reviewed.

Head-Face and Neck. The head linear acceleration in three directions is regarded by the group as measurable.

The head angular acceleration and the head to thorax relative angular displacement were taken as interesting. But the group thinks that, although the neck of the dummies may be good enough to estimate the injury potential at the head level, it is not so for the injuries of the neck itself in frontal and lateral impacts. It is proposed to adapt these measurements as soon as possible for head injury estimation purposes and to improve the neck of the dummy for a later assessment of neck injuries.

Head impact force and pressure are quite desirable parameters to be used in an in-vehicle test. But, the question is: What part of the head-face will impact a structure of the vehicle during the test; in other words, where is the force to be measured? Therefore, where is the load cell to be placed? The dummies are not designed to measure force at the head-face level. So, it is proposed that one look for head contact or for its probability to occur with other sizes of occupants during the global test. Then, if head contact is deemed possible, a separate test with a head form could be performed and, knowing the mass of the head, form an acceleration measurement that could be used instead of a force measurement. The number and conditions of these tests would need to be carefully defined.

Neck forces were not considered a measurement of pressing necessity.

Clavicle. The problem of clavicle loads was examined by the group. It did not use the clavicle bending load as a parameter and would prefer a geometric recommendation for shoulder belt.

The clavicle compressive load could be an index of the lateral impact severity and the English delegate recommends its measurement using a special side-impact dummy. But, as there is no agreement at present for the use of such a dummy, the group felt the clavicle compressive load measurement should be delayed.

Thorax. The thorax three-axes acceleration measured at the spine is deemed as a measurable parameter.

The thorax deflection measurement is not yet possible on standard dummies, but the majority of the group thinks it could be achieved relatively easily. Therefore, though the thorax deflection characteristics of most standard dummies are not considered as very realistic and the correlation with the human is not clearly defined, the group recommends thorax deflection as a currently measurable parameter. In the case of the OPAT dummy, this measurement is considered by the English delegate as realistic and is used in tests at present.

Thorax anterior-posterior load was not considered necessary if the load-deflection relationship of the dummy is known.

The group thinks that thorax lateral load is the most suitable parameter for thoracic injuries resulting from side impacts. Except on the special side-impact dummy, its measurement is impossible. So, the group proposes research in order to make this measurement feasible as quickly as possible, if, in fact, such measurement proves to be practical on standard dummies. In the meantime, other criteria such as acceleration or limitation of vehicle lateral structure deformation might be
used unless an agreement can be reached concerning the use of a special side-impact dummy.

For thorax loading, thorax surface pressure is thought to be a convenient measurement. The group recommends considering the possibility of using a contact pressure measurement on standard dummies. In several countries, such a parameter is regarded as very important to assess rib injuries under the shoulder strap. Further research is considered necessary to find an adequate measurement device.

Abdomen. From a general point of view, abdominal injuries might be assessed by recording parameters such as abdomen acceleration, abdomen applied force, abdomen contact pressure, and abdomen wall displacement on the dummy; however, these extremely difficult measurements are not yet possible on standard dummies. The group suggests research for the development of transducers, particularly those enabling contact pressure measurement and wall displacement estimation at the abdomen level. Similarly, on the Italian delegation's proposal, the group thinks it would be interesting to obtain information about internal pressure during the impact; such a measurement seems difficult, however, and needs important changes in the dummy, such as provision of liquid-filled sac at the abdomen level, enabling a fluid pressure measurement. Research is called for to investigate the feasibility of this measurement in the future on a dummy that must not be too sophisticated and that must be easy to use for standard tests.

If the restraint system includes a lap strap, an abdominal injury can be induced by the displacement of this lap strap before or during the crash. The group recommends that means should be developed for detecting incorrect positions of the lap strap before and during the impact to guard against submaring. The term “submarining” is used to describe a relative movement between the lap portion of the restraint system and the pelvic part of the occupant resulting in a displacement of the lap portion from the iliac crests up onto the abdomen, indicating a risk for abdominal injuries during the loading cycle of the restraint system. In this connection it has been noted that under the same crash configuration, some dummies show a submaring behaviour while others do not. The first are standing dummies (as SIERRA 292-850); the second, seldom submaring, are sitting dummies (as ALDERSON VIP 50 A) whose pelvic mobility has been modified in order to get an easier control and consequently a better reproducibility of the sitting position before the test. This aspect is of great importance because the upward displacement of the lap strap during the submaring depends on the pelvis’ ability to rotate. The group thinks sitting dummies are not completely realistic substitutes for the human in the submaring problem, and consequently recommends research to improve their behaviour. However, pending this improvement, the group considers these dummies suitable for use in crash tests.

Pelvis. The group considered pelvic lateral load measurement to be a very realistic and desirable measurement but, as for the clavicle and the thorax, they require a special side-impact dummy whose use is not generally accepted.

Pelvic three-axes linear acceleration is usually measured but some delegates question its validity as a good index of injury potential.

Femur. The group recommends the measurement of femur compressive load. Femur-bending load is also considered interesting, but it cannot be measured at present because, as yet, no practical technique has been devised.

Patella. Kneecap pressure was not deemed a needed parameter by the group.

Spine. The group asked for research to obtain a better knowledge of the tolerance of the spine and to determine the relevant parameters. Following this it may be necessary to examine the possibility of measurement on the dummies.

Problems Related to Side Impacts

From study of the different parameters to be measured on the dummy, it appears that
the main difficulty (which gave rise to disagreement between the members of the group) is the estimation of the injury potential in the side-impact configuration. At present, the only generally accepted methods of assessing side impact protection are measurements of acceleration on dummies and, in the opinion of some delegates, the limitation of intrusion. The group feels, however, that it must warn that these parameters only give an imprecise indication of the protection provided for the occupant and might perhaps lead to wrong conclusions. It would be better to use force measurements on either a standard dummy or a specially developed side-impact dummy. Work is being done on developing such dummies at present, but the results are not yet generally accepted. The Italian delegate considered that even if such dummies are used, intrusion limits should still be specified. On the other hand, a special side-impact dummy, along with its ability to provide force measurements, should show a dynamic behaviour good enough to enable realistic measurements at other levels (the head, for instance). Otherwise, it could not be used instead of a standard dummy, but only in addition to it.

In conclusion, assessing side impact protection gave rise to several questions. First, are special dummies needed for this purpose? Some members want only one dummy for all standard tests. The others would wish for only one dummy but, noting the difficulty of making realistic assessments of side impacts with a standard dummy designed for frontal impact, agree to the use of special dummies for side impact. Second, what importance should be given to the limitation of intrusion? In some members' opinion, it is not a desirable measure. For others, it would be a makeshift solution to be used instead of another more desirable measurement. For others, a limitation of intrusion, though it is not an injury criterion, is a very realistic indication of occupant protection in case of side impact if associated with the measurement of a parameter such as force or acceleration. Thus, for the particular problem of side impact protection at the thoracic and pelvic levels, no general agreement was reached and the question remains open.

APPENDIX 3. PROTECTION FOR NON-RESTRAINED CAR OCCUPANTS

The Need to Provide Protection for Non-restrained Occupants

When discussing protection for unrestrained car occupants, we are considering occupants of cars fitted with a form of restraint system requiring action on the part of the user to make it effective (active restraint system).

Although the wearing of seatbelts is already compulsory in many European countries and may become so in all in a few years' time, even with compulsory wearing, not everyone involved in an accident will be wearing a seatbelt. Apart from those who choose to ignore the law, legislation is almost certain to permit exemptions in some cases, such as delivery drivers travelling at less than a specified speed, people of unusual build unable to wear the belt safely, pregnant women during the later stages of pregnancy, and people with a morbid fear of restraint. Thus, it is likely that we need to insure a certain level of protection, not only for seatbelt wearers but also, as far as it is practical, for those who cannot or will not wear seatbelts.

The Practical Level of Protection

In considering protection for unrestrained car occupants, we must insure that the provision of such a protection does not lessen the protection afforded for restrained occupants. In most cases, it should be possible to devise means that enhance the protection for both classes of occupants.

The protection provided for unrestrained occupants should not be at such a level that the effort spent on providing the protection could have been more effectively spent in providing improved protection for restrained occupants or pedestrians struck by the car.

The mechanical strength of the human body structure is not affected by the wearing of a seatbelt so tolerance levels specified for restrained occupants must also be applied to unrestrained occupants. Not all these tolerance levels may be relevant and it may be necessary to specify some new levels.
Because we are dealing with cars equipped with active restraint systems, the group does not recommend an additional passive system that would give the same level of protection for unrestrained occupants. Therefore, if testing is felt necessary, it should be designed to represent impact conditions less severe than those used for restrained occupants.

Suitable Test Methods

Current legislation requires the use of conventional rig tests with simple-impact forms to assess some of the protection afforded by vehicles for unrestrained occupants. This type of test is readily reproducible and is relatively inexpensive, but recent research based on accident data [1] has indicated that these tests may not be sufficiently representative for the correct evaluation of design features intended for occupant protection. This deficiency may exist because the test form itself is not sufficiently representative of the relevant part of the human body or because its trajectory is not the same as that which occurs in the accident situation. It has been found, for example, that the stiffness and position of knee padding can have a marked effect on the head trajectory of an unrestrained occupant. Because the trajectory of the unrestrained occupant is more difficult to predict than that of the restrained occupant, and because modifications to the trajectory can be a valuable source of injury reduction for unrestrained occupants, it may be difficult to use a conventional rig test for solving this problem. There may be a stronger case for in-vehicle dummy testing when assessing the protective features provided for unrestrained occupants. On the other hand, in-vehicle testing includes many sources of variation and is much more costly; therefore, the group did not recommend any type of testing for the moment.

Reference


APPENDIX 4. PEDESTRIAN SAFETY

This paper contains the synthesis of EEVC answers and some American, Australian, and Japanese reports concerning pedestrian safety. The reports listed as references do not allow an exhaustive synthesis of the research conducted in these countries to be made because they only represent a part of the research carried out in this field.

As the national delegation answers did not indicate many figures, it appears difficult to do an exhaustive synthesis concerning pedestrian accidents. (This can be seen in the first item: "Accident Statistics.")

So, some data of this synthesis have been obtained from the report published by the U.S. Department of Transportation concerning pedestrian safety project (CCMS Report No. 27-1974).

Accident Statistics

From the delegation answers, it appears that pedestrian accidents can be considered as an important problem of traffic safety. Table 1 points out the frequency of pedestrian casualties [1-4].

The risk changes with age. It is high as soon as a child reaches approximately five years of age, and the risk stays high until 15 years. It can be noticed that the risk is also high for people around 65 years old [1, 2, 4-7]. But although the frequency of child involvement in pedestrian accident is higher, the severity of these accidents is lower than those involving adult pedestrians.

Types of Injuries. If we take into account the frequency of injuries, it can be noticed that the head is the body segment that is the most frequently injured followed by the lower limbs and the chest [1, 4, 7].

If we take severity into account, head injuries are followed by chest injuries [8].

Mechanisms of Injuries. Some accidents studies point out that the second impact of the pedestrian on the ground involves less serious injuries than the first impact on the car [4, 8].

Other studies are more cautious about the determination of injury causation. It seems that the severity of the injuries caused by the
impact against the vehicle depends on the stiffness of the struck area, and increases with impact speed. The second phase of the accident is impact against the ground, and the severity of this impact depends mainly on the body area hitting the ground first, and the velocity of this impact.

Data of Experimental Studies

Most of these studies were carried out with dummies, although some used cadavers. Many experimental studies concerning pedestrian safety are conducted in Europe, in the United States, and in Japan [1, 2, 4, 8-12].

From these, it appears that many parameters have an influence on pedestrian kinematics: posture, impact speed, precrash and postcrash braking, car shape, and area struck.

These studies are carried out in different conditions and it is difficult to compare their results. However, it is clear that the severity increases with the impact speed.

The pedestrian accident can be divided into two main impacts: impact against the car and impact with the ground.

The severity of the second impact can be evaluated in different ways by the experimental studies, but the severity of this second impact remains high when the head hits the ground first.

There are not many mathematical modelling studies of the impact of pedestrian and vehicle. We can quote the study carried out by the Japanese Automobile Manufacturers Association (JAMA) [11], which uses a 7-degrees-of-freedom model and finds results that seem to square with experimental studies.

Other studies are in progress in Europe and in the United States.

Current and Future Studies

In-depth accident studies are being increased in order to determine accurately the most frequent and the most severe configurations of pedestrian accidents. Moreover, some will enable a distinction between injuries caused by the vehicle from those caused by the impact against the ground.

Experimental studies conducted in the past referred essentially to adult pedestrians and were often made with dummies designed to represent vehicle occupants. Therefore, the influence of protection measures proposed for the adult are being studied on the child and the dummies used will be more realistic.

With a better knowledge of real accident conditions, it then will be possible to study, using mathematical modelling, the influence of some parameters (design or materials used when designing the front part of the car) on the severity of injuries.

Results of Studies on Vehicle Technology

Studies dealing with the technology of the vehicle in order to reduce the severity of

Table 1. Frequency of pedestrian casualties

<table>
<thead>
<tr>
<th>Country</th>
<th>France</th>
<th>Germany</th>
<th>Italy</th>
<th>Sweden</th>
<th>England</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian fatalities as a percentage of road traffic accident fatalities</td>
<td>18.8</td>
<td>30</td>
<td>25</td>
<td>19.6</td>
<td>37.9</td>
</tr>
<tr>
<td>Pedestrian injuries as a percentage of road traffic accident injuries</td>
<td>12.5</td>
<td>16</td>
<td>16</td>
<td>9.2</td>
<td>22.3</td>
</tr>
<tr>
<td>Pedestrian injuries in urban centre (%)</td>
<td>90</td>
<td>93</td>
<td>90</td>
<td>86</td>
<td>94</td>
</tr>
<tr>
<td>Pedestrian fatalities in urban centre (%)</td>
<td>65</td>
<td>73</td>
<td>65</td>
<td>67</td>
<td>81</td>
</tr>
</tbody>
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pedestrian accidents are proceeding along two lines.

1. Study of the shape and the materials of the outer part of the vehicle, to determine the kinematics of the struck pedestrian and to reduce the violence of head impacts especially on the bonnet, the windscreen, and the pillars, and to locate the bumper to avoid knee impact and in this way minimize the severity of lower limb injuries.

2. Study and development of means to prevent or reduce the probability of the second impact, of the pedestrian against the ground, or to reduce the severity of injuries resulting from this impact.

Everybody is aware of the risk run during the impact against the ground, which can be increased if the pedestrian is run over either by the striking vehicle or by another car.

Both approaches are complementary: The first one protects during the first stage of the accident (impact against vehicle), while the aim of the second one is to prevent the second stage (impact against the ground).

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The Use of Cost/Effectiveness and Cost/Benefit Studies for the Selection of Vehicle Safety Measures (EEVC) presented by PROFESSOR DOCTOR BERNARD FRIEDEL
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ABSTRACT

This report of the European Experimental Vehicles Committee presents the basis on which several European governments prepare their estimates of the relative costs, benefits, and effectiveness of vehicle safety measures. Discussed in some detail are the theoretical procedures adopted for cost/benefit and cost/effectiveness calculations, and a nine-step algorithm is given as an aid for using these methods.

A major reason for preparing this report was to show to what extent the different conclusions reached by different groups studying the same vehicle safety features resulted from differences in basic cost/benefit or cost/effectiveness procedures, from different economic and other assumptions, or from differences in costs or accident situations. An example of the evaluation of head restraints fitted to automobiles in two countries shows, in numerical form, how very different results can be obtained and the extent to which these arise from the various courses already discussed. It seems likely that teams will produce relative rankings for a series of safety measures that may not greatly differ, although the absolute levels may well be very different. The report concludes with comments on the need to check the sensitivity of findings for small changes in assumptions, based on the fact that the benefits of safety measures are far from independent of each other and in the context of using these procedures as aids in decision-making. A bibliography of research papers is included, giving fuller details of the various aspects of this subject.
INTRODUCTION

The European Experimental Vehicles Committee (EEVC) comprises members in government service from most European motor-manufacturing countries who are responsible for research into road vehicle safety and other vehicle features, such as noise, pollution, and energy. As part of its task in the coordination of research and development, EEVC requested at its fifth meeting (June 1973) that a report be prepared comparing national procedures and assumptions, for the economic assessment of safety measures in relation to their savings in accidents and casualties. After consideration of some early drafts, a paper [1] was presented to EEVC. It was decided that this paper should be rewritten and expanded into the present report, which also includes a discussion on the procedures for cost/benefit and cost/effectiveness studies, based on a paper by Marburger [2]. The aim of the report is to show what methods are used by some European countries for the assessment of the costs and contributions made by various measures for improving vehicle safety and similar matters and as an aid to decisionmaking for legislation. It also discusses the relative importance of the different national accident situations and the economic assumptions for these calculations in the countries using them.

Participants in this work are listed in appendix 1, and a list of papers and books used in the preparation of this study is given in appendix 2.

PROCEDURES FOR THE COST/BENEFIT ANALYSES OF SAFETY MEASURES IN MOTOR VEHICLES

Discussion of the Bases for Cost/Benefit and Cost/Effectiveness Procedures

Both cost/benefit and cost/effectiveness studies are attempts to put on a quantitative basis the ranking of the relative merits of different projects that might be adopted by a government or business organisation. They both compare the costs of introducing and keeping in operation a project with the benefits that will accrue from its introduction. The most obvious difference between cost/benefit and cost/effectiveness studies is that although both use a monetary basis for costs, the benefits in the former are expressed in monetary terms but in the latter they are expressed in more direct terms, such as savings in casualties or accidents for vehicle safety comparisons. Both are used mostly for planning of public expenditure; however, the procedures can also be used for matters such as car safety, which deal largely with private expenditure. The procedures for both cost/benefit and cost/effectiveness studies are described, even though in practice it seems that only the former is currently being used.

Cost/benefit analysis is an application of the theory of resource allocation—a subject at the heart of welfare economics. The aim of the method is to indicate an optimal, or most efficient, allocation of productive and other resources in a nation’s economy, given the initial availability of resources, their distribution amongst individuals, and any constraints upon their reallocation. At a theoretical level, the ultimate aim is to ensure that the efficiency of every monetary unit—be it invested in the defence sector, or for road safety, or whatever—is of equal value. In practice, however, the coordination of funds between sectors competing for resources is ruled out, and even within the sphere of transport policy, there are constraints upon resource allocation between areas such as safety and pollution [3, 4]. Practical evaluation is therefore concerned with suboptimisation, or “relative” efficiency [5]. When applied to investment or policy decisions, the role of cost/benefit analysis is to ensure that any changes will represent an allocative improvement, in terms of a movement towards an optimal allocation of resources, and that the solution chosen from the alternatives produces the greatest improvement. In this one-dimensional aim of efficient resource allocation, there is both strength and weakness—on the one hand cost/benefit analysis evades certain practical considerations, such as income distribution and sociopolitical constraints and considerations, yet on the other hand it sets up an ideal that can serve as a
point of orientation for pragmatic efficiency analyses [3]. It is arguable that cost/benefit analysis is concerned not only with the efficient allocation of resources but also with the distribution of these resources, and of the effects of their use among individuals in society. This means a move to greater efficiency does not necessarily result in an increase in social welfare—if some gain and some lose, the magnitudes of those costs and benefits do not alone indicate whether the changes are, on balance, regarded as beneficial.

The degree of monopoly and the encroachment upon the mechanism of the market by government interference (such as taxation) lead to a discrepancy between market prices and the genuine costs to the national economy, so that they do not, as a rule, correspond to the opportunity costs. Attempts have been made to reassess market prices by means of simulation experiments using internal or shadow prices [7-9], as well as by the application of the willingness-to-pay concept. For the time being, however, it is actually necessary to rely on market prices [10]. Account ought to be taken of the differences in the levels of indirect taxes applying to different goods and services, and in some countries when calculating costs, the average level of indirect taxation is substituted for the actual tax applying.

**Evaluation of Benefits**

“A project’s benefits are all those positive effects ... which were brought about by staging the project, whoever may profit from them.”[3] Further differentiation in direct [11], indirect, and intangible benefits, as is customary in the literature, can be disregarded in this study. The discussion about the evaluation of these components of benefit has been started over and over again on the basis of the question of whether fatally injured people can be evaluated in monetary terms. The limitation to economic facts results from the realisation that logically it is only possible to quantify the economic consequences of fatal accidents [4]. On this basis the question is therefore exclusively that of considering the economic contribution a person would have made had he not been killed in a traffic accident. Some countries have adopted more pragmatic approaches and some are discussed in a private communication [11].

Costs and benefits are quantified as far as is possible, and valued in money terms so that effects can be compared directly. When this is not entirely possible, a comparison of valued costs and benefits is incomplete, and account must be taken in the final appraisal of those factors that have been excluded. However, it should be pointed out that the monetary evaluation is not selected just because it
facilitates using a one-dimensional standard of value, but because of demonstrating

that in a national economy, organised on the principle of competition, where the nation by means of economic-based distribution measures achieves an income distribution felt to be just, the price a consumer is prepared to pay for an additional unit of a commodity would really reflect the individual gain felt by society and caused by the unit mentioned above [12].

Cost/benefit analyses in monetary terms proceed from the assumption that the ones affected by projects are the ones able to best estimate the consequence of public measures by their valuation of relative prices.

Discounting

The long duration of the effectiveness of the safety measures under discussion (the determination of which in this case does not cause any difficulties since it usually coincides with the lifetime of the vehicle) emphasises that costs and benefits occur at different times. They must be made comparable by applying an adequate mode of discounting to a certain date. The aim of this discounting is to reflect time preference and transformation possibilities. An appropriate discount rate is not discussed at this point, nor is there any argument about the method of discounting. It is important, however, to point out the necessity of discounting in cost/benefit analysis [13, 14]. Future costs and benefits are usually deflated to discounted values at the base year (normally the year the safety measure or vehicle is introduced). The use of constant prices at base-year levels for both current costs and future costs and benefits (with the future ones discounted to allow for the preference for current rather than future benefits) allows the effects of monetary inflation to be ignored.

Criteria for Decision

The volume of the evaluated and discounted cost and benefit data must finally be compared. Principally, the two criteria, "present-value rule" and "cost/benefit ratio," must be applied to determine whether benefits justify the costs incurred. Both methods fit the needs of the criterion of exclusion-positive cost/benefit difference and cost/benefit ratio (that is, benefit over cost) greater than one. In France, this criterion is being intensified by means of a minimum requirement as to the internal rate of interest—a coefficient of scarcity of money which, however, is not applied to vehicles. Where a capital constraint is operative, ranking or selection of a net present value of the cost ratio ensures a maximum return on the limited resources available. Costs are paid by car purchasers, but benefits accrue to several organisations and to many motorists. These considerations may alter the studies related either to government expenditure or to the national economy.

In the choice between alternatives, doubtless only the quotient formula is appropriate. However, if this method (perhaps through the indivisibility of alternatives) results in the adoption of a measure with a high quotient, and the rejection of a measure with a lower quotient but higher absolute net benefit, there are reasons justifying the application instead of the criterion of differences [3, 7, 16]. Netto [16] suggested a sensible refinement of the difference criterion: The economical alternatives should be ranked according to increasing cost; then the quotient of the cost/benefit differences between the later alternative (B) and the previous, not excluded, alternative (A) has to be worked out. In the case of a "marginal quotient" greater than one, (A) will be excluded. By this method, the decision is made in favour of the last project in the ranking table with a "marginal quotient" greater than one.

A recent development [17] is the method of consistent test procedures, which successfully deals with the problem of deciding which vehicle safety measures should be adopted when there are several different possibilities, each giving incremental benefits in terms of safety for increments of cost. It is particularly valuable when the performance of each measure is a continuous function of cost, for example, when deciding what test speed a vehicle should be designed to withstand. As the test speed is raised above that for the basic design, the cost increases and so does
the safety benefit. In the example of Lincke and Langner of Volkswagenwerk [17] there are possible structural and other design improvements to better withstand front, side, and rear impacts, and the method of consistent test procedures enables an optimum selection of improvements to be made for a given total cost.

Sensitivity Analyses

The margin of deviations from the chosen values for many data, assumptions, assigned values, and unquantified effects that find their way into cost/benefit analysis make it advisable to confirm a cost/benefit analysis with a sensitivity analysis on its findings. This is an attempt to test the sensitivity of the result in the light of certain changes of parameters (such as the assumed effectiveness of the measure, discount rates, or monetary sums). Special interest should be given to variables for which changes in possible values can lead to changes in rank of the measures being compared. Special weight should be given to this extra test if narrow decisions are to be made between choices (small cost/benefit differences, cost/benefit quotient approximately one).

PROCEDURES FOR COST/EFFECTIVENESS ANALYSES OF SAFETY MEASURES IN MOTOR VEHICLES

Distinctive Features of Cost/Effectiveness Analysis

Cost/effectiveness is not concerned with aiming at the optimum efficiency of the national economy or some small sector of it but rather the comparison of the effectiveness of measures, often expressed in nonmonetary terms. There may be several different targets of varying importance, and this fanning out of the target system must be mentioned as the essential distinction from cost/benefit analysis [4,18]. As mentioned in the following section, the effectiveness of different targets can be integrated into one measure by using a subjective weighting factor for each measure. Unless stated otherwise, procedures for these analyses are similar to those for a cost/benefit analysis. The evaluation of costs in both analyses is similar. In the study of primary safety measures that offer some probability of preventing road accidents, the measure of benefit is monetary in cost/benefit studies, but in cost/effective ones the probability of preventing accidents might be used as a scale for the main target. Effectiveness could also be expressed in terms of probable reductions in either fatal or all casualties, which could be restricted to car occupants if a car safety feature is being studied, or it might also include savings for other road-user casualties. These could be considered minor targets. One procedure for grouping the results of studies on one safety feature might be to weight the benefits for different targets with factors from zero to one and then add the results together. The selection of weightings must, to some extent, be a subjective one carried out by experts whose decisions would always be exposed to the criticism that they did not reflect conditions correctly.

An important situation arises when assessing vehicle safety measures, and that is the competition for the same benefits (casualty reductions) by many safety features being compared with each other. For example, the effectiveness of an accident avoidance feature would appear to be reduced if an occupant protective feature were given priority and deemed to save some of the casualties that might otherwise have been allocated to the accident avoidance feature. It is more convenient to study these interactions of benefits in cost/effective rather than cost/benefit analyses, though the latter could be modified to do so.

Evaluation of Benefits

The actual benefits are the same for all safety features no matter which method of analysis is adopted, but, contrary to cost/benefit analysis, cost/effectiveness analysis deliberately refrains from a monetary evaluation of benefits. It measures the individual intermediate benefits in physical units—according to the intermediate targets—and takes them into account in this form.
EXPERIMENTAL SAFETY VEHICLES

Whether or not it really was “the expression of some sort of giving up because of insurmountable difficulties in evaluation” [19], in any case, it had been hoped that considerable progress in the development of analysis procedures could be made after the necessity for monetary evaluation had been abandoned. Because a cost/effectiveness analysis attempts a comparison of total cost and total benefit [20], there must be a common agreement to limit the procedure to one descriptive measure of all relevant effects of the available alternatives [12], or there must also be a cost/effectiveness analysis to add up intermediate efficiencies that were differently measured.

One procedure for this analysis is as follows, although other procedures are possible. For every intermediate target a scale of points from 1 to 10 is set up. This scale corresponds to the degree of target achievement as follows: 1 point means a degree of almost no achievement (10 percent of target) and 10 points fully reaches the target (100 percent). The contribution of each intermediate target to the total is subjectively determined using any expertise available [21]. This is done by giving a weighting factor for each intermediate target, with the sum of these weights being one. The overall effectiveness is then given by the sum over all intermediate targets of (point scored on intermediate target scale x weighting for the intermediate target /10), and this effectiveness is then expressed on a scale between zero and one.

Discounting

Costs are discounted in analogy with the cost/benefit analysis. There may be difficulties, however, in the chronological harmonization of the physical intermediate efficiencies. It is usually assumed that, after a certain starting point, the intermediate efficiencies will flow continuously; that is, the flow of benefits is uniform per unit of time. Modifications to the discounting formulae could be made to allow for change. Additionally, allowance should be made for the situation when intermediate targets are achieved at different times from the full completion of the benefits; for example, when the benefits of the safety components do not cover the same period as the life of the car. For the time being, such modifications in discounting are not usually attempted, though it would be possible to discount partial benefits to present worth provided they can be quantitatively measured and, therefore, also be multiplied by a discounting factor.

Criteria of Decision

Preselection of all possible measures, as can be done in cost/benefit analyses, is not possible because there is no absolute measure of economic efficiency (positive cost/benefit difference and/or cost/benefit ratio) [19]. The relative advantage of a measure in comparison to others can be determined [22] independently of all other measures by the traditional cost/benefit procedure. Preselection of “effective” measures through cost/effectiveness analysis can be carried out by means of a comparison by pairs [19]. Figure 1 shows that A1, even though it is equally as effective as A2, should be given preference because of the lower costs it incurs. A3 is also superior to A2 because it has higher effectiveness, although the costs for both measures are the same. It is then up to the cost/effectiveness analysis to decide upon the advantage of A1 or A3.

Decisions reached by means of subtraction, as in cost/benefit analysis, cannot be made because costs and benefits have different dimensions. Yet it is possible to consider the ratio of the total efficiency of a measure to its cost (efficiency ratio). It becomes obvious that this quotient is inadequate as the sole criterion of selection, and needs supplement-

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Figure 1. Preselection of effective measures.
ing by minimum efficiencies and budget restrictions [19] (cf. step 8 of the algorithm). The problem of monetary and nonmonetary evaluations of benefit components has not been solved. In any case, combinations could be proposed in such a form that monetary benefits are defined as inverse costs and then subtracted from the project costs while the remaining total is compared with the elements of costs that are not monetarily evaluated. In this case, however, restrictions in ranking must be observed. Besides, the possibilities of transforming monetary target profits into degrees of target achievement and vice versa [13, 23] raise problems, but these have already been checked out by practical profitability analyses. This, of course, only makes sense if the relation between the points themselves has not been deduced from the relation between the monetary values.

Sensitivity Analyses

Sensitivity tests of the results of cost/effectiveness analyses for variations in critical parameters are indispensable. This is because of the numerous subjective influences (scale of target achievement, target weighting, and target system).

SUGGESTION FOR A HARMONIZED ALGORITHM IN COST/BENEFIT AND COST/EFFECTIVENESS ANALYSIS OF SAFETY MEASURES IN MOTOR VEHICLES

The relative merits of safety measures in motor vehicles can be assessed in many ways, differing from each other in details, but all could be called cost/benefit or cost/effectiveness procedures as described in the preceding sections of this paper. Inevitably, each country in Europe adopts somewhat different procedures from each other, in methodology as well as assumption, and the accident data are different. It happens that the procedures used in the Federal Republic of Germany and in Great Britain are remarkably similar, though the former uses the methods more precisely and requests by law that all public authorities follow them for appropriate measures of considerable financial importance. The algorithm now described is that adopted by the Federal Republic. In France, cost/benefit analysis is used in a generally similar manner but a distinction is made between a simplified cost/benefit method and a more exact a priori method. The latter is used to cover as comprehensively and exactly as possible all relevant effects and costs, while the simple method suffices to determine extreme or limiting values. For example, given a certain cost/benefit ratio, only the maximum permissible costs per vehicle are determined.

It is noteworthy that in government circles only cost/benefit procedures are used, though in research and industry cost/effectiveness analyses are carried out as aids to decision-making.

Algorithm in Nine Steps

Step 1: Definition of the Problem. The first step consists of defining the task of the cost/benefit study as exactly as possible. As an example: A series of traffic safety measures for cars (about 5-10 measures) is to be selected according to their degree of advantage for society as a whole and ranked according to priority. In practice, there may be a few alternative solutions, or even just one feasible solution.

Step 2: Approach to the Achievement of the Target. In this case, the ultimate target is the improvement of traffic safety—it is defined as the decrease in the numbers of fatalities, seriously and slightly injured, as well as material damage. This ultimate target shall be achieved by dividing the task into two subtargets: improvement of primary (accident avoidance) safety and secondary safety (road-user protection). It might be appropriate to propose a further subdivision of the subtargets into the tasks of improvement of safety inside the vehicle and outside the vehicle (this applies to secondary safety only). The second step also includes the definition of target criteria (measuring unit and, as the case may be, minimum effectiveness and target date).

Step 3: Factors Affecting Performance of Measures and Limitations To Be Accepted for the Study. Within the field of vehicle safety it
is necessary to identify the different safety problems and possible alternative solutions. Consideration must be given to the effects of one safety measure on the potential of another, and the extent to which different measures compete, both within the fields of car safety and road safety in general, and with other areas of public concern.

Step 4: Preselection of Measures. Measures from which only marginal target improvements could be expected should be excluded from the analysis right from the start. Similarly, measures primarily intended for other purposes and those whose specific contributions may not readily be estimated may also have to be excluded. This could lead to an early shifting of weights in favour of passive measures. Measures should be included whose efficiencies have already been explored—safety belts, interior padding, steering column, driving mirror, door locks and handles, windscreen, seats, and brakes. In France, great emphasis is being placed on an a priori limitation of measures regarding vehicle safety features. For this purpose, a selection of the main accident types and frequencies is made and every 15th accident protocol will be analysed with regard to the risk of being involved in an accident depending on vehicle parameters. In addition, this investigation will be supported by clinical tests of persons having been involved in accidents. Using these means, technical vehicle features have been developed which promise to be highly effective. However, the final preselection by means of the exclusion criterion will only be possible after the costs and benefits have been determined.

Step 5: Recognition and Description of Advantages and Disadvantages—Their Occurrence in Time, Regardless of Where They Occur or Who Is Affected.

a. Disadvantages. In a profitability analysis of safety measures for motor vehicles, the following types of costs should be taken into consideration: the opportunity cost of the resources used in the investment, service repairs, and costs of operation, as well as the cost because of pollution (for example, increased exhaust gases because of higher fuel consumption of safety vehicles whose weight might be increased). These may include increased fuel consumption, journey-time delays, and increased costs because of reductions in sales.

b. Advantages. The benefits should exclusively recognise the number of accidents that will be avoided (primary measures) and the reduced consequences of the accidents that will not (secondary protective measures). Further concrete achievements will be attempted after the evaluation (cf. step 7).

Steps 6 and 7: Determination of the Measuring Scale and Evaluation of the Advantages and Disadvantages of Step 5. The types of costs mentioned in step 5a will be monetarily evaluated as a matter of course, at market prices as a rule, and occasionally decreased by the share of indirect tax. Despite all differences of opinion about the benefits, there seems to be a possible consensus about the monetary evaluation of the number of fatalities and serious and slight injuries avoided. (In France, benefits are only expressed in monetary terms.) The number of objections may decrease considerably once this procedure is properly interpreted. Unquantified effects should be noted for consideration in the overall assessment. The strength of the evidence on which estimates are made, and the nature of the explicit or implicit assumptions necessary, should be indicated.

Step 8: Discounting and Overall Assessment of Measures. Benefits and costs in monetary terms are compared by discounting to present values. Where ranking of alternatives is required, the “present-value rule” (working out differences) or the “cost/benefit ratio” is applied as the ranking criterion. Where noncompeting (in the sense of being direct alternatives) safety projects producing net present values would more than exhaust the available budget, some selection criterion such as the net benefit (cost ratio or the marginal-quotient rule of Netto) will be required in order to maximise the benefits.

If the costs are compared with the nonmonetary benefits, discounting may be neglected for the time being, but the target date must be clearly emphasised. On the basis of the quotient rule, the ranking criterion is then that, if the effectiveness of a measure
grows steadily with investments, the selection of alternatives is possible as follows:

The measure with the highest efficiency ratio is applied until budget exhaustion, provided the projected minimum effectiveness is achieved. If costs and effectiveness change discontinuously due to the indivisibility of the measures, these measures are then applied in the order of decreasing efficiency coefficients. In some cases, discontinuous variation in measures, caused by budgetary restrictions, may lead to the following:

- A measure with the higher efficiency and higher overall effectiveness is rejected in favour of a less efficient measure, which, however, stays within the budget.
- A less efficient measure, whose overall effectiveness is higher, is rejected and a measure with higher efficiency but lower overall effectiveness is used instead.

Any remaining budgetary funds are spent according to the projected minimum effectiveness.

Step 9: Sensitivity Test. For sensitivity analyses in terms of money, it is recommended that these cover estimated effects, the assumptions made, the costs estimated, the parameters of “current value” and “discount rate,” and the “value attributed to the economic loss caused by a person killed in a traffic accident.”

The effect of the nonmonetary benefits on the result must on all accounts be examined by varying the weighting of the targets, the levels of possible target achievement, the estimated effects of the assumptions made, and the estimated costs.

COMPARISON OF ECONOMIC ASSUMPTIONS MADE FOR EVALUATION STUDIES

Basic Reasons for Differences Between Findings from Similar Studies

As stated in the introduction, the concern of EEVC is that the reasons should be understood for the differences that arise between findings from economic appraisal studies of vehicle safety carried out by the various countries working together in EEVC. This part of the present report attempts to show why these differences occur even after basic methodology has been agreed to. It is a new presentation, but includes some material from reference [1] based on a questionnaire that was circulated to member countries requesting information on a number of statistics and economic variables used by them for these evaluations.

Essentially, three types of differences were revealed, with various implications. First, there are the differences in methods adopted that do not reflect basic differences in the interests of the countries concerned. Where there is a choice between alternative methods and assumptions with no single solution, and where the conclusions reached in evaluations depend upon the selections made, it is possible that solutions reached independently in the various countries will yield different results. This may be reflected in the balance between advantages and disadvantages, or in the ranking of alternatives. Where differences of this sort are involved, the implication is that the apparent difference in priorities between countries may be spurious and that some solution should be sought to yield a common choice, and ranking, of safety measures.

The second difference that arises results from the use of different input information by countries, and reflects real differences in the relative interests of the members. For example, the discount rate chosen may differ between countries because of different attitudes to the discounting of the future. (Although it could of course be simply a difference in the choice of one from a number of possible rates, as in the previous paragraph.) Similarly, the application of the United Kingdom’s method of deriving a value of life would result in a higher value in the Federal Republic, because of the higher level of real earnings per capita in that country. In the latter example, the implication is that it would be reasonable to spend more per life saved in Germany than in the United Kingdom, because more resources are available. Such real divergence of interests or values will give rise to some difference in the results of studies. The resultant differences in the indi-
cated absolute or relative advantages of alternative safety measures would then reflect a real difference of priorities between the countries concerned. Again, the extent and importance of such differences can only be assessed empirically.

The third type is similar to the second. The accident situation will vary from country to country, in terms of the number, severity, type, and nature of accidents and injuries. The relative importance of different accident situations and safety solutions will vary, to a degree, between countries. Similarly, the effectiveness of a particular measure, or the best solution to a particular problem, will vary. Again, it is an empirical question as to how important such differences are.

In practice, of course, it will not always be possible to identify the cause of differences between countries. There may be a number of factors involved, and there will be differences because of our imperfect knowledge. For example, contradictions in the assumed effectiveness of seatbelts between two countries may reflect a true distinction in the effectiveness of belts in the accident situations prevailing in those countries, or it may reflect a simple difference in the estimation of what is in fact the same degree of effectiveness. It is only where there are major differences between countries that it is important to determine whether there is a real difference of priorities or a spurious one.

DETAILED DISCUSSION OF ASSUMPTIONS MADE IN STUDIES

Differences Among Countries

It is not the intention of this paper to compare in detail the methods of evaluation chosen by the member countries, or to argue that any particular method has outstanding merit. While there are basic similarities in the approaches to evaluation by member countries, there has been no attempt to synthesise these to produce a single evaluation procedure. It would not in any case be practicable to do so in the context of the EEVC, since the procedures adopted by different countries are usually applied in other sectors of their economies. In this section, differences in the values assigned to variables are discussed in the context of an outline of the common elements in the appraisal methods of member countries. In the following section, the implication of such differences in practice is considered by way of a comparison of some vehicle safety evaluations carried out by three of the member countries.

The Base Date

Typically, we can assume that safety devices or developments will give rise to costs at the time of their being built into, or fitted to, cars. The initial cost of such devices can therefore generally be treated as being incurred either at a single point of time (or sometimes a single time period) or as being incurred continually from that base date as new cars are produced. The particular assumptions made will depend on the details of the methods employed and on the nature of the proposal being considered. The effects of new measures, mainly accident savings or casualty savings but sometimes other costs and benefits, are then usually considered in terms of this base date. Occasionally, some other base date is chosen, but this will not influence the results of the evaluation (that is, the relative magnitudes of costs and benefits), although the choice of the date at which the measure is implemented may well do so.

Deflating Future Costs and Benefits

Because the costs and benefits resulting from a safety measure will be spread over a period of years, during which time the general level of prices will typically rise, it is usually necessary to deflate the value of future costs and benefits and to indicate them all in terms of the costs prevailing at the base date (unless there has been a change in the real value of costs or benefits rather than the purely monetary value).

Discounting

Having thus identified all costs and benefits in commensurate terms, those occurring in
the years after the introduction of the measure are normally discounted according to the rate of discount adopted by each country. Essentially, the future is discounted for one of two reasons. First, there is the fact that resources available today are worth more than the same quantity next year, because of the transformation possibility—resources can be invested to produce resources of a higher value at a future date. Because of this, future costs and benefits are worth less than similar effects in the base year.

Second, there may be true time preference, with society having a preference for resources available today as opposed to those available at a future date, irrespective of any transformation possibility. This preference may be reflected in a rate of discount. In practice, it may be difficult to isolate the time preference and the transformation element in a country’s discount rate. Member countries do not have a common basis to their discount rates. Between countries there may be differences both in transformation possibilities and in time preference. In addition, the rate chosen will in practice often depend upon estimates of the rates of return on private investment, which may differ among countries, or on interest rates applying elsewhere in the respective economies. In the case of the United Kingdom, for example, the discount rate is based upon an estimate of the rate of return earned on an average on (riskless) investments in the private sector. The rate so derived may or may not be appropriate, and there is no reason why it should be similar to the rate adopted in another country. It could be argued that a discount rate for safety measures should reflect public attitudes to spending resources now for future safety benefits, which may well imply lower discount rates than commonly chosen for the other reasons already discussed.

In practice, it is futile to attempt to rationalise the discount rate adopted by individual countries, or to attempt to understand why they vary. What matters in practice is how great the differences in rates are and what the implication is for the appraisal of measures. Right or wrong, there is no option but to assume that variations reflect real differences in the interests of the respective countries. The discount rate applied can therefore be taken as the required rate of return on resources invested in vehicle safety, generally irrespective of whether the costs are met from public funds or are paid by private individuals.

The higher the discount rate adopted, the greater the relative importance attached to immediate effects as opposed to long-term effects. Where benefits (and costs) are spread evenly over a given period of years, the sum of discounted benefits may be derived by multiplying the benefits in a given year by the discount factor, derived from the discount rate, and the period of years concerned. The higher the discount rate, the lower the discount factor.

Table 1 shows the discount rates and discount factors (assuming a 10-year period) for France, Germany, and the United Kingdom. The discount factor for Germany is 13 percent higher, with the implication that the cost/benefit ratio would also be 13 percent higher in this case. The result is that the potential benefit from any safety measure, where costs are followed by benefits, is higher in Germany than in the other two countries. Further, where there are alternative measures with different time distributions of benefits (and costs), the higher rates adopted by France and the United Kingdom will favour measures with early benefits, as opposed to those with later benefits, more strongly than

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<th>Country</th>
<th>Discount rate (%)</th>
<th>Discount factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>b10</td>
<td>6.37</td>
</tr>
<tr>
<td>Germany</td>
<td>c7</td>
<td>7.20</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>d10</td>
<td>6.37</td>
</tr>
</tbody>
</table>

aAssuming a life span of 10 years.
bDiscount rate since 1971.
cDiscount rate from 1969 to 1972. Source: W. Kentner, 'Die Verkehrssicherheit als Wirtschaftliche Planungsgrösse, Strasse und Autobahn, 12 642-647, 1972. Alternative rates suggested were (1) 6.5 percent in Arbeitsgruppe Wegekosten, 'Bericht über die kosten der Wege des Eisenbahn-, Strassen-, and Binnerschiffsverkehrs in der Bundesrepublik Deutschland,' Schriftenreihe des Bundesministers für Verkehr, Heft 34 and (2) 5 percent and 7 percent in Angeboten des Bundesministers für Verkehr.
dDiscount rate since 1968.
the lower rate adopted by Germany. Consequently, the relative rating of alternatives will differ, and the overall ranking of alternatives may differ among Germany and France and the United Kingdom.

The Time Span

The effects of a safety measure are assumed to continue for a limited period of time. In the case of vehicle safety, this is often assumed to be the life of the car. Clearly, the longer the period assumed, the greater the net benefit, other things being equal. In the situation where the life of the car is assumed to be the relevant period, the expected lifetime of cars may be of significance where it varies among countries. Table 2 shows estimates of the average age of vehicles being scrapped in 1972 in the six countries questioned. Considerable care would be needed in comparing these average-age estimates. It is quite possible that the figures for each country are not strictly compatible, and they can be taken only to illustrate the point that there could be real differences in the value of measures between countries because of differences in vehicle life.

Table 2. Average age of cars scrapped in 1972

<table>
<thead>
<tr>
<th>Country</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>a10</td>
</tr>
<tr>
<td>Germany</td>
<td>a,b 10</td>
</tr>
<tr>
<td>Italy</td>
<td>9</td>
</tr>
<tr>
<td>Netherlands</td>
<td>9</td>
</tr>
<tr>
<td>Sweden</td>
<td>12</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>a11</td>
</tr>
</tbody>
</table>

*a*Includes cars scrapped due to accident damage.

*b*Average life of station wagons is 8.9 years.

There are a number of other important considerations. The life of a car need not necessarily represent a good guide to either the distance it travels during its life or to the expected accident involvement. Further, the use of a car diminishes with age, and it would be possible to allow for this when discounting benefits to the base date, although in practice this is not done. For a number of reasons it is likely that differences in estimates of the life of vehicles would be poor indicators of real differences among countries. However, differences in assumptions made about vehicle life will have an effect upon conclusions, and there is a case for arguing that where comparisons are to be made between countries, a common vehicle life should be assumed. The choice of the assumed life will affect not the ranking of projects within a country, but rather the relative size of costs and benefits.

Expected Accident Involvement

The benefits to be derived from any safety measure will depend upon the efficacy of the measure in reducing accident involvement or severity, or in reducing injury, and on the expected accident involvement of the car in question. A safety development may be relevant to one or a number of accident situations, and may have a different effect in each. The benefits to be derived per car will therefore depend upon the average expected accident involvement of the car concerned, which will in turn depend upon the expected accident future of the country concerned.

Because of differences in road networks, traffic volumes and mixes, the characteristics of roads and the environment through which they pass, the size and performance of vehicles, the safety measures in operation, driver characteristics, and so on, no two countries face the same accident scenario, either in total or per car. The average expected accident involvement for each car will depend upon the country in which it is to be used. Both the expected number of accidents and the nature of those accidents will vary, as will the efficacy of any safety measure.

The advantage to be gained from any safety measure will therefore vary between countries. The relative advantage of different types of safety measure will similarly vary. These are real differences, with the implication that it is quite possible that different accident measures would be suitable for different countries. Clearly there are considerable advantages in common safety measures, as witnessed by organisations such as the EEVC, but it must be recognised that there will, on occasion, be very real differences of interest.
between countries, that may or may not be suitably covered by a compromise solution.

In table 3, car-occupant casualties in the member countries for 1973 are shown. There are differences both in the number of accidents per car per annum, and in the nature of those accidents. Safety measures will consequently not have the same effect in each country, and the relative efficacy of measures will also vary. Consequently it is not possible to indicate the likely extent of savings in each country without specific reference to safety measures. Further, the value of benefits will depend upon the value attached to the costs of those accidents in each country.

The Efficacy of Safety Measures

As has been stated above, the benefits from any safety measure will depend in part upon the effectiveness of that measure in reducing accidents or injuries, and the effectiveness is likely to vary among countries in many instances. Leaving aside any differences in the pattern of accidents and injuries, which have already been discussed, there will be real differences in effectiveness because of the nature of roads, vehicles, and drivers, and because of variations in the structure and effectiveness of other safety measures in the countries concerned. Clearly the difference in effectiveness will be much greater in some instances than in others, and sometimes there may be no significant difference at all. For example, some countries require the wearing of seatbelts, and this reduces the possible effectiveness of further safety measures when compared with values for countries not requiring them.

Again it is not possible to compare effectiveness levels among countries since they will vary according to the measure, or sets of measures, concerned. Nevertheless, any differences will affect both the absolute and the relative attractiveness of measures. A further complication in practice is that there will usually be a difference between the estimated level of effectiveness and the true effectiveness, with differences among countries, which acts to distort the true difference in effectiveness between countries (and also to distort the true relative attractiveness of measures of each country). This is an unavoidable source of error. The correct procedure would be to estimate separate effectiveness rates for each country as far as possible, rather than to assume a common level of effectiveness.

The Costs of Safety Measures

As has been mentioned, this work is commonly concerned either with safety devices fitted to new cars, or with safety requirements for vehicle design standards. In both cases, costs are primarily incurred at the time of manufacture or sale, although in some cases there will be subsequent costs because of replacement or maintenance. In a few instances, there will be a requirement for the fitting of devices to existing vehicles. Where this is so, the cost per unit may well differ from that incurred with a new vehicle (and the benefits will also probably be less, because

Table 3. Car occupant casualties 1973

<table>
<thead>
<tr>
<th>Country</th>
<th>Casualties</th>
<th>Number of cars (thousands)</th>
<th>Casualty rates per million cars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Killed</td>
<td>Injured</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>7 920</td>
<td>195 000</td>
<td>13 920 (1972)</td>
</tr>
<tr>
<td>Federal Republic</td>
<td>7 820</td>
<td>300 000</td>
<td>15 704</td>
</tr>
<tr>
<td>Great Britain</td>
<td>3 050</td>
<td>167 000</td>
<td>13 492</td>
</tr>
<tr>
<td>Italy</td>
<td>4 560</td>
<td>140 000</td>
<td>14 800</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1 360</td>
<td>26 000</td>
<td>2 900 (1972)</td>
</tr>
<tr>
<td>Sweden</td>
<td>630</td>
<td>15 000</td>
<td>2 457</td>
</tr>
</tbody>
</table>
of a shorter effective life and possibly to a lower effectiveness level). From an economic point of view, the decision to fit a device to new and existing cars should be based upon separate justifications, although the cost of devices may depend upon whether one or both categories are involved.

The cost of applying safety requirements will be likely to vary to some extent between cars, because of both the size variation and other factors specific to individual makes of cars. Because the car population varies between countries, unit costs may also vary. Further, there may be real differences in the costs for the same resources between countries, which will mean that the cost of safety devices to the same standards may vary between countries. There may be differences that apply to all resources, as, for example, where one country enjoys significant economies in scale because of a high volume of production. There will also be real differences in the relative costs of different goods between countries, reflecting differences in their relative advantages. The consequence of this is that unit costs may be higher in one country than in another, thereby reducing the attractiveness of that measure in absolute (and perhaps in relative) terms; or it may be that the solution that is optimal to a specific safety problem may differ between countries. Once again, it is not possible to point to an overall effect, since it will vary with the safety requirement concerned.

As was discussed earlier, the method of costing adopted is that of opportunity cost pricing. The cost of any resource is said to be equal to its value in its next best alternative use, which in practice can usually be taken to be shown by its market price. For vehicle safety capital costs, the cost that is relevant is the cost of manufacture per unit, plus a margin for normal overheads, distribution costs, and normal profits, plus the average level of indirect taxation operative in the country concerned. In practice, this will usually equate with the retail cost of the improvement, modified, if necessary, for taxation. It is not obvious how costs of a safety measure may be estimated when the measure is fitted to new cars as an optional extra with an incremental price tag that reflects sales rather than cost conditions. For example, some care is required in the appraisal of new measures to ensure that all costs are identified and included—the fitting of windscreen glass involves both an initial cost and also a cost associated with the replacement of broken screens. Care is also needed to ensure that the cost included is a realistic long-term cost, rather than a high cost associated with small-scale production, or a low cost of the type sometimes employed to sell a safety device where subsequent replacement or maintenance will be frequent and expensive.

**Accident Costs**

The principal benefit of safety measures is, of course, the consequent reduction in the number and severity of accidents and injuries. To compare these savings with the costs of the measures, values need to be assigned to the benefits achieved. As has been discussed, the number and nature of such accident and casualty savings will vary from country to country for a number of reasons. The value attached to such savings will also vary among countries.

In tables 4 and 5, the average costs assigned to accidents of different severities—fatal, serious, slight-injury, and damage-only accidents—are shown for France, Germany, the Netherlands, Sweden, and the United Kingdom. The values shown are in terms of the home currency and in the years for which values were provided.

It is difficult to translate such values to a common base, because of the limitations of the official rates of exchange (a problem that will be discussed later). In addition, there are problems in converting to a single base year, because of possible differential rates of growth of such values since the dates for which they were provided. Despite this, but remembering its importance, a comparison of values for France, the Federal Republic, and the United Kingdom for 1975 is shown in table 7 later in the paper, updated where necessary according to respective inflation rates. The values shown should be regarded as very approximate, but they do provide an
### SECTION 2: GOVERNMENT STATUS REPORTS

#### Table 4. Average costs per accident

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Damage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>France (F)</td>
<td>1973</td>
<td>386 000</td>
<td>256 000</td>
<td>-</td>
<td>50 000</td>
<td></td>
</tr>
<tr>
<td>Germany (DM)</td>
<td>1968</td>
<td>340 000</td>
<td>15 000</td>
<td>3 000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Netherlands (FL)</td>
<td>1968</td>
<td>63 904</td>
<td>3 687</td>
<td>1 600</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sweden (Kr)</td>
<td>1972</td>
<td>502 500</td>
<td>83 000</td>
<td>1 600</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1973</td>
<td>26 000</td>
<td>1 900</td>
<td>350</td>
<td>150</td>
<td>e2 300</td>
</tr>
<tr>
<td></td>
<td>1968</td>
<td>16 980</td>
<td>1 230</td>
<td>220</td>
<td>90</td>
<td>1 600</td>
</tr>
</tbody>
</table>

- Direct and indirect costs.
- The only indirect costs are those because of loss of leisure time.
- The source of these figures is the Dutch Economic Institute. This is not a government institution.
- Direct costs only.
- Total costs of all accidents divided by the number of injury accidents.

#### Table 5. Average costs in Sweden, France, and the United Kingdom, in different currencies

<table>
<thead>
<tr>
<th>Currency and country</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Damage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Francs:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>386 000</td>
<td>256 000</td>
<td>-</td>
<td>50 000</td>
<td></td>
</tr>
<tr>
<td>Sweden (1972)</td>
<td>532 900</td>
<td>88 000</td>
<td>1 700</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>283 400</td>
<td>20 700</td>
<td>3 800</td>
<td>1 600</td>
<td>e25 100</td>
</tr>
<tr>
<td>DM:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>231 000</td>
<td>15 360</td>
<td>-</td>
<td>30 000</td>
<td></td>
</tr>
<tr>
<td>Sweden (1972)</td>
<td>338 400</td>
<td>55 900</td>
<td>1 100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>170 000</td>
<td>12 400</td>
<td>2 300</td>
<td>980</td>
<td>e15 000</td>
</tr>
<tr>
<td>Lire:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>50 540 000</td>
<td>3 350 000</td>
<td>-</td>
<td>6 540 000</td>
<td></td>
</tr>
<tr>
<td>Sweden (1972)</td>
<td>61 786 000</td>
<td>10 206 000</td>
<td>196 000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>37 086 000</td>
<td>2 710 000</td>
<td>499 000</td>
<td>214 000</td>
<td>e3 281 000</td>
</tr>
<tr>
<td>Guilder:</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>242 350</td>
<td>16 100</td>
<td>-</td>
<td>31 400</td>
<td></td>
</tr>
<tr>
<td>Sweden (1972)</td>
<td>341 300</td>
<td>56 400</td>
<td>1 100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>177 800</td>
<td>13 000</td>
<td>2 400</td>
<td>1 030</td>
<td>e15 700</td>
</tr>
<tr>
<td>Kroner:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>378 000</td>
<td>25 050</td>
<td>-</td>
<td>48 900</td>
<td></td>
</tr>
<tr>
<td>Sweden (1972)</td>
<td>502 500</td>
<td>83 000</td>
<td>1 600</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>277 500</td>
<td>20 300</td>
<td>3 740</td>
<td>1 600</td>
<td>e24 600</td>
</tr>
<tr>
<td>Pounds:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>35 400</td>
<td>2 350</td>
<td>-</td>
<td>4 600</td>
<td></td>
</tr>
<tr>
<td>Sweden (1972)</td>
<td>44 100</td>
<td>7 300</td>
<td>140</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>26 000</td>
<td>1 900</td>
<td>350</td>
<td>150</td>
<td>e2 300</td>
</tr>
</tbody>
</table>

- Direct and indirect costs.
- The only indirect costs are those because of loss of leisure time.
- Damage figures not available.
- Direct costs only.
- Total costs of all accidents divided by the number of injury accidents.
interesting indication of the extent of the differences in the values assigned.

The values shown reflect more than just the differences in valuations. The costs per accident also reflect the nature of the accident concerned, and differences in their average severity and in their consequences. Even in the case of fatal accidents there may be some variation, because of small differences in the number killed on average in each fatal accident, and in the number and severity of other injuries to those involved. However, in this case, the difference that results is likely to be of little importance. Similarly, the nature of all injury accidents and of damage-only accidents will vary between countries.

It is also important to note that the division of nonfatal-injury accidents into serious and slight accidents is not done on a common basis, which negates the relevance of any comparisons suggested by the figures. Attention is therefore better focused on fatal accidents, though it should be remembered that the value attached to fatal accidents will be dominated by the value attached to the saving of life, perhaps the most contentious of values.

The basis of the costs assigned to accidents and casualties is not the same for each country. Quite different methods and assumptions are applied, but it is not the intention of this paper to consider these differences in any depth. The major difference does of course come in the value attached to life itself and to suffering, the other elements being more truly costs that can be identified, quantified, and more readily valued in monetary terms.

Leaving aside the values assigned to life and similar elements, the costs assigned will differ between countries because of differences in the nature of accidents and injuries, differences in the real resource costs associated with such accidents, differences because of estimation errors, and differences in some of the methodological assumptions made. Some of these differences will reflect dissimilar real costs, and some will reflect the methods adopted. The real differences in costs are correctly reflected in the values assigned, but it could be argued that, in the case of the other differences, there would be some advantage in the adoption of common assumptions and treatment of costs.

Some of the resource implications of death and injury, such as the loss of productive output, can be identified and valued. Society is, however, concerned with more than these resource savings where the saving of life and the avoidance or reduction of injury are concerned. It can be reasonably argued that it is impossible to put a value on life itself, but there is a limit to the resources that society is willing and able to devote to the saving of life, and this fact needs to be reflected in the values chosen, which in turn lead to the allocation of resources to safety. We are therefore concerned not so much with the value of life, but with a measure of the value of resources that each country is willing to devote to the saving of life.

The difficulties of determining an appropriate value of this sort are immense, and the values assigned at present tend to be fairly tentative. In the case of the United Kingdom, for example, the method adopted has been to estimate the resource costs resulting from the loss of a life on average and to add to this a national allowance for society’s willingness to devote more resources to the saving of life than are justified by the resource savings that result. The value so derived is specified as a minimum value only.

It is therefore to be expected that values will vary among countries. For example, the value of lost output per life will be greater in Germany than in the United Kingdom, because of the higher output per head. The resource consequences of the loss of a life will vary among countries. In addition, the willingness of the country to devote resources to life saving, or its ability to do so, will vary. Finally, because of the difficulties in determining an appropriate value, if only a minimum one, there will be differences between countries only because of the choice of a value made. Assigned casualty costs are shown in tables 6, 6A, and 6B.

Whatever the reasons for the difference in values that results, the application of such values will result in rather different conclusions in the safety evaluations for each country. The main effect will be to alter the ratio of costs to benefits for each proposed
SECTION 2: GOVERNMENT STATUS REPORTS

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>France (F)</td>
<td>1973</td>
<td>320 000</td>
<td>a48 000</td>
<td>a1 600</td>
<td>26 500</td>
</tr>
<tr>
<td>Germany (DM)</td>
<td>1968</td>
<td>310 000</td>
<td>11 400</td>
<td>1 800</td>
<td></td>
</tr>
<tr>
<td>United Kingdom (£)</td>
<td>1973b</td>
<td>23 000</td>
<td>1 300</td>
<td>40</td>
<td>830</td>
</tr>
<tr>
<td></td>
<td>1968b</td>
<td>14 960</td>
<td>810</td>
<td>25</td>
<td>520</td>
</tr>
</tbody>
</table>

A Average cost per serious and slight casualty 14 000 Fr (8 400 DM; 1 833 000 Lire; FI 8 790; 13 700 Kr; £1 300).
B Average cost per casualty specific to a casualty-loss of output, and medical, funeral, and indirect costs.

Table 6. Average cost per casualty

Table 6A. Average costs per casualty in Germany and the United Kingdom (1968) in different currencies

<table>
<thead>
<tr>
<th>Currency and country</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Francs:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>385 000</td>
<td>14 100</td>
<td>2 200</td>
<td>6 160</td>
</tr>
<tr>
<td>United Kingdomb</td>
<td>177 400</td>
<td>9 600</td>
<td>300</td>
<td>4 970</td>
</tr>
<tr>
<td>DM:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>310 000</td>
<td>11 400</td>
<td>1 800</td>
<td>4 970</td>
</tr>
<tr>
<td>United Kingdomb</td>
<td>142 900</td>
<td>7 740</td>
<td>240</td>
<td>6 160</td>
</tr>
<tr>
<td>Lire:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>48 400 000</td>
<td>1 780 000</td>
<td>280 000</td>
<td>776 000</td>
</tr>
<tr>
<td>United Kingdomb</td>
<td>22 319 000</td>
<td>1 208 000</td>
<td>37 000</td>
<td>6 400</td>
</tr>
<tr>
<td>Guilder:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>281 000</td>
<td>10 300</td>
<td>1 600</td>
<td>4 500</td>
</tr>
<tr>
<td>United Kingdomb</td>
<td>129 600</td>
<td>7 000</td>
<td>220</td>
<td>6 400</td>
</tr>
<tr>
<td>Kroner:</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Germany</td>
<td>401 000</td>
<td>14 800</td>
<td>2 300</td>
<td>6 400</td>
</tr>
<tr>
<td>United Kingdomb</td>
<td>185 000</td>
<td>10 000</td>
<td>310</td>
<td>520</td>
</tr>
<tr>
<td>Pounds:</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Germany</td>
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<tr>
<td>United Kingdomb</td>
<td>14 960</td>
<td>810</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>

A Average cost per serious and slight casualty 14 000 Fr (8 400 DM; 1 833 000 Lire; FI 8 790; 13 700 Kr; £1 300).
B Average cost per casualty specific to a casualty-loss of output, and medical, funeral, and indirect costs.

measure rather than to alter the relative merits of alternatives.

Nonsafety Costs and Benefits

We have above been concerned primarily with costs and benefits in terms of safety. However, many of the safety measures will have nonsafety implications, and many of the requirements made of manufacturers will relate to nonsafety matters, such as pollution control and fuel consumption. This paper is concerned only with safety measures, though the same principles of evaluation would apply to other questions. Where safety measures have nonsafety effects, these should be costed and treated in the same way as safety effects, where possible.

The Exchange Rate Problem

One of the difficulties involved in the comparison of economic evaluations done in different countries is that of translating the costs and benefits calculated in one country into comparable values in terms of another country's currency. The official rate of exchange between two countries is a less than perfect indicator of the relative value of the two currencies. For comparison purposes, a means of comparing the resource cost of costs and benefits in each country is needed rather
## Experimental Safety Vehicles

<table>
<thead>
<tr>
<th>Currency and Country</th>
<th>Fatal</th>
<th>Serious</th>
<th>Slight</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Francs:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>320 000</td>
<td>a48 000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom b</td>
<td>251 000</td>
<td>14 200</td>
<td>440</td>
<td>9 050</td>
</tr>
<tr>
<td><strong>DM:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>192 000</td>
<td>a28 800</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom b</td>
<td>150 000</td>
<td>8 500</td>
<td>260</td>
<td>5 400</td>
</tr>
<tr>
<td><strong>Lire:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>41 879 000</td>
<td>a6 282 000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom b</td>
<td>32 807 000</td>
<td>1 854 000</td>
<td>57 000</td>
<td>1 184 000</td>
</tr>
<tr>
<td><strong>Guilder:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>201 000</td>
<td>a30 100</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom b</td>
<td>157 000</td>
<td>8 900</td>
<td>270</td>
<td>5 700</td>
</tr>
<tr>
<td><strong>Kroner:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>313 000</td>
<td>a57 000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom b</td>
<td>246 000</td>
<td>13 900</td>
<td>430</td>
<td>8 860</td>
</tr>
<tr>
<td><strong>Pounds:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>29 400</td>
<td>a4 400</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>United Kingdom b</td>
<td>23 000</td>
<td>1 300</td>
<td>40</td>
<td>830</td>
</tr>
</tbody>
</table>

a Average cost per serious and slight casualty 14 000 Fr (8 400 DM; 1 883 000 Lire; £1 790; 13 700 Kr; £1 300).

b Average cost per casualty specific to a casualty-loss of output, and medical, funeral, and indirect costs.

Table 6B. Average costs per casualty in France and the United Kingdom (1973) in different currencies

than their money value converted via the rate of exchange. To a point, it would be possible to make comparisons in these terms, but there are limitations. A particular problem is that there may be different sets of relative prices in each country, so that there may be no unique solution to the problem.

It is probably not worthwhile, in practice, to attempt to devise a more appropriate rate of exchange, although it is important to bear the problem in mind when comparing values. The major effect of any distortion in the exchange rate will be to alter the magnitude of both costs and benefits when looking at an evaluation carried out by another country. The exchange rate should not affect the ratio of costs to benefits, or the ranking of alternative projects by that country. The greater danger comes when information (such as the cost of a particular safety device) from another country is converted via the rate of exchange and used in an evaluation by the country concerned.

**Summary**

This section has discussed some of the elements of economic evaluations in the field of vehicle safety, with some reference to the differences in values and assumptions between countries. Differences have been identified that reflect real differences in the suitability of measures for different countries, as well as differences that result purely from the assumptions and values chosen and that do not reflect any difference of interest. In the next section, comparison is made of the differences that can result as a consequence of these factors when several countries apply their methods of appraisal to the same safety problem. To do so, it has been necessary to apply a rate of exchange, the limitations of which should be borne in mind.
COMPARATIVE EXAMPLES OF SAFETY EVALUATION

Basic Comparison

To compare fully the methods of evaluation employed by member countries and to investigate the consequences of differences in methods, assumptions, and values would be a task beyond the scope of this paper. Differences could be expected both in the magnitude of estimated costs and benefits and in the ranking of alternative measures. A large number of examples from each country would need to be compared before conclusions could be reached on the significance of the differences concerned. There are, at present, too few examples available to EEVC to permit such an exercise.

Instead, a far more limited exercise will be undertaken. For three countries, Germany, France, and the United Kingdom, the implications of differences in the basic assumptions are considered, looking at the effect on the discounted value of benefits over the life of a car, given that an identical reduction in casualties would have been effected in each case. There would then be further differences because of differences in the particular situation being faced—the initial accident and casualty situation, the effectiveness of the specified measure and the costs of measures would each be specific to the countries concerned and, while perhaps similar, they would be the same only by chance.

In table 7, the values applied by each of these countries are shown, and the discounted values of the saving of one casualty of average severity each year for 10 years are compared. Benefits are assumed to grow at a rate of 3 percent a year in real terms in each case, reflecting the increase in national wealth. For the sake of comparison only, it is assumed that in each case 3 percent of the casualties would be fatal. The values shown for France are based upon 1974 values, up-rated, and are not official figures. Because of the difficulties of transforming values into values in terms of the currencies of other countries via exchange rates, the resultant values shown should be regarded as rough indicators only.

It will be noted that, while very similar values are applied by France and the United Kingdom to the saving of life, the value

<table>
<thead>
<tr>
<th>Table 7. A comparison of the value of casualty savings in 1975 values for France, Federal Republic of Germany and the United Kingdom</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Value</strong></td>
</tr>
<tr>
<td>Value of a life saved</td>
</tr>
<tr>
<td>The estimated cost of a casualty of average severity (nonfatal)</td>
</tr>
<tr>
<td>The average value assigned to the saving of all casualties</td>
</tr>
<tr>
<td>Discount rate applied (%)</td>
</tr>
<tr>
<td>The discounted value of one average casualty saved each year (10 years)</td>
</tr>
</tbody>
</table>
EXPERIMENTAL SAFETY VEHICLES

applied by Germany is about 70 percent higher. In part, this may be taken as a reflection of the higher income per capita in Germany and of the consequent ability to devote more resources to the saving of a life. This is not, however, the only factor, as is shown by the fact that the French value is no higher, despite having a higher income per capita than the United Kingdom. Differences in the methods adopted for determining appropriate values are equally important. It is particularly difficult to identify a definitive method for valuing the saving of life. A priori reasoning provides no guide to the relative value attached to the saving of life by each country; consequently, it is not possible to say how far observed differences and similarities reflect the willingness (and ability) of countries to devote resources to it. The consequence, however, is that where a safety measure will yield benefits mainly in the form of the saving of life, such a measure will appear to be much more attractive in cost/benefit terms in Germany, given an equal saving of life.

Looking at the costs assigned to nonfatal casualties, substantial variation is again observed. It is particularly interesting to note that the estimated cost is almost twice as high for France as for Germany, a reversal of the relative sizes of fatal-accident costs. In part, this reflects differences in the severity of injuries, but the major factor is differences in methodology. Again, it cannot be assumed that the apparent difference in costs reflects an equal real difference.

Taking both fatal and nonfatal casualties, the significant difference is between Germany and France on the one hand, and the United Kingdom on the other. The problems of interpretation apply equally here. The important point is that such differences in values can have a major effect on the relative outcomes of cost/benefit appraisals in each of the countries. Different conclusions may be reached on the merits of proposals for no reasons other than this.

Table 7 also brings out the difference in discounted values that results from the use of different discount rates. Whereas the cost of an average casualty is shown to be slightly higher in France than in Germany, after discounting casualty savings over 10 years, the relative positions are reversed. It might be noted, however, that at least in this case the differences arising from discount rates are not large.

Detailed Comparison of Value of Head Restraints

An example of how differences can affect the conclusions reached in practical analyses, and how such differences can be compounded by differences in the estimated savings in physical terms, is shown in table 8. It compares the potential values of fitting head restraints to the front seats of all cars in the Federal Republic of Germany and the United Kingdom.

Table 8. A comparative study of the mandatory fitting of head restraints to the front seats of all cars, Federal Republic of Germany and the United Kingdom, 1975

<table>
<thead>
<tr>
<th>Item</th>
<th>Germany</th>
<th>United Kingdom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated efficacy of head restraints (% reduction of casualties)</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>Estimate of casualties saved:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatal</td>
<td>151</td>
<td>20</td>
</tr>
<tr>
<td>Serious</td>
<td>1,356</td>
<td>680</td>
</tr>
<tr>
<td>Slight</td>
<td>6,029</td>
<td>3,720</td>
</tr>
<tr>
<td>Value of savings in first year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM 94,3m (£15.7m)</td>
<td>£2.2m</td>
<td>(DM 13m)</td>
</tr>
<tr>
<td>Discount rate (%)</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Assumed annual growth in real value of benefits (%)</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Discounted value of savings over 10 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM 943m (£157m)</td>
<td>£15.3m</td>
<td>(DM 92m)</td>
</tr>
<tr>
<td>Cost of restraints (per car)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assumption A</td>
<td>DM 50 (£8)</td>
<td>£10</td>
</tr>
<tr>
<td>Assumption B</td>
<td>DM 90 (£15)</td>
<td>£14</td>
</tr>
<tr>
<td>Total costs for all cars:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assumption A</td>
<td>DM 1,003m (£167m)</td>
<td>£130m</td>
</tr>
<tr>
<td>Assumption B</td>
<td>DM 1,806m (£301m)</td>
<td>£182m</td>
</tr>
<tr>
<td>Benefits as percent of costs:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assumption A</td>
<td>94</td>
<td>12</td>
</tr>
<tr>
<td>Assumption B</td>
<td>52</td>
<td>9</td>
</tr>
</tbody>
</table>

Notes.—The possibility of savings to rear-seat passengers is excluded but was considered in sensitivity testing.

It is assumed that there are no maintenance or replacement costs.

All cars are assumed to be equipped in the first year and to have a 10-year life.
Kingdom. This is perhaps rather an extreme example of the sorts of differences that can be found in preliminary analyses, and it points to the need for further investigation. A number of simplifications are necessary to aid comparability, and values are shown in both currencies, converting via an estimated exchange rate, so the values shown should be taken figuratively.

Although no case for the mandatory fitting of head restraints could be made out on the evidence assumed here (although at assumed cost A in Germany there is a marginal position), there are very large differences in the ratios of costs to benefits, which are now discussed briefly.

One of the factors already identified is the difference in the values applied by the two countries. If the U.K.-casualty-cost values were applied to the estimated casualty savings in the Federal Republic, annual benefits in that country would have been only DM 49.9m.

The additional annual benefit identified in the case of the Federal Republic, because of the higher number of casualties that it is estimated would be saved, has a higher proportion of fatal injuries. In part, this reflects the higher risk of becoming an automobile casualty in Germany, but the major difference comes from the estimates of the proportion of casualties that might be prevented by the provision of head restraints. Limited data are available and it is possible that the United Kingdom estimate for this is low, while that for the Federal Republic is high.

The combined effect of a lower discount rate and a higher assumed growth in the real value of casualty savings resulted in the estimate of discounted benefits over 10 years being equal to 10 times the annual saving in Germany but only 7 times the annual saving in the United Kingdom. Differences in the assumed costs of restraints produced further differences in the ratios of costs to benefits, but these were of secondary importance.

The implications of these preliminary studies were that any evaluation would depend critically on estimates of the number of casualties to be saved, and particularly on the number of casualties suffering injuries in situations where restraints might be effective. Since reasonably reliable estimates of costs are to be expected, the area of crucial difference between the two countries (once improved estimates of casualty savings have been made) is the variations in the monetary values assigned to casualty savings. Differences in the adopted discount rates, in the life assumed for vehicles, and in the rate of growth of the real value of savings are seen to be of rather secondary importance in practice, although they clearly could be significant in marginal analyses.

The rather limited comparisons suggest that there are certain important areas on which attention should be concentrated where international comparisons of safety alternatives are being considered. Clearly it is very important that estimates of the situations in which a measure may be effective, and of the likely degree of effectiveness, should be as well based as possible, and where there are apparent differences between countries that cannot be readily explained by national safety differences, there is a case for further investigation. It has also been shown that differences in the values assigned to casualty savings can have major effects on the absolute and relative merits of safety proposals. (Where accident costs are being considered rather than casualty costs, the differences between countries are not usually so marked. This reflects differences in the assigning of identified costs between individual casualties and accidents.) It might be argued that there is a case for further research to identify the extent to which the differences in the values used represent true differences between countries rather than the results of methodological assumptions and estimation difficulties.

SENSITIVITY, INTERDEPENDENCE OF FINDINGS, AND OVERALL APPRAISAL PROCEDURES

Sensitivity Testing

We have discussed how the conclusions reached in economic appraisals can vary considerably with the values assumed; estimates of the accidents that might be influenced, and of the efficacy of safety measures; the choice of assumptions about the life of vehicles or
EXPERIMENTAL SAFETY VEHICLES

safety equipment, discount rates, and the rate at which the real costs of casualties and accidents grow; and the estimates made of the costs of producing, maintaining, or replacing safety equipment. It is generally recommended that sensitivity testing be carried out to test the extent to which appraisal conclusions depend upon the particular estimates made and the values assumed. There will always be uncertainty about the applicability, cost, effectiveness, and suitability of safety measures, and alternative assumptions within the likely range should be tested. Conclusions that are largely independent of the assumptions made will clearly carry more weight than those that depend critically upon particular assumptions that may or may not hold. In addition to testing the sensitivity of the conclusions, such procedures help to identify the critical areas that may justify additional scrutiny. The verification of the crucial values and assumptions will then confirm the conclusions tentatively reached.

Standard values and assumptions adopted for all safety measures, such as casualty values and discount rates, may be taken as fixed in many situations. It is necessary to bear in mind any alternatives that might be adopted in different circumstances, and to consider the sensitivity of the conclusions of studies to the particular values in use. The acceptance or rejection of some safety measures will depend upon such values. It is therefore prudent to be aware of the extent of the variation of values that might be reasonable, and to note how well established and accepted such values are. For example, the values currently assigned to the saving of life may be well established, and commonly employed in evaluations. Clearly their use is necessary from the point of view of the comparison of alternatives, but in most cases the estimate of the value of life can be regarded as only a minimum estimate of the willingness of society to devote resources to life-saving activities. The fact that savings so valued may be less than the costs does not automatically preclude the acceptance of the measure involved.

The Interdependence of Safety Measures

It is important to remember that few safety proposals are independent of past and future safety measures. Past safety measures are, of course, part of the safety scenario against which safety proposals are considered, but their impact and implications should be borne in mind, especially in the case of recent measures whose full effect may not yet have been felt. The main concern, however, is with those measures, currently being introduced or under consideration, which may be expected to have an effect upon future accident situations. Some will interact with the measure being considered to produce an effect not equal to that of the two measures alone. For example, the impact of belted and unbelted passengers on windscreens differ, and this alters the injuries sustained with different types of windscreens.

In many cases, the justification of a safety proposal may depend upon the acceptance or rejection of another safety measure. Of prime importance now is the question of the introduction of the mandatory wearing of seatbelts. The effectiveness of seatbelts is such that if the wearing level increases substantially, casualty savings are expected that will leave fewer casualties to be saved by other means and may remove the justification for other safety measures. This will apply equally to direct substitutes, such as interior padding whose benefits may be less for belted passengers, and to quite independent measures, such as antilock brakes. Each successive measure, whether or not it reduces the risk or the consequences of accident involvement, will tend to reduce the potential benefits from further measures. (Similarly, other developments may tend to increase the incidence or severity of accidents and thereby increase the potential of safety measures.) The range of possible measures and their consequences should therefore be borne constantly in mind.

The difficulty is that many future measures are uncertain. Some are more likely than others, some will have a larger effect than others, and both of these factors will influence the weight attached to them. This points to the need for comprehensive planning, to identify and evaluate those developments that are likely to occur and to choose and order measures that are likely to be suitable. This may mean that on occasion a less attractive measure in terms of its immediate effect may
be preferred because of a greater effect in a later period. There may also arise an existing commitment to a particular measure that will remove the justification of another offering greater benefits.

It is also important to bear in mind the distribution of measures and their effects over time. Where measures complement each other, their sequence of introduction and timing may influence their ability to further improve the accident situation. When a selection of possible measures is being made at one time for, say, a new design of car, the method of consistent test procedures [17] enables an optimum choice to be made.

The Context of Cost/Benefit and Cost/Effectiveness Studies

The methods of appraisal considered in this paper may constitute useful aids to decision-making in the field of safety, but they cannot provide complete solutions in themselves. What they can do is to identify and quantify as far as is possible the effects of accidents and safety measures, pointing to the implications of proposals in physical and human terms, and, to an extent, comparison of such factors can be made in monetary terms. There will always remain a number of factors that cannot be taken into account in such an appraisal, matters that are uncertain or that have political or social considerations not reflected in the magnitude of costs and benefits. Many things have to be taken as they stand, such as technical, financial, and political constraints on what can be done. Within these constraints, cost/benefit and cost/effectiveness studies can point to the implications of alternatives, can evaluate them in absolute and relative terms, can indicate those safety measures that offer a net gain to society, and can indicate a possible ordering.

Generally, there remain a number of considerations to be taken into account that may modify or reverse the conclusions reached in the appraisal. The results of the economic appraisals of safety proposals must therefore be looked at in a wider context. First, there are the effects that cannot be adequately evaluated, in whole or in part. These must be considered in a social-political context to assess their significance, which is a task for the decisionmaker. There may also be political or social weightings attached to the costs and benefits that are summed and compared in the appraisals. The distribution of such costs and benefits, in terms of who is affected, and how greatly, is as important as the relative size of such costs and benefits. In a safety context this can be particularly important. A cost/benefit appraisal may indicate certain costs and slightly smaller benefits, but what if the costs are small time delays spread amongst some millions of motorists, and the benefits are savings in injury and death for a few thousand. Such considerations can only be dealt with in the wider process of considering safety proposals. Other considerations also come into play—there may be international commitments to certain standards, or pressures on the domestic car manufacturing industry arising from safety requirements in other countries. There may be public attitudes that result in pressure for or against measures that are not fully reflected in safety appraisals.

Conclusions

It is hoped that the report will be of value to countries using or intending to use cost/benefit and cost/effectiveness studies as aids to decisionmaking. Although much of the detail in the report emphasises the differences that can easily arise, it is by careful attention to detail that useful results can be obtained. The three factors which largely determine the estimate of the balance between benefits and costs are the estimates of the numbers of people at risk in the situation being studied, the proportion of these that might be protected by the safety measure, and the monetary values placed on saving casualties. Comparative studies of several safety measures in one country are likely to be more accurate than different studies for the same measure in a number of countries. However, the report indicates how the latter may be compared.

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APPENDIX 1. PARTICIPANTS IN THE STUDY

This work was not carried out by a formal Working Group of EEVC but was supervised from time to time by the main committee, whose members made many helpful comments. One or two special meetings were held and from those attending the following made written contributions.

Mr. J. C. Bluet          Organisme National de Sécurité Routière (ONSER), France
Mr. M. Halpern-Herla    ONSER, France
Mr. M. Y. Systermans    ONSER, France
Prof. B. Friedel        Federal Highway Research Institute (BAST), Germany
Dr. Marburger           BAST, Germany

Mr. F. C. Flury          Institute for Road Safety Research, Holland
Mr. G. Walraven          Rijksdienst voor het Wegverkeer, Netherlands
Mr. G. Ekberg            The Swedish Road Safety Office
Mr. B. Mattsson          The Swedish Road Safety Office
Mr. A. Barton            Transport and Road Research Laboratory (TRRL), UK
Mr. D. A. Benson         Department of the Environment (DOE), UK
Mr. I. D. Neilson        TRRL, UK

The Status of the Japanese ESV Program

ITAKEKI KOYANGAI
Deputy Director
Automobile Division, Machinery and Information Industries
Bureau Ministry of International Trade and Industry Japan

I am grateful for this opportunity to present a progress report on the development of Experimental Safety Vehicles (ESV’s) in Japan.

The development of Compact Experimental Safety Vehicles in Japan was initiated in 1970 under the U.S.-Japan memorandum concerning a cooperative ESV development project. For this project, three Japanese automobile manufacturers started to develop ESV’s. These manufacturers are Nissan Motor Co., Toyota Motor Co., and Honda Motor Co.

In the autumn of 1973, the first ESV’s were delivered to the Japanese governmental agency concerned with evaluational testing by Nissan and Toyota. The tests were conducted by the Japan Automobile Research Institute, Inc. (JARI) in the spring of 1974.

The Japanese Government provided financial assistance to each of the manufacturers for their research in this field. The amounts
EXPERIMENTAL SAFETY VEHICLES

were 600 million yen for both Nissan and Toyota’s ESV projects.

All the results obtained from the development and testing stages were reported at previous International ESV Conferences. It is felt that these opportunities to exchange information, not only intranationally but most importantly on an international scale, permitted the great leaps forward that ESV development has experienced. These exchanges of technical feasibility and efficiency study results have paved the way for further developments, particularly in the field of safety.

At this time, Japanese ESV projects have attained their intermediate goal and are presently marking time until technological advances make it possible to realize further improvement. Therefore, immediate attention should be given to the question of how to develop future safety technology scientifically. Safety technology is a vital component of all consumer-related development projects. At present, the Japanese Government intends to provide aid to those institutions which undertake research in this field.

Now, I would like to speak about the new project that is being conducted as a followup to the now completed ESV project. Currently, attention in Japan has been focused on the development of individual subsystems with a sharp eye on safety. This is unlike the ESV project that was concerned with the production of a complete vehicle. For example, one of the new technology development themes for fiscal 1976 is an anticrash auto brake system employing a radar system. We hope that the results of these studies combined with what we learned from the ESV projects can be practically applied to production vehicles.

In this regard, traffic accident statistics in Japan these days have been significantly decreasing in fatalities and body injuries. This primarily results from the dedication of concerned organizations to reduce traffic accidents. These organizations include the Ministry of Transport, the police agencies, automobile manufacturers, and many other agencies and individuals. As a direct result of this effort, the accident rate was reduced by 3.6 percent from 1974 to 1975. However, there were still 10,792 persons killed and 622,467 persons injured in traffic accidents.

In view of this situation, general plans for national traffic safety measures were proposed at the National Traffic Safety Countermeasures Committee meeting in March of this year. This plan should not only ensure motor vehicle safety but include overall traffic safety programs, road maintenance, and the traffic environment as a whole. Attention will also be focused on the education of both motorists and the general public, promoting safe driving practices, and ensuring that traffic rules are strictly observed.

In addition, studies will be conducted on the causes of traffic accidents and all other traffic-related matters. Thus, it is our purpose to promote safety measures and countermeasures that will be effective for the whole traffic system.

In closing, I feel that we are all required to make a great joint effort as well as an individual effort to develop and realize practical traffic safety technology and to ensure that the wide aspects of traffic safety be properly disseminated throughout the industry and society.

U.S. Status Report on ESV Programs

JOHN W. SNOW
Administrator
National Highway Traffic Safety Administration
U.S. Department of Transportation

It is a distinct pleasure to add to Secretary Coleman’s earlier welcome to you. Let me just say that, on behalf of the National Highway Traffic Safety Administration, I am delighted that you are here.

This afternoon, I will present a status report of the United States’ program on integrated safety vehicles. But first, I want to express my appreciation for the cooperation we have received since the Fifth Experimental Safety Vehicle (ESV) Conference in London, 2
years ago. This international program has been a splendid example of nations cooperating with other nations to help resolve a problem common to each—how to make motor vehicle travel by our citizens as safe as possible.

Many of the papers to be presented later in this conference will report on the beneficial influence of the international research and development reported during prior conferences.

And I am especially pleased to note that a number of safety features based on initial evaluation of experimental safety vehicles have been incorporated voluntarily in production automobiles. I commend those companies that have introduced the improvements, and I encourage all manufacturers to continue developing safety initiatives voluntarily.

We have moved forward, since the London conference, in exchanging ideas and data through the testing of experimental vehicles. In particular, I want to thank the Governments of the United Kingdom and France, along with their participating manufacturers, for the opportunity to continue cooperative testing of the British Leyland Marina and the Renault Basic Research Vehicle.

Since its founding 10 years ago, the National Highway Traffic Safety Administration (NHTSA) has moved on a number of fronts to reduce accidents on our Nation's highways and the deaths and injuries resulting from them. We have worked on improving the safety characteristics of motor vehicles, the ease and safe movement of traffic, and the skill and awareness of our drivers. We have had good success, working in cooperation with State and local governments, industry, and private organizations. For example, in 1966, our Nation faced a harsh reality: 55,000 persons lost their lives in traffic accidents. Since then, we have achieved a 40-percent reduction in the fatality rate—a formidable accomplishment, indeed.

This sizable loss reduction rate was generated by a number of important actions. Certainly, vehicle modifications had much to do with the improvement, particularly between 1966 and 1970. Then, as the United States faced—as did other countries—a critical energy problem, we moved to a national 55-mi/h speed limit law that, today, continues to save lives and fuel.

We see the curve flattening in terms of vehicle modifications, simply because we cannot expect the same safety benefits for the costs of achieving them. The cost/benefit ratio simply is not as high as it was in the early years of our program. This suggests that we must turn our attention to modifying the behavior of the people who use our highways—to win wider acceptance of observance of our 55 mi/h law, of wearing seatbelts, and of educating drivers not to drink before or while driving.

We will also continue our search for safety gains in the vehicle itself, but it is clear that we cannot expect the same quantum reduction in fatalities experienced in the past. This is why I place major emphasis on U.S. participation in, and continuation of, our research and development work on, the international ESV program.

But there is another aspect of our work that should benefit from the ESV program. My agency now has a new role, in addition to its overall motor vehicle regulatory function—we now have regulatory responsibility in the area of automobile fuel economy. By congressional action, we are required to administer the average fuel economy standards for passenger cars starting with the 1978 model year.

Under our law, automobile manufacturers must meet an average fuel economy of 18 mi/gal in the 1978 model year, 19 mi/gal in 1979, and steadily increasing to 27.5 mi/gal for 1985 models. And this must be accomplished while giving due consideration to the complex relationships between our national goals in safety, energy conservation, environmental protection, and economy of resources—the so-called "S3E" concept.

Meeting these new responsibilities will require an expansion of our programs in systems analysis and integrated test vehicle development. The U.S. Research Safety Vehicle (RSV) program has helped in reducing vehicle weight and in recognizing the interaction between safety and other social goals.

There are four elements of our RSV program that I will comment on today. The first
is the RSV program itself, which was just getting underway at the time of the London conference. The second concerns the status of the international test program. The third involves the status of our supporting research, and the fourth deals with opportunities for the future.

THE RSV PROGRAM

The systems engineering approach to automotive safety that was initiated by our Department of Transportation is currently being pursued in the RSV program. The goal of the program is to provide insight into the vehicle's interactions with other important societal goals in the S3E concept.

For example, we want to demonstrate the technical feasibility of integrating advanced state-of-the-art automotive systems into a vehicle that will provide improved safety performance consonant with the other S3E goals.

We want to evaluate improved automobile safety performance with the projected total traffic system, with environmental protection policies, with efficient energy utilization, and with consumer considerations.

The RSV program, in addition, will enable us to acquire engineering data to assist in the development of motor vehicle safety standards for the mid-1980's. It will also permit us to expand our research data base of total systems performance in car-to-car collisions relative to aggressiveness and in pedestrian/cyclist accidents.

These goals supplement and expand the broad overall goals of the ESV program to validate advanced safety concepts, to stimulate public awareness of improved safety, to encourage international automotive industry cooperation, and to accelerate the improvement of production cars.

The RSV program has four phases. Phase I, which was completed in May 1975, involved studies to define S3E-related problems, develop 1985 projections, develop cost/benefit methodologies, evaluate countermeasures, and propose specifications for the integrated test vehicles to be designed in phase II.

Phase II is scheduled for completion in November 1976. This phase involves two contractors, Calspan and Minicars, who are designing integrated test vehicles with advanced safety features that will be cost beneficial in the 1985 time period. Phase II includes analysis, design, subsystems fabrication, system integration, and development testing.

Phase III will include the final vehicle design, systems development testing, and fabrication of the integrated test vehicles for government testing. The phase will be 21 months in duration.

Phase IV, which will overlap the latter part of phase III, will consist of the independent test and evaluation by the Government of the phase III vehicles.

The phase I results were reported at an International Conference here in Washington in May 1975, but I think it would be useful to summarize our basic findings.

In spite of the increasing price of fuel, the number of automobiles is expected to increase over the long term. The increasing number of drivers is the strongest influencing factor in our projected increase in the automobile population. Accordingly, the number of vehicle-miles traveled is projected to increase over the long term. Higher fuel costs and improved public transportation may slow down the rate of increase but are not expected to reverse the trend.

There was general agreement in the trend toward smaller cars but some disagreement in the magnitude of the shift. The magnitude of the shift is, of course, dependent on a number of factors, including the consumer acceptance of the small cars offered.

In order to further encourage public acceptance of lighter, more fuel-efficient automobiles, cost, producibility, marketability, and consumer considerations should be important parts of the RSV program.

In view of the increase in numbers of lightweight cars expected on our highways by 1985, the less than 3,000-pound car is a profitable area for integrated test vehicle research. This research must balance S3E goals, but must also insure that small car buyers do not have to pay a penalty in safety in order to gain fuel economy.

The general distribution of accidents is not expected to change for the 1985 time period.
However, the severity may be expected to increase because of the larger number of small cars interacting with larger cars in the 1985 vehicle mix.

This phase was also useful in identifying profitable areas for improved occupant protection and in better understanding the societal cost of accidents.

Phase II, now in progress, consists of advanced engineering efforts by two contractors—Calspan, which has a major subcontract with Chrysler for design and fabrication support, and Minicars, which has a number of subcontractors including Monsanto, Budd, and RCA.

The Calspan/Chrysler vehicle is a four-door, five-passenger sedan with a front, transverse engine. The engine is a 1 716 cc, top-of-76 technology gasoline engine.

Major structural improvements incorporated in this vehicle include: zero damage in a 7-mi/h frontal impact, pedestrian protection at 20 mi/h, occupant protection for a 40-mi/h side impact, and occupant protection in 45- to 50-mi/h frontal barrier crashes without creating excessive aggressiveness to occupants of other vehicles.

The Calspan/Chrysler approach involves the modification of an existing vehicle—the Simca 1308. In designing modifications, the contractor is making extensive use of analytical tools such as computer models for automobile structures, restraint systems, occupants, and pedestrians. These models are being validated by subsystem and system tests.

The Minicars RSV is a two-door, four-passenger sedan with a mid/rear transverse engine. The vehicle weight goal is 1 920 pounds in production. The Minicars vehicle involves a large number of innovative features to improve safety, economy, and resistance to damage.

Minicars is basing its safety goals on societal benefits derived from accident statistics. The objective of the Minicars design is to minimize injuries under those accident conditions which cause the higher societal losses. The design is oriented toward survival in common real-world accidents.

In order to pursue the Minicars approach, innovations are required in vehicle technology, cost/benefit methodology, and vehicle testing. The resulting RSV is an all new subcompact vehicle. Validation of the design will provide an assessment of the cost and benefit of innovative safety features and an evaluation of future compliance test methods for vehicle crashworthiness and compatibility.

The two RSV approaches complement each other. Each provides a different but necessary segment of vehicle technology.

Phases III and IV of the program will provide a demonstration and evaluation of the practicality and benefits associated with each vehicle design. Such an evaluation is necessary, both to assist decisionmaking on further performance-oriented standards and as a basis for technical interaction with the automotive industry on producibility, economics, and marketability, as well as on safety technology.

INTERNATIONAL COOPERATION

The second area of activity involves international cooperation. The basic intent of the International ESV program has been to promote participation by governments of major automobile-producing nations in sponsoring the development of complete integrated test vehicles or ESV subsystems. The governmental involvement and automobile industry participation has been extensive, and I feel that the prudence and viability of this approach has been impressively demonstrated.

Since the inception of this program, the cause of automotive safety has received active attention on an international basis. We should be proud of our individual efforts and accomplishments. Perhaps more significantly, we should be proud of the solid spirit of international cooperation that has been established. This spirit of cooperation has resulted in extensive exchange of information both directly between individual organizations and in the international forums provided by the five prior international ESV conferences. In addition to the exchange of information, one of the most visible aspects of this international program has been the exchange of ESV's.

This cooperative effort has been productive and I would like to express the thanks of the U.S. Government to the Governments of the
United Kingdom and France, and to British Leyland and Renault for providing vehicles for our evaluation and testing.

RELATED RESEARCH

The third area I would like to comment on involves research. During the last conference, a number of areas were identified that require further research: biomechanics, accident analysis and cost/benefit, uniform testing techniques, pedestrian safety, accident avoidance, crashworthy structures, and restraints.

I would like to summarize our major accomplishments in each of these areas.

In biomechanics, evidence has been developed to show that maximum upper-belt force with appropriate consideration of body weight and age can be utilized as a measure of human tolerance in a belt system. Continued work may yield a dynamic belt system tolerance standard and compliance test methodology in the near future. This work was made possible through the contributions of French and German research in biomechanics. A paper will be presented on this subject in seminar 4.

Studies conducted this year indicate that certain measures of acceleration made on the head during impact may indeed contain sufficient information to predict closed head injury during crashes.

A crash victim simulator computer model has been improved to lower the operating costs by a factor of 10 to 12 for many cases of interest. In addition, the model has been further validated and used in the design of the RSV restraint and pedestrian protection system.

In accident analysis and cost/benefit, a nationwide data collection effort is now underway to collect data on crash severity and injury. The injury data will include details needed to better estimate the societal cost of injury.

The initiation of our National Accident Sampling System will occur during fiscal year 1977. The first phases of the system have been designed, and the procurement and training of teams at 10 sites across the United States will proceed in late 1977. Results will be more timely than has been possible heretofore and nationally representative with statistical measures of confidence limits.

The RSV phase I program presented several viable approaches to cost/benefit analysis. Methodologies developed by Ford, Minicars, and Volkswagen are providing the bases for further advances in cost/benefit analysis.

In the area of uniform testing techniques, British Leyland and Renault integrated test vehicles have been tested to conditions mutually agreed upon by representatives of participating countries. Future exchanges of this type will further the cause of uniform testing techniques.

The United States’ evaluation of the dummy developed by the British Transport and Road Research Laboratory for side impact testing was conducted to further provide uniform comparison of data from participating laboratories.

On pedestrian safety, a repeatable test for evaluating various pedestrian protection concepts has been developed. Also, tentative results of a pedestrian impact study indicate that the injury attenuation performance of a current RSV proposed front-end design may increase the permissible impact velocity for a given level of injury by as much as 5 to 10 mi/h.

Research on accident avoidance has involved several activities. Two major driver-vehicle programs have been completed generating the first NHTSA-sponsored research in this field and new methods for analysis of the driver-vehicle as a closed-loop control system. A program is near completion that brings together all relevant driver-vehicle test data, both private and Government-sponsored, within a common framework for analysis and interpretation.

Automotive recorder research which will develop an economical crash recorder to provide real-life accident data has been initiated. Collision avoidance radar research is being conducted, with goals of avoiding and mitigating crashes.

Electromagnetic interference/compatibility research is continuing. This program is concerned with the safety aspects of malfunctioning electronics as their use in motor vehicles increases.
On crashworthy structures, an initial series of crash tests to evaluate the frontal crashworthiness of lightweight subcompact vehicles (less than 2,000 pounds) has been completed. Four different vehicles were tested at 40 mi/h in barrier crash tests; selected car-to-car tests were also conducted.

Controlled vehicle crash tests and analyses are being performed to provide data to identify and quantify aggressiveness and to assess aggressiveness of current vehicles.

Scale model crash-testing techniques have been developed and applied to compatibility studies of subcompact and full-size cars, and a nonlinear finite element computer program for analyzing automobile structures under crash loadings has been developed.

Vehicle Safety Research in Canada

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INTRODUCTION

This status report is the first from Canada to the International Technical Conference on Experimental Safety Vehicles (ESV). The Government of Canada, and more particularly the Road Safety Branch of the Department of Transport, has observed the development of the ESV and Research Safety Vehicle (RSV) programmes with keen interest since their inception. Canada, having no significant indigenous automotive design capability, did not participate directly in the ESV programme; nonetheless, a small programme of research in vehicular safety has been developing since 1971 in support of the Canada Motor Vehicle Safety Standards. The somewhat broader terms of reference for this sixth conference appeared to offer an opportunity for a brief review of this programme.

Although Canada has not had any independent automotive design capability for some years, the manufacture of automotive parts and complete vehicles is a major contributor to Canada's total output and to her exports of manufactured goods. The industry has become increasingly significant since the signing of the Canada-U.S. Automotive Products Agreement, commonly known as the Auto Pact, in 1965. That agreement permitted the rationalisation of vehicle production for the North American market to the mutual advantage of the two countries. It also, however, brought to an end the design and production in Canada of vehicles specifically for the Canadian market.

It was against this background that the U.S. Senate passed the Traffic Safety Act of 1966, which called for the development of U.S. Federal Motor Vehicle Safety Standards (FMVSS) to take effect some 2 years from the date of the act. Discussions between the Canadian Federal Government and the 10 provinces led to the conclusion that parallel legislation and regulations were necessary in Canada. The Motor Vehicle Safety Act was finally passed by Parliament in 1970.

The discussions between the Federal and Provincial governments also produced consensus on the need for the Federal Government to "correlate, plan and support road safety research in Canada." Accordingly, when the Road Safety Branch was established it contained two major operating divisions—one with the responsibility of administering the Motor Vehicle Safety Act and Regulations and the other with the responsibility of coordination, planning, and support of research over the entire field of road safety.

The specific objective of the research activity has been defined as the development, evaluation, and promotion of cost/effective solutions to road-safety problems. Insofar as the passenger automobile is concerned, it would clearly have been impractical for us to have attempted the development of radical new design solutions to safety problems. Our research efforts have been mainly directed to the evaluation, in a Canadian context, of vehicular countermeasures originated elsewhere. The projects I shall now outline are those which have been or are being supported by the Road Safety Branch and relate directly to the passenger automobile.
COLLISION AVOIDANCE

As might be expected from the background I have just described, the initial programme of research in the crash-avoidance area consisted essentially of small individual projects dealing with rather limited questions on particular vehicle standards. For example, the Canada Motor Vehicle Safety Standards have always permitted the manufacturer to fit certain Economic Commission for Europe (ECE)-approved headlamps in lieu of the usual North American sealed-beam units. The initial decision to allow this option was made purely on engineering judgment, without any quantitative analysis of possible difficulties resulting from the use of both types of vehicle lighting on the road. A project to study the possible safety problems was therefore undertaken at our request by the National Research Council of Canada. While it did not lead to quick and conclusive results on the possible safety problems, the project has contributed significantly to fundamental understanding of visual perception at night and of the role of headlighting in that process. A rather complete mathematical model of the detection of objects in the roadway has been developed on the basis of extensive and detailed experimental measurements. Interim results in the development of the model have been reported in other international meetings and its development is now virtually complete.

Another ad hoc project relating to a specific standard concerned the cost/effectiveness of improvements to the defogging and defrosting systems of the passenger automobile. Improvements were specified in terms of performance or additional hardware, and an attempt was made to quantify the potential accident reductions and costs attributable to each of several possible measures. A modelling approach was adopted that attempted to include a range of climatic and other variables. This approach was only partly successful; however, the study did confirm the conclusion of a brief in-house study of winter accidents involving reduced vision, namely, that the total number of recoverable accidents was too small to justify any appreciable addition to the cost of the vehicle, such as would be involved in the mandatory installation of a rear-window defogging system.

The first major subject area to be considered in a more systematic way was motor vehicle inspection. The Federal-Provincial discussions preceding the creation of the Department of Transport's Road Safety Branch showed clearly that most Provincial governments considered the implementation of an effective programme of compulsory vehicle inspection to be a matter of some priority. They were, however, aware that approaches differed widely between jurisdictions in North America and elsewhere. As a result, a study of motor vehicle inspection was initiated to attempt to answer the various questions implicit in the Provinces' interest.

A brief in-house review of the available research on motor vehicle inspection systems led to some quite definite conclusions on what one should do if one were intent on improving the average mechanical condition of vehicles in use. The use of frequent, periodic inspections of objective measures of vehicle-system performance or condition and the maximum possible level of State control over the operation of the system were clearly indicated. Equally, however, the connection between an effective motor vehicle inspection system and a reduction in accidents involving mechanical malfunctions had not been convincingly demonstrated.

Following this study, consultants were retained to review and document the current status of motor vehicle inspection in Canada and to organize a seminar, at which a balanced perspective of the available research information was to be presented to the Provincial officials responsible for motor vehicle inspection. The general principle of a national minimum standard for motor vehicle inspection was to be introduced to the discussions at the seminar to assess its feasibility and acceptability. It quickly became clear at the seminar that motor vehicle inspection is a subject on which convictions are strongly held while objective data to support them are scarce. It was finally concluded that there were insufficient grounds for an effort in Canada to introduce systems and procedures likely to be more uniformly effective. Had there been a stronger consensus, the effort might have been justifiable, but in the light of the somewhat speculative nature of the safety
benefits of more effective inspection, it clearly was not.

The conclusion of this exercise suggested two further possibilities: first, to consider what could be done within the scope of the Motor Vehicle Safety Standards to improve the effectiveness of provincial inspections and, second, to consider alternative methods of attacking the problem of malfunction-related accidents. Such alternative methods were considered to include lifetime performance standards and on-board system monitoring.

A cursory review of design practice in the automotive industry suggested that there was no consistent approach to design for inspection. Consultants were retained to review current best practices and identify those design features of safety-related systems which facilitated inspection, made the judgment of system condition more objective, or made the inspection more relevant to performance on the road. Electronic systems were specifically excluded, as was any requirement for special purpose inspection equipment. It was also specified that the implied cost of any proposed improvement should be effectively zero, since the derived safety benefits were likely to be rather small.

The consultants identified some 16 features or devices offering improved inspectability. The majority related to the braking system and included such items as integral wear indicators for brake drums and discs and provisions for direct visual inspection without disassembly. The final report on this study is being printed at the time of writing this status report.

In considering possible alternative approaches to the reduction of malfunction-related accidents, we decided not to study lifetime performance standards in any detail, being deterred both by the probable cost of such standards and by the technical problems of demonstrating compliance. We preferred instead to initiate a review of the technical feasibility and cost of on-board monitoring of the vehicle system variables most critically involved in malfunction-related accidents. From published information on malfunction-related accidents, we identified the 20 most critical variables. This list included such items as tire pressure, left-right brake balance, and occupant compartment carbon monoxide concentration. Our consultants then undertook a study of the technical feasibility and cost of monitoring each of the identified variables and combining all the monitors into an integrated system.

A general conclusion of the study was that the feasibility and costs of the system were primarily determined by the available sensors. It was considered simply impracticable to monitor certain of the identified variables, and, while cost/effectiveness was not an explicit factor in the study, the costs of monitoring certain other variables appeared excessive in relation to the probable maximum effectiveness. However, sensor technology is apparently developing quite rapidly and it seems probable that the cost/effectiveness of such systems is likely to improve considerably in time. The final report on this study is being printed at the time of writing this status report. No further studies of countermeasures for malfunction-related accidents are planned for the present, but the subject is under continuing review.

In the course of studies of particular collision-avoidance countermeasures, and especially in attempting to estimate the impact of particular countermeasures on accident experience, the major importance of the driver’s behaviour, both before and after the implementation of the countermeasure, has become increasingly apparent to us. Not only is the current utilization of systems contributing to collision avoidance often surprisingly low, but the driver’s response to an “improvement” in system performance is essentially unpredictable. A major objective of our research over the next few years will be to understand better how drivers use the safety systems that are available to them and, more importantly, how they respond to presumed improvements in those systems. It appears increasingly futile to us to pursue engineering improvements in collision avoidance systems whose benefits in practice are indeterminate because of the adaptive behaviour of the driver. The planned research will include both accident investigations and experimentation with instrumented vehicles in traffic.
CRASHWORTHINESS

Limitations on available resources have caused our research in this area to be quite narrowly focused on occupant restraints. One particular concern was the development of some basis for assessing the impacts of alternative regulatory policies with regard to passive-occupant protection. Accordingly, a study was undertaken to develop cost/effectiveness projections for various types of occupant-protection systems in Canada.

Since there existed no representative Canadian data on the distribution of impact directions and severities for accident-involved passenger automobiles, the objective of the first phase of the project was to develop an estimate of this distribution by an appropriate sampling procedure. The Society of Automotive Engineers (SAE) Collision Deformation Classification (CDC) was used as the basic descriptor of primary impact direction and severity. Photographic and numerical data reported by cooperating insurance company adjusters were analyzed and combined to generate the required distribution of impact directions and severities. A sample of some 2,600 vehicles was analyzed and stratified by season and by geographical region. The geographical regions were represented in the sample in approximate proportion to the annual regional totals of reportable accidents involving passenger vehicles.

In the second phase of the study, baseline estimates of the distribution of injury severity for unrestrained vehicle occupants were made from the distribution of impact directions and severities using Automated Instrumentation System AIS versus CDC correlations derived from the CPIR file at the Highway Safety Research Institute of the University of Michigan. These baseline estimates were then compared with projections for a population of passenger-vehicle occupants variously restrained by lap and torso seatbelts and air cushion restraint systems.

The validity and accuracy of the results of this study were obviously influenced by a number of factors. The small sample of accident-involved vehicles considered precluded any precise estimation of the proportion of high-severity collisions, which appears to be the major determinant of the effectiveness in preventing fatalities of either of the two major types of restraint system. The paucity of detailed data on the performance of combined lap and torso belts and the even worse situation for the air cushion system were also particularly restrictive. It was not possible to reach any precise conclusions on the relative overall effectiveness of the two major alternative restraint systems in the Canadian situation. However, when costs were considered, it was concluded that a quite moderate wearing rate for the lap and torso seatbelt offered about the same cost/effectiveness as the air bag.

Particular aspects of the work carried out in this study have been reported at the 19th Stapp Car Crash Conference and at a meeting of the American Association for Automotive Medicine. The final report on the study is now being prepared for publication.

The principal advantage of passive occupant restraints lies in their high utilization rate in comparison with conventional seatbelts. However, a number of governments throughout the world, notably in Australia, have achieved very high rates of seatbelt use through legislation. During the course of the project I have just described, similar legislative action by at least one of the Canadian provinces appeared imminent. A brief in-house study was therefore undertaken to examine the probable impact of such legislation in Canada. The study covered such factors as the availability of the various types of seatbelt systems in the current passenger vehicle population, current voluntary rates of seatbelt use, and estimated seatbelt effectiveness. Seatbelt use under legislation varied parametrically. Despite some significant differences of detail between the Canadian and Australian situations, the study suggested that very similar proportional reductions in traffic fatalities would be achieved for similar rates of belt use.

The first Provincial seatbelt law was enacted by the Province of Ontario, about a year later than had at first been expected, on January 1, 1976. Interpretation of the results has been rendered rather difficult by a simultaneous reduction of highway speed limits in the Province and some fairly large changes in...
the statistics of all types of accidents. Marked reductions in vehicle-occupant injuries and fatalities followed the enactment of the law but it may be some time before the contributions of the several factors involved can be estimated with any confidence.

The final study that I shall mention is intended to increase our knowledge of the injury mechanisms experienced by passenger-vehicle occupants who are fully restrained by lap and torso belts. In the event that more Provinces follow the example set by Ontario and more recently by Quebec, it will become particularly important to determine to what extent further refinements can be made in the detail design of the total interior occupant-protection system to maximize the effectiveness of the restraint system.

At the time the study was initiated, there were relatively few detailed data available on fully restrained occupants—perhaps 400 cases on the CPIR file at the University of Michigan. The great majority of these occupants either were uninjured or suffered only minor injury. We therefore set out with the objective of obtaining data on about 500 fully restrained occupants who had suffered injuries to AIS 2 or greater. In fact, we have had considerable difficulty in finding cases at the rates projected before the study for a number of reasons. Accident rates have tended to be somewhat lower during the current year and, in regions both with and without seatbelt-use laws, there is evidence that seatbelt use in accident-involved vehicles is appreciably less frequent than in the overall vehicle population. We hope to report on this study in more detail at a later date.

CONCLUSION

This brief overview of recent research in Canada has necessarily been restricted to those projects which relate most directly to the development of safer passenger automobiles. I would be very pleased to provide additional information on any of the projects I have outlined during the remainder of this conference and to talk about some of our plans and projects in related areas such as accident-data collection and commercial vehicle safety.
A Status Report on the Calspan/Chrysler RSV

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ABSTRACT

The Research Safety Vehicle (RSV) program encompasses automobile safety, economy, resource conservation, and emissions appropriate for the U.S. economy in the late 1980's. The Calspan/Chrysler approach is based upon derivation of the RSV from a current, advanced, state-of-the-art production automobile. Adoption of a base vehicle approach provides a practical method for introducing incremental changes in vehicle design consistent with program goals and typical automotive production constraints.

The RSV is being developed within the framework of projections, specifications, and a preliminary concept developed in our phase I program. More salient aspects of that study are briefly reviewed in this report.

The Simca 1308, recently introduced to the European market, was selected as the base vehicle. In many respects, this automobile represents an advanced state-of-the-art engineering practice. Characteristics of the base vehicle that are pertinent to the study are discussed.

Design features of the RSV that distinguish it from the base vehicle are considered in detail. Major program development efforts have been expended in the areas of crash safety where extensive changes were made in the bumpers, body structures, and restraint systems. These features have been incorporated into a producible automotive design.

It is recognized that the RSV project includes four phases and the preliminary nature of the results obtained to date must be fully understood and appreciated. Nevertheless, these results seem highly encouraging in relation to performance characteristics that might eventually be incorporated into future motor vehicles.

INTRODUCTION

The objective of the RSV program, as defined by the National Highway Traffic Safety Administration (NHTSA), is to provide research and test data applicable to automobile safety requirements for the mid-1980's and to evaluate the compatibility of these requirements with environmental policies, efficient energy utilization, and consumer economic considerations. Accordingly, it is recognized that, in the performance of this program, factors extending well beyond a strict consideration of safety are to be investigated. Reduction of highway-accident losses, particularly human injuries and fatalities, remains the major concern in the study.

The overall program is being implemented in four distinct phases:

Phase I: Program definition
Phase II: Vehicle-design development
Phase III: Vehicle-design optimization and final vehicle fabrication
Phase IV: Test and evaluation

Phase I began in January 1974 and was completed in April 1975. This activity was followed by phase II which began in July 1975 and is scheduled for completion in November 1976. This report presents considerable information on the Calspan/Chrysler RSV; however, it is important that the reader appreciate the somewhat preliminary nature of the results. The basic design will undergo
additional tests, redesign, and analyses before the overall program is completed. Although these preliminary results appear to us to be highly encouraging, a final assessment of the program significance cannot realistically be made until phase IV is completed.

To understand our approach to RSV development, it is necessary to review some of the pertinent background material. All RSV phase I contractors were given considerable freedom in the development of both the RSV specifications and the approach that would be undertaken in order to develop the vehicle. The only major program restriction was that the RSV not weigh more than 3,000 pounds. Early in phase I, Calspan decided that its recommended approach should stress current (or expected near future) automotive design practice and vehicle producibility. Consequently, Chrysler Corporation, an organization highly respected for its contributions to automotive engineering, was invited to participate in the program.

The results of our phase I study established the basic framework within which the RSV is being developed. For this reason, we provide a brief review of the more salient phase I results that greatly influenced our approach. The reader interested in specific details of the phase I study should consult the four-volume final report [1].

BACKGROUND

Because the RSV was directed toward the development of a vehicle suitable for the mid-1980's, it became necessary to analyze several trends that are expected to influence future U.S. automobile design practices. In general, we tended to focus attention on the time between now and the end of this century. Such a time period was felt to be realistic in relation to the program objectives. Certainly, the design of mid-1980 vehicles will be influenced by economic, social, and technical constraints operating between now and the time of introduction. Once introduced, the requirements that are suitable for the vehicle are dictated by the conditions operating during the vehicle lifetime—assuming a nominal 10-year vehicle lifetime extends the period of interest to the mid-1990's. Finally, it is our feeling that, because of material resources and other environmental factors, vehicle disposal constitutes an important part of the study. Thus, within this context, the study is influenced by several factors extending for an approximate 25-year period.

Results of our investigation strongly suggested that future automobile design practice, at least in the United States, would be importantly influenced by the availability of natural resources. The effect will be a notable and important downsizing in all automobiles. Figure 1 shows the projections for vehicle mix developed for the period between 1970 and 2000. It is important to note that, at least with this forecast, the median curb weight for automobiles operating on U.S. highways in 1985 is expected to be between 2,500 and 3,000 pounds. (Also note the projected RSV point on figure 1.) For the purposes of the
SECTION 3: INDUSTRY STATUS REPORTS

assumed that the overriding factors in automobile-use expectations were related to passenger compartment accommodations and usable luggage capacity. It was our feeling that, although consumers would likely, even if reluctantly, accept smaller cars, they would not accept great reductions in what they perceive to be required capacity. Interior

study, we elected to pursue development of a car that would tend to approximate the median within the projected mix.

The basis for the projection of much lighter weight cars was based, for the most part, on the published estimates of both domestic and worldwide availability of natural resources. Recent projections for depletion of many vital resources are shown in figure 2, which is taken from reference [2]. The situation of petroleum is particularly alarming. Within the next 50 years, the world supply of oil may be depleted. As a consequence, fuel economy of future motor vehicles must take on increasing importance. The situation of other vital minerals, many of which are used in automobile production, is equally distressing. Thus, it is suggested that the combined influences of resource depletion of both petroleum and certain vital minerals will force public acceptance of smaller, lighter cars.

Of course, consumer expectations will also influence future designs. That is, perceived consumer expectations must be met in order for the automobile to be a viable product in the marketplace. For this program, it was

characteristics of a number of production cars were reviewed and RSV interior characteristics were then recommended to approximate those of cars which are felt to be nominally acceptable for family use. Table 1 shows the recommended ranges for various RSV interior dimensions, contrasted with those of the Plymouth Valiant and Dodge Coronet. It is evident in this chart that the RSV interior was expected to at least approximate current compact-car interiors.

In addition to the factors mentioned, it was felt that safety requirements would continue to have an increasing influence on vehicle design. Indeed, as the overall vehicle mix moves toward a greater proportion of smaller cars, the public's natural inclination to associate greater safety with increased vehicle weight (and size) is expected to accelerate demands for increased crash protection. Thus, it was suggested that the importance of safety (particularly crashworthiness) will increase significantly within the next decade.

When considering crashworthiness requirements for a mid-1980 vehicle, it is important to view the situation within the context of

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<tr>
<td>H-point couple distance</td>
<td>33.3</td>
<td>33.2</td>
<td>32-34</td>
</tr>
<tr>
<td>Effective head room</td>
<td>37.2</td>
<td>37.3</td>
<td>37-39</td>
</tr>
<tr>
<td>Minimum effective leg room</td>
<td>35.9</td>
<td>36.7</td>
<td>37-38</td>
</tr>
<tr>
<td>Shoulder room</td>
<td>55.5</td>
<td>59.3</td>
<td>54-56</td>
</tr>
<tr>
<td>Usable luggage capacity (ft³)</td>
<td>16.2</td>
<td>19.1</td>
<td>14-19</td>
</tr>
</tbody>
</table>

Table 1. Interior car and body dimensions
the expected vehicle mix (see figure 1). Within that projected vehicle mix, the RSV, representing a "median" weight vehicle, should be expected to have an almost equal likelihood of having accidents with cars that are significantly heavier and lighter. For example, in today's environment, a 2,500-pound car is most likely to encounter a heavier vehicle in an accident. In 1985, however, a 2,500-pound car would have an approxi-
mately equal likelihood of encountering either a much heavier or a much lighter car. Hence, the demands on the RSV for crash compatibility with other cars are greater than those necessary for a car of similar weight operating in the present environment. Furthermore, it was our feeling that future requirements should give some consideration to pedestrian protection—a situation that is completely lacking in present automobiles. As a result of these considerations, a zonal concept was developed for the RSV.

The basic crash zone concept is illustrated in figure 3. As shown, there are three specific zones in the front structure and two for both the side and rear structures. It is, of course, recognized that a given zone may be involved in a number of different collisions. For example, zone 1 plays a part in all frontal collisions. Nevertheless, the controlling factors in the performance properties of this zone are pedestrian protection and minimization of vehicle change. Similarly, as shown in figure 3, basic crashworthiness-design motivation for all other parts of the vehicle structure were at least philosophically defined.

Finally, it is important to note the extent of demanding crash-performance specifications imposed on the RSV. These are summarized in table 2. Both a goal and minimum impact speed condition were specified for each collision mode. A strong effort is being made toward achieving the goals established for each impact type. However, it was felt that providing a range would allow systematic trade-offs to be made as the vehicle design was being developed. Such trade-offs are indeed being made as the program progresses.

Before leaving the topic of RSV impact specifications, the matter of vehicle intrusion and injury criteria should be briefly addressed. No specific intrusion requirements were imposed on the vehicle design. Intrusions that did not interfere with the function of providing occupant protection were deemed acceptable. Occupant protection systems are to be evaluated in relation to specified injury criteria. For the study, current Federal Motor Vehicle Safety Standard (FMVSS) 208 injury-criteria limits were selected.

Once the basic framework within which the program would operate was established, it became necessary to develop an approach for development of the RSV.

**BASIC APPROACH**

Because the RSV is intended to reflect automotive technology in the mid-1980 time

<table>
<thead>
<tr>
<th>Direction</th>
<th>Impact object</th>
<th>Configuration</th>
<th>Impact speed (mi/h)</th>
<th>Comments</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Goal</td>
<td>Minimum</td>
</tr>
<tr>
<td>Front</td>
<td>Fixed flat barrier</td>
<td>0° to 45°</td>
<td>50</td>
<td>40</td>
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<tr>
<td></td>
<td>Fixed pole barrier</td>
<td>Center impact</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Fixed flat barrier</td>
<td>0°</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Fixed flat barrier</td>
<td>RSV 50% offset</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>RSV</td>
<td>Center impact</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Side</td>
<td>RSV</td>
<td>0° to 45°</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>Rear</td>
<td>RSV</td>
<td>0°</td>
<td>50</td>
<td>45</td>
</tr>
</tbody>
</table>

*Speed for each car.*
frame, the program must be viewed as having rather short-term objectives in relation to automotive transportation. Typical leadtimes for implementation of feasible concepts into production automobiles require 3-5 years. Furthermore, commitment to such implementation (at about 1980 for a 1985 car) must be based upon existing demonstrated and feasible production methods. Thus, automobiles that are likely to be produced and marketed in the mid-1980’s are expected to be based upon advanced automotive technology representative of the late 1970’s and early 1980’s.

As a result of our particular concern for producibility and the limited available program resources, it was decided that the RSV should be derived from a production automobile. With this approach, producibility questions could be evaluated on an incremental rather than a global basis. That is, because the base vehicle is currently being produced, only the incremental design changes between the base vehicle and the RSV need to be investigated in order to establish the production feasibility of the resulting design.

Although this approach provides a rational basis for assessing vehicle producibility, it also results in a number of constraints on the subsequent vehicle design because the RSV must then reflect, for the most part, the basic geometrical design, drive system, chassis, and other properties of the base vehicle. Such constraints are not considered overly demanding, but they certainly do provide important restrictions. For example, with this approach, it is not feasible to relocate the engine in order to provide increased crush distance during frontal collisions.

It was essential that appropriate concern be exercised in the selection of the base vehicle. This selection constituted a significant part of the phase I effort. It was important that candidate base vehicles be ones which were suitable for expansion into a future vehicle design. Thus, such a vehicle must represent many aspects of the latest automotive state-of-the-art technology. Yet, it is equally important that the vehicle be reasonably representative of a wider class of automobiles. Clearly, if the base vehicle represented a “unique” design, then the eventual generalization of the RSV results to the automobile industry would be in serious question.

The base vehicle selected for the RSV is the Simca 1308, recently introduced by Chrysler France to the European market. This automobile, shown in figure 4, has interior occupant/cargo room equal to that of typical American compact cars (that is, a four-door Plymouth

Figure 4. Base vehicle—Simca 1308.
SECTION 3: INDUSTRY STATUS REPORTS

Valiant). Design features of the car include transverse front engine, front drive propulsion system, four-cylinder engine, unitized construction, and five-door (hatchback) layout. All of these features are expected to become increasingly popular in future American family cars.

A major factor in the selection of the Simca 1308 as the base vehicle was its transverse front-engine/chassis layout shown in figure 5. This arrangement allows excellent passenger-compartment space characteristics. Furthermore, the transverse engine allows one to maximize front crush distance in relation to overall hood length. The front drive, coupled with independent rear suspension, permits the fuel tank to be placed between the rear wheels providing excellent fuel system protection in the event of rear collisions. Finally, the absence of a drive shaft tunnel in the passenger compartment floor permits straight, constant section cross members to be placed in the underbody structure. Structural reinforcements may be internally contained within the various underbody cross members. This design results in greater passenger compartment structural integrity in both longitudinal and lateral loading directions.

Passenger compartment space, cargo capacity, and curb weight were generally important in the selection of the Simca 1308. These data for the Simca are summarized in the third column of table 3. The recommended ranges for these parameters for the RSV (see fourth column) are also shown. In general, the values for the Simca are reasonably close to those required for the RSV; yet, its curb weight of 2,317 pounds is well below the 3,000-pound RSV contract specified limit. Thus, some expansion in vehicle dimensions as well as major crashworthiness improvements would be possible without exceeding weight requirements.

To illustrate the more advanced nature of the Simca design, similar data for the Pinto and Vega are provided in table 3. These two vehicles were introduced to the public in the late 1960's and must by now be considered rather mature designs. Certainly, comparing Pinto and Vega data to the RSV range suggests that development of the RSV from this type of vehicle would be extremely difficult. Thus, it was clear that, in order to develop the kind of car required, it would be necessary to select a small, lightweight, base vehicle unlike those traditionally produced in the United States.

Because the base vehicle had the various features noted above, it was then possible to concentrate RSV design efforts on crash-safety considerations. That is, such characteristics as compartment cargo space, and fuel economy were assured because these features would generally carry over from the base vehicle. The first step in the RSV development process was naturally a valid establishment of the base vehicle performance characteristics.

BASE VEHICLE EVALUATION

Extensive safety tests were performed with the base vehicle. These tests indicated the base vehicle active safety characteristics (braking, handling, and so forth) met or exceeded the respective RSV requirements in nearly all instances. The only major exception appeared to be the case of braking where a front-brake system failure condition was simulated. In this instance, the specified stopping distance was exceeded. It was found through subsequent testing that changing to a diagonal split brake system (rather than the base vehicle front/rear split) corrected this problem. Because of the excellent performance of the base vehicle active safety system, it was possible to direct a major program effort toward crash safety.

Both dynamic crash and static crush tests were performed with the base vehicle. The tests that were performed are schematically illustrated in figure 6. Static crush tests were performed on the front, rear, and side of the vehicle. These data were necessary in order to establish an initial condition for the structural modeling effort (see later discussion) and to provide some guidance in selecting impact
Figure 5. Schematic illustration of the Simca running gear components.

Table 3. Car and body characteristics

<table>
<thead>
<tr>
<th>Item</th>
<th>1975 Pinto</th>
<th>1975 Vega</th>
<th>Simca</th>
<th>RSV range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front compartment (inches):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effective headroom</td>
<td>37.3</td>
<td>37.1</td>
<td>37.2</td>
<td>36-39</td>
</tr>
<tr>
<td>Maximum effective leg room—accelerator</td>
<td>40.8</td>
<td>43.5</td>
<td>41.1</td>
<td>40-42</td>
</tr>
<tr>
<td>Shoulder room</td>
<td>52.5</td>
<td>51.3</td>
<td>54.7</td>
<td>54-60</td>
</tr>
<tr>
<td>Hip room</td>
<td>51.8</td>
<td>47.2</td>
<td>–</td>
<td>54-60</td>
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<tr>
<td>Rear compartment (inches):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-point couple distance</td>
<td>28.7</td>
<td>27.4</td>
<td>31.2</td>
<td>37-39</td>
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<tr>
<td>Effective headroom</td>
<td>35.8</td>
<td>35.3</td>
<td>36.4</td>
<td>35-38</td>
</tr>
<tr>
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<td>51.0</td>
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<td>53.5</td>
<td>54-60</td>
</tr>
<tr>
<td>Hip room</td>
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<td>54-60</td>
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<tr>
<td>Luggage compartment:</td>
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<td></td>
</tr>
<tr>
<td>Usable luggage capacity (ft³)</td>
<td>6.3</td>
<td>8.7</td>
<td>11.6</td>
<td>14-19</td>
</tr>
<tr>
<td>Curb weight (lb)</td>
<td>2 613</td>
<td>2 558</td>
<td>2 317</td>
<td>2 500-3 000</td>
</tr>
</tbody>
</table>
SECTION 3: INDUSTRY STATUS REPORTS

STYLING

Both exterior and interior styling were deemed to be an important part of the RSV development. Because of limited program resources, it was decided that an attempt would be made to have the RSV carry over a maximum number of the base vehicle exterior body panels. Yet, it was also considered important that the RSV exhibit a distinctly different appearance than the base car and, if possible, improve aerodynamic drag. Finally, in view of the pedestrian impact requirements, it was recognized that a completely different front facia would be necessary.

A number of different front- and rear-styling themes were considered and developed into full-scale clay models. These were reviewed and an RSV exterior design was selected. The selected design led to the RSV illustrated in figure 8, where photographs of the front and rear views are provided. The contrast between the RSV and the base vehicle (refer to figure 4) clearly illustrates the carryover of body parts from the base car; yet, the RSV provides a fresh upgrading of the already attractive appearance of the base car. Although aerodynamic drag characteristics were not investigated, the RSV appears, at least from a subjective viewpoint, to provide improvement in drag properties.

A similar styling effort was directed towards the RSV interior. Again, an effort was made to maximize carryover parts. The areas of the vehicle that provided the greatest challenge were the door-trim panels, lower instrument panel (knee restraints), and rollbar structure. Each of these appears to have been resolved into attractive, functional components.

CRASH SAFETY

The RSV crash-safety activity is schematically illustrated in figure 9. As noted in the illustration, base vehicle crash properties as discussed previously constituted an initial input to this scheme. The crash-safety activity was divided into three principal categories: bumper, structure, and restraints/interior. In each case, engineering, design, and test activi-
Figure 7. Base vehicle after various crash tests.
ties were carried out at the subsystem level. Once desirable performance was established in all categories, a total vehicle system was developed and system integration testing was initiated.

At this point, it is emphasized that the basic philosophy underlying the Calspan/Chrysler crash-safety development is that this subject is now mature, that is, there exists a number of analytical tools that may be used in conjunction with limited experimentation to establish the final engineering design. Indeed, it was felt that the RSV program should conclusively demonstrate this point. Accordingly, extensive computer simulations were employed in all aspects of bumper, structure, and restraint development activities.

Figure 8. Front and rear views of the RSV.
 EXPERIMENTAL SAFETY VEHICLES

illustrated, the system employs a high-density/urethane foam skin with crash energy management provided by a low-density-energy-absorbing foam. The principal purpose of the bumper system is to provide pedestrian impact protection and minimize vehicle damage during low-speed collisions (refer to zone 1 in figure 3).

The basic shape of the exterior surface was established through a series of computer simulations. For this purpose, the Calspan-developed 3-D crash-victim simulation was employed. Energy-absorbing foam properties were established as a result of a specified body-block impact requirement (100-lb, 8-in diameter form must impact at speeds up to 20 mi/h without exceeding 60 gravity) and flat-barrier-impact requirements (no vehicle damage for vehicle/barrier impacts up to speeds of 8 mi/h). Numerous tests of this nature were performed in order to verify the adequacy of the design.

The RSV specifications do not require front-end impact with a dummy. Battelle, Columbus Laboratories, has, under contract with NHTSA, developed such test procedures in an attempt to simulate vehicle/pedestrian

Bumper

The front-bumper design and installation are schematically illustrated in figure 10.2 As

2 In this discussion, only brief consideration is given to the bumper system. The reader interested in more details should consult the paper by Kruse [3].
impacts. An RSV front structure was made available to the Battelle program and they performed a number of pedestrian-impact tests where both child and adult dummies were used. Preliminary test results, as reported by Pritz [4], suggest that the RSV front bumper might have important implications relative to reducing the severity of vehicle induced pedestrian injuries in both children and adults.

Structure

The most significant impact of the RSV design on the base vehicle is in the structure. The requirements on the structure were that it be developed in accordance with the various characteristics outlined previously for the zone concept (again refer to figure 3). Additionally, this part of the vehicle has the greatest potential impact on eventual producibility. All proposed structural-design changes were investigated to determine what their impact would be on the methods used to produce the base vehicle. Finally, because of a recyclability requirement placed on the vehicle and limitations in domestic supplies of aluminum (see fig. 2), steel was used (for the most part) in the structural design. As a weight-saving measure, aluminum was employed in the hood and trunk lids.

The basic structural changes between the RSV and the base vehicle are schematically illustrated in figure 11.3 As is evident in the illustration, major changes were made in the front- and side-structural components. As a weight-saving measure, high-strength, low-alloy (HSLA) steel was extensively employed in these structural changes.

The structure was developed using analytical/empirical methodology. With this approach, the vehicle is modeled as a system of spring/mass elements. Basic models used in the program for various types of collisions are schematically illustrated in figure 12. With this technique, weights of specific vehicle components (that is, passenger compartment, engine, and so forth) are lumped and associated with the masses shown in the models.

Specific structural elements are associated with each “spring” element. Force deflection data for the various structural elements are determined through a series of static crush tests. Dynamic strain rate effects are treated in an approximate manner in the computer software.4

As noted previously, the crush-test data developed for the base vehicle were used in the initial simulations. At this point, design changes were postulated for the various structural elements. Computer simulations proceeded in an iterative manner until RSV impact requirements were satisfied by the simulations. Corresponding design changes were then developed into a base vehicle body-in-white structure and subsequently crush tested. Resulting force-deflection data were then employed in revised simulations.

In order to achieve the performance goals of the program, two design interactions were required for both front and side structural systems. At that point, the overall structure was felt to be sufficiently developed so that the program could proceed to system-integration testing. The final RSV passenger-compartment acceleration body-crush results for a simulated front-barrier impact is presented in figure 13. Also shown on the illustration is the range developed in our phase I study (cross-band region). The RSV profile follows the same general trend as proposed during the phase I study (three distinct levels for the various front-structure zones), except it is displaced somewhat to the right. The reason for this is that the bumper required a greater displacement characteristic than was anticipated in the original study. Observe notation relative to bumper and structure deformation on figure 13.

In addition to the impact requirements stipulated in the phase I RSV specifications (refer to table 2), an effort was made to insure that the RSV would not have a severe adverse effect on other heavier and lighter cars. Thus, vehicle compatibility was extensively investigated throughout the structural development. For this purpose, the models

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3 Details on the front-structure development are provided by Glasgow and Treece [5]. A similar methodology was used in the development of the side and rear systems.

4 The basic structural modeling approach with particular emphasis on car-to-car collisions is covered in a forthcoming paper by Greene [6].
Figure 11. RSV structural changes.
Figure 12. Models employed in collision simulation.
illustrated in figure 12 were used. Representative small (Honda CVCC) and large (Plymouth Fury) cars were selected for the study. Front, side, and rear crush-test data were developed for both cars. Relying on an extensive review of available crash-test data for these cars, judgments were made concerning the maximum allowable crush that could be tolerated on each vehicle. An extensive array of collision possibilities was then simulated.

Partial results of the compatibility study for front and side car-to-car impacts are illustrated in table 4. As noted, the study involved four different cars, Simca (base vehicle), Honda, Plymouth, and RSV. Table 4 shows the estimated maximum permissible impact speeds among these various cars during both, aligned front-to-front and perpendicular front-to-side collision modes. Comparison of the RSV to the Simca provides an indication of the relative difference in performance resulting from the structural alterations. For example, maximum frontal-impact closing speed for a Simca-to-Simca collision is 65 mi/h while that for RSV-to-RSV is 89 mi/h. On the other hand, maximum closure speed for Simca-to-Honda is 63 mi/h and RSV-to-Honda is 58 mi/h; correspondingly, the Simca-to-Plymouth is 48 mi/h while the RSV-to-Plymouth is 78 mi/h. Thus, the nature of the trade-off between the RSV and the base vehicle when impacting other weight vehicles was established, at least in a qualitative manner.

Restraints/Interior

The front-seat restraint for the RSV is a passive torso belt, with the option of a
Figure 14. Schematic illustration of front-seat restraint system.

Semipassive lap belt system. The items that comprise the system are schematically illustrated in figure 14. There are two features, the movable D-ring and inflatable torso belt, that merit further discussion.

The passive feature of the torso belt is achieved through a motor-driven, movable D-ring. In the belt “on” position, the D-ring is located on the center pillar. In the “off” position, the D-ring is moved up the center pillar and forward on the roof header to the point where the header meets the A-pillar. The drive mechanism is a motor-driven, spiral-wound cable and drive-gear device, which is currently used in some production automobile sunroofs.

The inflatable torso belt is intended to serve two necessary functions. The inflation process tightens the belt around the upper torso and thereby allows the occupant to partially “ride-down” the structure during more severe frontal collisions. The inflated belt also improves the distribution of the restraint forces on both the upper torso and head. Because of the lower contact pressures acting on the occupant (when compared to conventional belts), this system allows higher belt forces to be imparted to the occupants. Thus, interior space inside the vehicle can be used more efficiently while arresting the occupants’ forward motion.

The RSV preliminary restraint system design was developed using the Calspan Crash Victim Simulation (CVS) model. The technique used in the study is described by Massing et al. [7]. Basically, the simulation permits extensive analysis of parametric varia-

5 Although the paper addresses a somewhat different topic, Kidd and Walsh [8] present data obtained with cadavers using various restraint systems. Their data tend to confirm this conclusion.
tions in belt forces, knee restraints, anchor locations, and so forth. For the computer simulation study, passenger-compartment-deceleration properties were determined from the structural model simulations (described in the discussion on the structure). Hence, structural response characteristics directly influenced the restraint system design activities. A typical 50-mi/h barrier simulation for a 50th-percentile occupant with the selected restraint system is illustrated in figure 15.

Once the preliminary design was established, the restraint system was evaluated with the Calspan HYGE sled. More than 100-occupant exposures were generated in three different sled-test series. During this period, limited computer simulations were performed to augment the sled results. Typical 50-mi/h barrier, 50th-percentile occupant response data are presented in figure 16. The data are extremely encouraging in relation to the very demanding impact condition.

The rear-seat occupant restraint is a conventional three-point unibelt system, except that force limiting is provided in the upper torso belt. It is noted that the impact performance requirements on the rear-seat occupant specify only a 30-35-mi/h barrier impact range (refer to fig. 5).

To provide energy management during lateral collisions, a special energy-absorbing door trim panel was developed. The panel, along with the RSV door structure, is illustrated in figure 17. Occupant-impact energy absorption is provided by an aluminum honeycomb placed in the trim panel. Because of the desire to keep the door structure as narrow as possible, it was mandatory that a highly efficient energy-absorbing media be used. Numerous candidate materials were evaluated; however, aluminum honeycomb appears to be the most suitable choice for these particular applications.

Figure 15. RSV occupant restraint-system computer simulation.
Figure 16. Impact data from sled tests.

Figure 17. Energy-management door-trim panel structure.
The performance of candidate material and designs were verified through a series of drop tests. For this test, dummy torso, pelvis, and upper leg components are placed in the drop tower. Experiments were conducted with drop heights allowing for impacts at speeds up to 20 mi/h.

After verification of all subsystems, the crash-safety effort moved to system-integration testings.

System Integration

The system-integration testing began in September and is scheduled for completion in early November 1976. Thus, the test and evaluation effort is still incomplete and results gathered to date are of an extremely preliminary nature.

The planned system-integration tests are schematically illustrated in figure 18. At present, all five tests shown for vehicles 1 and 2 have been conducted. In all instances, the preliminary results are extremely encouraging. For example, figure 19 shows photographs of both the base vehicle and the RSV after 45-mi/h barrier impacts. The improved structural performance of the RSV is apparent from these photographs. Equally important, preliminary occupant exposure data suggest that all measured parameters meet (or nearly meet) the injury criteria. It is strongly felt that anticipated future design refinements will correct any deficiencies uncovered in these initial tests.

VEHICLE SYSTEMS

As noted in previous discussion, most of the chassis-related vehicle systems of the base vehicle will carry over to the RSV. An exception was the adoption of a diagonal-split braking system for the RSV. The RSV brake system is schematically illustrated in figure 20.

A major change between the base vehicle and RSV powerplants will be evident. In addition to safety requirements, the phase II contract imposes fuel economy and emission goals on the program. At the time of negotiation, however, it was clearly recognized that

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6 Femur loads on the driver dummy may exceed limits.
Figure 19. Vehicles after 45-mi/h barrier impact.
major program resources were not expected to be spent in engine development. Thus, it was anticipated that present state-of-the-art powerplants would be used in the RSV.

Within these restrictions, various engines were considered for the RSV. Primarily because of its emissions equipment, the 1716-cc engine that Chrysler will market with its

Figure 20. RSV brake system.

Figure 21. Engine compartment and belt-drive system.
future subcompact car will be used in the RSV. Packaging studies were conducted to determine how this engine and related equipment would fit into the RSV. The overall engine house layout for the 1,716-cc engine with optional equipment and emissions control devices is illustrated in figure 21. Expected performance of this engine in relation to contract goals are stated below:

<table>
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<th>Emissions</th>
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<td>HC (g/mi)</td>
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<tr>
<td>CO (g/mi)</td>
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</tr>
<tr>
<td>NOX (g/mi)</td>
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<td>Performance</td>
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<tr>
<td>35-60 mi/h (s)</td>
<td>24.00</td>
<td>15.5-18.0</td>
</tr>
<tr>
<td>50-70 mi/h (s)</td>
<td>22.00</td>
<td>17.5-20.0</td>
</tr>
</tbody>
</table>

7Full optional car with automatic transmission, air conditioning, power steering, and power brakes.

Even though neither the fuel economy nor the emission goals are expected to be realized, the results are gratifying in relation to performance of many cars in current production which have similar occupant space/cargo capacity. This is particularly significant in view of the fact that no program resources were available for powerplant systems development.

DISCUSSION

The objective of the study is essentially to bring all of these items together into a system that represents a reasonable automobile. Although the RSV program is far from complete, the kind of automobile that is emerging from the study is now becoming apparent. Principal features are illustrated in figure 22. Certainly, phase III of the program can realistically be expected to result in a vehicle that has essentially all of these features. Until that time, however, the preliminary nature of results reported to date should be fully appreciated.
REFERENCES

   *Volume II—RSV program definition and foundation; accident data, automobile usage, natural resources, related safety costs*, Calspan Report No. ZN-5450-V-12, April 1975.


A Summary of the Minicars RSV Program

DONALD E. STRUBLE
RSV Program Manager, Minicars, Inc.

INTRODUCTION

In January of 1974, Minicars, Inc., was awarded a phase I Research Safety Vehicle (RSV) contract, along with four other competitive contractors. Each contractor had the assignment of projecting the automotive environment of the mid-1980's, characterizing the vehicles that would operate in that environment, issuing performance specifications accordingly, and developing an RSV preliminary design to satisfy the specifications. At the close of phase I, proposals were submitted for phase II, in which all of the vehicle systems were to be developed, tested, and integrated with each other. Minicars was one of two contractors selected to pursue these objectives, and it is the purpose of this paper to broadly summarize the results of our phase II efforts.

RSV PROGRAM OBJECTIVES

The S3E Concept

The objective of the RSV program, as described in the “Statements of Work” for both phase I and II, is:

- to provide search and test data applicable to the automotive safety performance requirements of the mid-1980's, and to evaluate the compatibility of these requirements with environmental policies, efficient energy utilization, and consumer economic considerations.
As Dr. James B. Gregory, former administrator of the National Highway Traffic Safety Administration, pointed out in his presentation at the London Experimental Safety Vehicle Conference:

All three areas [energy, environment, and economy] are factors in the future design of vehicles, and we want to keep them in mind as RSV proceeds. In discussing safety, energy, environment, and economy, I have called this concept the S3E...

It is thus clear that in the RSV program, safety must not be treated in isolation. The same can be said for the promulgation of U.S. Federal Motor Vehicle Safety Standards (FMVSS), and we think it is significant that the U.S. Government is utilizing the technological data base generated by the RSV program to support its rulemaking activities.

In our admittedly biased opinion, the Minicars RSV is the epitome of the S3E concept. It demonstrates that national goals for safety, fuel economy, and emissions can be compatible, and can all be met with a producible, marketable, and relatively economic product.

**Marketability and Producibility**

It is obvious that no matter how safe a system is, no matter how well it performs, it will not save a single life nor mitigate a single injury unless it finds its way into the hands of, and is used by, the general public. Therefore the RSV and all its systems were designed to be translatable into an affordable, mass-produced product that would be appealing to U.S. car buyers. Of course, the only way to prove the producibility and marketability of anything is to actually produce it and sell it, and it is obvious that the RSV will never reach that stage. However, during the course of the program we have discovered that all of the RSV systems have been, or are being, contemplated or developed by the industry itself, so it seems likely that the marketability and producibility of these systems will eventually be proven, by way of their assimilation by the automotive industry and their incorporation on mass-produced and mass-marketed vehicles. In fact, the only significant producibility question during the program has focused on the RSV structural concept, and a detailed cost estimate of this system by the Budd Company indicates a cost comparable to that of the Pinto structure, in quantities of 300,000 per year.

The issues of producibility and marketability bear directly on the degree of interest in the program shown by the automotive industry, since designs that are deficient in these areas can be dismissed as mere laboratory exercises, with no bearing on the real world. Similarly, an impractical design would be unlikely to provide useful information for rulemaking purposes. Therefore, in order to insure that the project result in a meaningful demonstration to both Government and industry of what can be done to satisfy national goals in the mid-1980's, and to contribute to a valid data base for FMVSS, we tried to make the RSV design as marketable as possible, and we included only those features that could be (or would be) incorporated by the automotive industry in the time frame of interest.

**Maximizing the Safety Payoff**

The goal of enlightened Government rulemaking is to produce the greatest public good, with all factors (positive and negative) being considered. Accordingly, a requirement of the phase I Work Statement was to design the RSV to maximize the safety payoff (consistent with energy, environment, and economy). For analytical purposes, "safety payoff" was interpreted by Minicars to be the total yearly societal benefit (in 1985) minus the total yearly investment. Design features were then categorized according to whether they accrued (a) a quantifiable safety payoff, (b) a safety payoff that is not quantifiable with current analytical techniques, or (c) no safety payoff at all. Restricting our attention to the quantifiable safety payoff, it was then apparent that a large number of paths exist for accruing a safety payoff, and the analytical problem became one of finding the optimal path. In other words, we had to select the combination of safety systems that would produce the greatest net yearly benefit, on the basis of substituting RSV's for all the
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vehicles in a certain car class (which was to be determined analytically).

In order to determine which car class the RSV should be targeted for, we made a detailed projection on 1985 societal costs, based on projected market shares, vehicle weights and usage, collision speeds, and accident modes. We found that the highest 1985 societal costs (assuming no improvements to current vehicles) would be accrued by subcompacts, in the 2,000- to 2,600-pound weight range. This is shown in figure 1. In other words, the subcompacts pose the greatest problems from a societal cost point of view, which also means that safety systems installed in such vehicles would have the maximum potential for accruing benefit. Consequently, we decided that the RSV would be marketed as a subcompact, and that it would be in the subcompact weight range.

This was all consistent with the contractual limitation on the RSV design of 3,000 pounds. However, rather than merely meeting the letter of the contract, we determined that S3E goals would be best served by keeping the weight as low as possible—at the lower end of the subcompact weight class. However, marketability would be enhanced by making the interior as commodious as possible, so the goal of the RSV design was to combine the interior space of a compact car with the exterior size of a subcompact car and the fuel economy of a sub-subcompact car.

The Effects of Weight

As previously mentioned, RSV program goals included strong considerations for energy, environment, and economy in addition to safety. All of these considerations are affected by weight.

For any vehicle, the life cycle energy requirements are made up of two parts: the energy required to produce the vehicle, and

Figure 1. Societal cost of accidents by vehicle class.
the energy required to operate it during its lifetime. It is clear that if we were to do nothing to a vehicle design except reduce the amount of materials required, the production energy would be reduced concomitantly. Moreover, the reduced weight would lead directly to improved fuel economy, which would lead in turn to reduced requirements for energy to operate the vehicle. Of course, fuel economy improvements could also result from the development of more efficient powerplants, but such development efforts have never been a part of the RSV program.

The effect of vehicle weight on fuel economy invites a second approach to reducing vehicle weight: substituting lighter (but probably more energy-intensive) materials instead of or in conjunction with reducing the amount of material. This approach has the effect of forcing a trade-off between production energy requirements and operational energy requirements. Nevertheless, both approaches have been used in the RSV design, causing a reduction of 35 percent in the former and 45 percent in the latter, for a total reduction of 44 percent in the life cycle energy requirements relative to a current production vehicle having comparable interior volume.

A further benefit of using less material is to reduce the purchase price of the vehicle. Of course, material substitutions could result in higher costs per unit weight, so once again there is the opportunity to trade off purchase price versus operating costs, on the basis that lighter and more exotic materials could improve the fuel economy. An illustration of such a trade-off is provided by the 1977 General Motors Cars, though it remains to be seen whether reduced fuel costs will compensate for the higher purchase prices relative to the 1976 GM models.

Finally, the effect of minimizing vehicle weight is to permit the use of certain fuel-efficient engines designed for small cars. For example, the Honda Accord engine would probably not be acceptable to the driving public if used in a 3,000-pound car, due to inadequate acceleration performance. In addition to being fuel-efficient, however, this stratified charge engine provides the best compromise between fuel economy and emissions that is available in a current production engine. Therefore, good performance in the environment dimension of S3E could also be achieved if the RSV weight could be kept in the same range as that of the Honda Accord (about 2,100 pounds), and this is probably the most important aspect of the low-weight goals established for the Minicars RSV.

THE MINICARS APPROACH TO ACHIEVING PROGRAM OBJECTIVES

The Minicars approach to program objectives has been hinted at already—to use the most rational approach possible in the establishment of the vehicle architecture and in the selection of subsystems, recognizing that much of vehicle design entails subjective as well as objective choices. Examples of this approach are treated in the following text.

Accident Analysis Findings

As already suggested, detailed analyses of societal costs and safety system benefits were used extensively in phase I to determine the RSV market class, to define the safety problem to be solved, and to establish the priorities among various candidate safety systems. These procedures were described in detail in the Minicars Phase I Final Report, and in papers delivered at the Fourth International Congress on Automotive Safety in San Francisco, and need not be repeated here. However, during phase II, the analytical work was continued, and is summarized in a paper entitled "Phase II RSV Accident Analysis Techniques," by Keith Friedman, which is being presented at this conference. A detailed presentation of the results will appear in the final report for phase II.

The primary objective of this work was to update and improve the analysis of current societal costs, according to accident mode and velocity, so as to provide a firm, rational basis for the construction of the phase IV test matrix. The most detailed data base available for this analysis is the Multi-Disciplinary Accident Investigation (MDAI) file, which is known to have some severe biases. In the
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phase I work, these biases were adjusted by means of matching the distribution of Injury Levels (on the American Medical Association’s Abbreviated Injury Scale) found in the Cal II file. In the subsequent phase II analysis, this matching procedure was applied separately for six different accident categories, or modes: front, side, and rear vehicle-to-vehicle collisions, front and side fixed-object impacts, and rollovers.

Once the file adjustment was completed, then the distribution of societal cost by accident mode and velocity could be obtained. These distributions are summarized in table 1.

This simple table suggests a rational way to select test modes and to evaluate the results in terms of reductions in societal costs. The most accurate assessment of these reductions would come from emphasizing, in the test matrix, those crash modes that contribute the greatest portions of the total societal cost. For example, the table suggests that for every fixed-object side impact conducted, we would logically run eleven frontal vehicle-to-vehicle tests, or, if the number of tests is limited, we might forgo the fixed-object side impact altogether. Moreover, the table gives some indication of what the appropriate test speeds might be. The greatest rate of accrual of costs tends to occur at the 50th-percentile velocity (the velocity below which half of the costs are accrued), and small increases in system performance at this speed can lead to substantial increases in societal benefits. By the time system performance reaches the 75th-percentile velocity, however, the law of diminishing returns starts to set in, so it is not entirely coincidental that RSV performance goals tend to be comparable to the 75th-percentile velocities. Accordingly, a rule of thumb used in establishing test speeds for significant crash modes was to use the 75th-percentile velocity, unless anticipated system performance indicated otherwise.

Of course, it can be pointed out that the accident modes described so far are not very specific; that is, they do not give much guidance as to how to set up a test. Accordingly, societal costs were analyzed in a much more detailed way, with accident modes being defined, for example, by the case vehicle direction of impact force, the case vehicle damage area, the angle between the vehicle centerlines in a vehicle-to-vehicle collision, and so forth. An example of this detail is shown in table 2, which provided the basis for establishing the phase IV test matrix.

For any given mode in table 2, the velocity distribution in that mode can be examined so as to determine the 75th-percentile velocity. (This would probably be different from the 75th-percentile velocities of table 1, because the modes of table 2 are subsets of the original six modes.) Such a procedure was applied to the test modes used in phase II, and it was discovered that oblique side impacts in which the struck car is stationary (a test mode used many times in U.S. Government test programs) are virtually nonexistent in the accident files. Therefore, we set out to determine the most representative side impact mode, and the 75th-percentile velocity in that mode. Table 1 indicates that this would be a vehicle-to-vehicle impact.

The first information can be obtained from table 2, from which we find that the combined societal costs for left- and right-side damage areas are distributed as shown in figure 2. Clearly the preponderance of costs lies in the center and front damage areas. This information indicates strongly that side impacts should produce side-center and front damage areas, which, for all practical purposes, means that the “A” post should be engaged. This is in conflict with previous side impact test procedures.

The second step in determining the appropriate side impact test mode is to determine the impact angle that should be used (that is,

<table>
<thead>
<tr>
<th>Accident mode</th>
<th>Percent of total societal cost</th>
<th>50th-percentile closing velocity (mi/h)</th>
<th>75th-percentile closing velocity (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle-to-vehicle:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>47.5</td>
<td>67</td>
<td>90</td>
</tr>
<tr>
<td>Side</td>
<td>25.4</td>
<td>36</td>
<td>48</td>
</tr>
<tr>
<td>Rear</td>
<td>5.8</td>
<td>26</td>
<td>38</td>
</tr>
<tr>
<td>Fixed object:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>9.2</td>
<td>34</td>
<td>46</td>
</tr>
<tr>
<td>Side</td>
<td>4.4</td>
<td>39</td>
<td>49</td>
</tr>
<tr>
<td>Rollover</td>
<td>8.0</td>
<td>43</td>
<td>57</td>
</tr>
</tbody>
</table>

Table 1. Distribution of societal costs


The angle between the vehicle centerlines at the time of contact). Logically, this determination should be made on the basis of the largest portion of societal costs in accidents that produce side-center and front damage areas. The result of our investigation was that a large portion (70 percent) accrues for impact angles between 75 and 105 degrees. On the other hand, only 20 percent of the cost occurred for impact angles between 45 and 75 degrees. We therefore drew the conclusion that the impact angle should be approximately 90 degrees.

The third step is to determine the velocities of the struck and striking vehicles. To do so, we generated a bivariate table of societal cost for this impact mode, with the two velocities as variables, and we found a clustering of costs along the main diagonal of the table. The conclusion: the velocities should be approximately equal.

With this piece of information, we plotted the distribution of cumulative societal costs in the selected test mode, as a function of closing velocity. We found the 75th-percentile velocity to be about 52 mi/h. The correspond-
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75th-percentile velocities. These are presented in Table 3, along with the impact speeds actually used.

RSV Front-Structure Optimization

In the preliminary design activities of phase I, it was recognized that rational design of the structure should consider the entire range of significant accident modes, or better yet, should minimize the societal losses for all accident modes, taking into account the costs incurred by the occupants of vehicles struck by the RSV, as well as the RSV occupants themselves.

These considerations produce conflicting requirements for the RSV front structure. RSV occupant protection in frontal impacts is enhanced by a square-wave front structure; that is, a front structure in which the crush force rises rapidly to a level that then remains essentially constant throughout the remainder of the crush. In order to provide protection at high impact speeds, this force level would generally be fairly high—60,000 to 100,000 pounds—depending on the amount of frontal crush available. On the other hand, side-structure force levels tend to be much lower,

![Diagram showing percent of total societal loss by side damage area.]

Table 3. 75th-percentile closing velocities

<table>
<thead>
<tr>
<th>Mode</th>
<th>75th-percentile closing velocity for societal cost (mi/h)</th>
<th>Closing velocity used in phase II tests (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full frontal barrier 0° (frontal fixed-object-distributed damage)</td>
<td>57</td>
<td>51</td>
</tr>
<tr>
<td>Offset/angular frontal barrier (center-left and center-right damage)</td>
<td>40-42</td>
<td>45</td>
</tr>
<tr>
<td>Front center pole</td>
<td>46</td>
<td>—</td>
</tr>
<tr>
<td>Rollover</td>
<td>57</td>
<td>30</td>
</tr>
<tr>
<td>Aligned frontal vehicle-to-vehicle (V-V frontal distributed damage)</td>
<td>96</td>
<td>90</td>
</tr>
<tr>
<td>Offset frontal vehicle-to-vehicle (V-V center-left and right damage)</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Offset frontal vehicle-to-vehicle (V-V left and right damage)</td>
<td>90</td>
<td>—</td>
</tr>
<tr>
<td>Vehicle-to-vehicle side; 90° impact angle, velocities equal, conventional into RSV</td>
<td>50-55</td>
<td>a52</td>
</tr>
<tr>
<td>Vehicle-to-vehicle side; 90° impact angle, velocities equal, RSV into conventional</td>
<td>50-55</td>
<td>a52</td>
</tr>
<tr>
<td>Vehicle-to-vehicle oblique side; struck car stationary; conventional into RSV</td>
<td>(b)</td>
<td>35</td>
</tr>
<tr>
<td>Vehicle-to-vehicle oblique side; struck car stationary; RSV into conventional</td>
<td>(b)</td>
<td>30</td>
</tr>
<tr>
<td>Vehicle-to-vehicle square rear</td>
<td>38</td>
<td>40</td>
</tr>
</tbody>
</table>

*aEach vehicle moving at 37 mi/h.

bNo statistical representation in accident data. Therefore 75th-percentile velocity cannot be identified.
because the vehicle architecture precludes having strong lateral load paths in the occupant package volume. If the RSV front end were designed to be fully compatible with a soft side structure, the resulting front-end softness would produce a serious degradation in the ability to protect RSV occupants in high-speed frontal collisions. Similarly, a hard RSV front end that is designed to interact with other hard front ends or fixed objects at high speeds would be so hard as to completely cave in a soft side structure. This, then, is the essence of the design dilemma: to effect a compromise between high crashworthiness and low aggressivity so as to minimize the total societal cost of accidents involving RSV's.

The result of this compromise is strongly dependent on the nature of the other vehicle with which the RSV is assumed to interact. In fact, the result is particularly sensitive to the force levels that can be generated by the side of the "other" vehicle, since side impact intrusion can only be limited by keeping frontal crush forces below this level. In 1985, most of these "other" vehicles would be conventional cars, even if RSVs were substituted for all subcompacts. We made the important decision, therefore, to design the RSV to impact conventional 1985 vehicles, not to impact other RSV's.

Of course, we cannot know what the exact nature of these 1985 vehicles will be, but all indications point to significant weight reductions, in order to meet national fuel economy goals. Since these reductions are being accomplished primarily by material substitutions (for example, plastics and aluminum for steel) and size reductions, it seems unlikely that conventional car crashworthiness will improve, especially in the absence of a 40- or 50-mi/h occupant-protection standard. We decided, therefore, to assume that 1985 vehicles will be structurally similar to current production cars.

In the Minicars phase I effort, an attempt was made to optimize the RSV front structure and resolve the conflict between high crashworthiness and low aggressivity. However, there was a general lack of crush data for conventional car side structures, and the only information we had seemed to indicate a crush characteristic that rose to 40 000 pounds over the first 12 inches, and remained constant thereafter. This led to the optimized RSV frontal crush characteristic shown in

Figure 3. RSV frontal crush characteristics.
figure 3, with three plateaus: (a) an initial plateau (bumper crush) for damage immunity at speeds up to 10 mi/h into a barrier; (b) an intermediate plateau at a force level (37,000 pounds) just below the strength of conventional-car side structures, minimizing aggressivity; and (c) a final plateau at 75,000 pounds, to provide high-speed frontal crashworthiness.

Shortly after commencing phase II activities, Minicars performed some preliminary crush tests of small cars, and found that they were much softer than anticipated. Recognizing the significance of this discovery, not only for RSV structural design but also for side impact protection standards, the Government issued a contract modification that allowed us to explore this question further, and to reconsider the RSV frontal-structure optimization. A series of static crush tests was performed on four vehicles that were considered to span the 1985 automobile mix. Including large cars and small, foreign and domestic, two-door and four-door, the selected vehicles were a Chevette, a Datsun B-210 two-door sedan, a Datsun B-210 four-door sedan, and a Chevelle Malibu Classic two-door hardtop. In addition, an RSV was crushed to provide a comparison. Two crush modes were selected for each vehicle: (a) a 90-degree (perpendicular) crush in which the "A" post was engaged, representative of the most costly side impact mode; and (b) a 300-degree (oblique) crush in which the "A" post was not engaged, representative of the crash-test mode used frequently for side-impact tests. It was thought that the two modes would also provide upper and lower

Figure 4. Side crush as a function of applied force for 90° impacts.
bound, respectively, to the side structure strength.

The results of these tests are shown in figures 4 through 7. In the 90-degree mode, the large car (Chevelle) behaved according to our phase I estimates. However, the small production cars were again very much softer, and were remarkably similar in performance, with maximum force levels ranging from 24,000 pounds in the perpendicular mode, to 13,000 pounds in the oblique mode. The RSV, on the other hand, was roughly as stiff as the Chevelle in the perpendicular mode, and nearly twice as stiff as any of the production cars tested in the oblique mode.

With this information in hand, the frontal-optimization study could be performed in accordance with the methodology indicated...
in figure 8. Basically, the procedure consisted of computer simulations of frontal and side collisions over a range of vehicle classes and accident modes and velocities, with this variation being accomplished for each RSV frontal structure under consideration. For side impacts, the candidate RSV front structure was crashed into a "large" conventional car and a "small" conventional car, this choice of struck-car classes being determined from the side-crush test results. Average weights for small and large cars were 2,400 and 3,800 pounds, respectively, as determined from phase I projections of the 1985 environment. Accident modes were defined as oblique and perpendicular. For frontal impacts, accident modes were defined as fixed-object or vehicle-to-vehicle, with the latter involving the front of either a small or a large car. For both accident types, the closing velocity was varied in 10-mi/h increments.

In the optimization study, the computer simulation results were used to determine which RSV frontal crush characteristic would result in the lowest total societal cost (recognizing that scope limitations precluded evaluating the RSV frontal structure for all accident modes and struck vehicle classes). This required a relationship between the occupant response (as determined from computer simulations or laboratory tests) and the average societal cost per injury (as accrued in actual accidents). Such a relationship can be constructed by comparing laboratory data with actual accident data, for similar crash conditions. Such considerations during phase I resulted in figure 9, in which the three curves reflect the fact that different restraint systems impose different load distributions on the occupant, and hence different injury severities. During phase II, a corresponding transformation between the laboratory and the highway was developed for side impacts, based on more detailed information than was available previously.

To compare laboratory data with accident data and thus develop the transformation, it was necessary to rate the impact severity. A number of parameters are available for this purpose, but the most likely candidates seemed to be the velocity change $\Delta V$ and the side crush distance, applied in each case to the vehicle containing the occupant whose injury was being assessed. Examples of the laboratory data, plotted versus these two crash severity parameters, are shown in figures 10 and 11. From these graphs, $\Delta V$ was judged to be the better measure of crash severity, since...
Figure 8. Optimization study methodology.

Side impact cost calculation

- Car class
  - Padding drop tests
  - Padding crush characteristics
- Mode (oblique and perpendicular)
- Static crush tests
- Side structure crush characteristics
- Velocity
- Side impact computer simulation
- Peak chest g's
- Transformation to societal cost for side impacts
- Average cost per injury
- Multiply frequency by severity
- Total cost of RSV front into conventional side
- Frequency by mode
- Frequency by velocity
- Sum

Frontal impact cost calculation

- Mode (car-to-car and fixed object)
- File of conventional car frontal crush characteristics
- Velocity
- Frontal impact computer simulation
- (To be varied)
- Crash pulse
- Airbag/occupant computer simulation
- Chest severity index
- Transformation to societal cost for frontal impacts
- Average cost per injury
- Multiply frequency by severity
- Total cost of RSV front into conventional front and fixed objects
- Frequency by mode
- Frequency by velocity
- Sum

Total cost of RSV frontal involvements

(To be minimized)
Figure 9. Phase I transformation from laboratory injury measure to societal cost.

Figure 10. Laboratory test data plotted against ΔV.

Figure 11. Laboratory test data plotted against crush.

It produced less scatter (presumably because it is more directly responsible for occupant injury). Similar plots were made for chest severity index (SI) versus crush and ΔV, but the use of peak chest g’s tended to produce less scatter in both cases. The next step was to examine the accident data, which could be filtered by seating position (all positions, or nearside occupants only) and injury status (injured occupants only, or injured and uninjured occupants). These two filters, plus the choice of crash severity parameter, led to $2 \times 2 \times 2$, or eight, possible transformations, which are shown in figures 12 and 13. Adjusted correlation coefficients for these curves ranged from 0.732 to 0.914, indicating a choice of several excellent transformations. As a general rule, crush yields a better correlation than does ΔV. This may appear contrary to the conclusion drawn above, but is undoubtedly due to the inability to accurately estimate ΔV for actual accidents. Furthermore, use of nearside occupants only tends to give better correlation than does the use of all seating positions, as might be expected. No definite conclusions could be drawn for injury status.
Having developed transformations relating dummy injury measures (peak chest g’s) to societal cost, the results of the computer runs could now be expressed in terms of the average societal cost per injury. These could then be multiplied by the frequency of injuries in each category, resulting in the total cost in each category. When these costs were then summed over all the categories, the total societal cost could be compared for each of the RSV frontal crush characteristics under consideration.

The least costly frontal characteristic is shown in figure 3, in which it can be compared with the original characteristic. It is clear that the new intermediate plateau (which is present to provide compatibility with conventional car side structures) is only slightly above the bumper crush plateau. (The slight step between the two plateaus is necessary if crush in 10-mi/h impacts is to be confined to the bumper, which is in turn necessary for damage immunity.) As such, this intermediate plateau provides the softest practical frontal structure, unless either the low-speed damage immunity is compromised, or the performance of the replaceable front section is reduced below 20 mi/h.

The softness of the optimized crush characteristic is due simultaneously to the lack of side impact occupant protection in conventional vehicles (due in turn to the lack of structural strength and padding energy absorption capability), to the very long frontal crush stroke available in the RSV, and to the superb frontal occupant protection offered by the RSV airbag restraints (to be discussed later). These restraints are unusually insensitive to the RSV frontal crash pulse, which allows the pulse to be significantly nonideal without seriously degrading restraint performance. Also the long crush stroke permits lower force levels for a given energy absorption capability, thus avoiding much of the structural “bottoming out” that would occur with shorter available strokes. Finally, conventional car side impact protection is so poor as to require all of the additional help that the
RSV front structure can provide. This suggests, of course, a high priority for future rulemaking activities regarding side impact occupant protection.

Designing for Minimum Weight

The problem of weight has been bedeviling automobile designers since the beginning of the auto industry, and this problem is particularly worrisome today. Current attempts at weight reductions focus on reducing vehicle dimensions (at least on the exterior), and on material substitutions. Obviously, we can only go so far in reducing exterior dimensions without beginning to compromise interior accommodations. Both size reductions and material substitutions must have questionable effects on vehicle crashworthiness. Consequently, it seems that if we are to go much further in reducing weight, while simultaneously demonstrating improved crashworthiness, we must go to a new concept for a crashworthy energy-management system (the structure). We must find a way to avoid the 300- to 500-pound increases that have been associated with crashworthiness improvements in the past.

With this objective in mind, in 1973 the Government awarded a contract to Minicars to improve the crashworthiness of the Pinto, while keeping any weight increases to 240 pounds or less. In satisfaction of this requirement, Minicars developed the foam-filled sheet metal concept, in which closed sheet metal boxes were filled with rigid energy-absorbing foam. This concept is described in more detail in a paper entitled “Development of Lightweight Crashworthy Vehicle Structures,” by Richard B. Tanner, which is being presented at this conference. Basically, the purpose of the metal is to contain the foam and to carry road loads (loads generated by normal vehicle operation). The sheet metal gages are generally lighter than in a conventional vehicle. While the sheet metal also contributes to crashworthiness, the burden for high crashworthiness performance falls on the foam. By adjusting the sheet metal gages and the foam density, the crush characteristics of the structure can be finely “tuned” to provide crash pulses of the desired shape.

Since the foam/sheet metal combination produces a high energy density (energy absorption capability per unit weight of material) relative to conventional techniques, the high-speed energy management requirements can be met while using less material. Furthermore, the volumetric nature of foam-filled sheet metal structures makes them quite omnidirectional, meaning that the structure can absorb energy safely when loads are applied from a variety of directions. This last feature is significant, because societal cost accounting indicates that high costs are accrued in frontal oblique impacts—not just in square-on frontal collisions.

By the end of the Pinto modification program, we were demonstrating a total net weight increase of 100 pounds. Nevertheless, with the installation of advanced inflatable restraint systems (also developed by Minicars under Government contracts) in the modified Pinto, occupant injury at 50-mi/h velocity changes was on the order of one-half to two-thirds the values considered allowable by the U.S. Government.

At the outset of the RSV program, we realized that we could simply extend the Pinto modification effort to the RSV structural design, and meet the nominal safety and weight requirements. However, having been involved in a vehicle modification program, we also recognized that additions or substitutions to a production structure could not demonstrate the degree of integration or producibility that is inherent in production cars. After all, production cars are designed from scratch. Moreover, to demonstrate the full potential of this new structural concept for weight reductions, we decided that the most appropriate approach would be to design the RSV from the ground up.

RSV Structural Design

The RSV structural design was guided by some philosophical considerations that have an important influence on the results. This is easily demonstrated by comparing the RSV design to that of the U.S. family sedan ESV's. Our primary concern in this and other National Highway Traffic Safety Administration
(NHTSA) programs is to save the occupant, and not the car (except in low-speed impacts). Therefore, our ultimate objective is to reduce the societal cost of injuries, which relates to reductions in dummy injury measures, as indicated in figures 11 and 12. In short, the criterion for success in crash tests focuses on occupant response, and is not overly concerned with such structural parameters as the crash pulse or the intrusion, except insofar as these influence occupant injury (by way of ejection, for example). Consequently, no intrusion requirements per se have been specified for the RSV. This allows us to permit significant intrusion in areas not used by the occupant in his deceleration, or in areas which would produce only limited societal costs. For example, we have no specified limit on toeboard intrusion, on the basis that foot and lower leg injuries are not costly compared to other injuries, although it is clear that eventually such intrusion would become unacceptable. (For all practical purposes, structural collapse in other areas, such as in the restraint mounts, would occur in conjunction with extensive toeboard intrusion, and would represent a much more serious problem.)

Aside from philosophical considerations, the RSV structural design was given fundamental guidance by the results of the phase I societal cost analysis, which indicated clearly that primary attention should be given to frontal and frontal oblique impacts, with less attention to the side and very little to the rear. Moreover, the RSV frontal structure should be designed for low aggressivity when striking the relatively weak sides of conventional cars, as discussed previously. These considerations all point to the need for a front structure that can crush efficiently at low-force levels over long-crush distances, and that can tolerate and efficiently manage oblique impacts. The best way to achieve these objectives, while minimizing weight, cost, and complexity, is to locate the engine where it will not interfere with frontal structure crush. Therefore, the decision was made early on to locate the engine between the rear

Figure 14. RSV front structure configuration.
wheels, and to devote essentially the entire front of the car to crash-energy management, for both low-speed and high-speed impacts. As a result, the frontal structure consists essentially of a foam-filled platform, 9-inches thick, that forms the floor of the forward luggage compartment (see figure 14). Additional crash loads are generated by longitudinal collapse of the foam-filled sheet metal fender boxes that are located above the front wheels. This additional load path, while helpful in reducing vehicle pitch in frontal collisions, is primarily intended to generate additional forces in car-to-car offset collisions.

From the frontal platform and the frontal fender boxes, longitudinal loads are transmitted longitudinally through the door and through the sill, both of which are also foam-filled. Door strength is augmented by two longitudinal columns—one along the sill, and one just below the window opening. From there, frontal crash loads go into foam-filled sheet metal boxes that coincide with the top of the rear spring towers, and through the rear sill kickups, to which are mounted the engine and suspension control arms.

To generate maximum strength in side impacts without compromising the interior accommodations, the sills were braced laterally by three foam-filled sheet metal boxes: one under the toeboard, one under the front seats, and one under the rear seats. These are shown in figure 15. To transmit lateral loads from the door to the rest of the structure, strong shut faces were provided around the entire periphery of the door. In addition, crash pins were added to the fore and aft ends of the upper longitudinal door beam. These pins also serve to keep the door closed during frontal collisions.

Additional support of the toeboard in frontal collisions was provided by a reinforced foam-filled sheet metal forward tunnel that ran along the car centerline from the toeboard to the lateral member under the front seats. A rear tunnel between the rear seat footwells houses a crash-proof fuel storage cell, which is installed from underneath the car. The high fuel economy of the engine permitted this cell to fit in a small space, since it holds approximately 8.5 gallons.

The least crashworthy part of the structure is probably the rear of the RSV, because
rather little crush distance is provided for rear impacts. Again, this priority was established by the phase I societal cost-accounting procedures. However, the engine and suspension are mounted on a sturdy steel tubular framework—the engine cradle—which carries substantial longitudinal and transverse crash loads. Moreover, the engine cradle permits the engine, transmission, and suspension to be assembled outside the car, and then brought in for installation as a single unit.

RSV Occupant Protection

With regard to occupant protection, the RSV design philosophy was to choose the restraint systems that would maximize the safety payoff. For side- and rear-impact protection, and for rollover protection, there is not too much choice in this regard, but for frontal protection a variety of candidate restraint systems can be identified. These include the standard 3-point belt system, 3-point force limited belts, and 3-point inflatable belts for all seating positions. In addition, we considered advanced airbag systems for both the driver and the right front passenger, based on previous development programs undertaken by Minicars for the NHTSA. This previous experience gave us detailed insight into the design of each of these restraint systems. For each candidate system, the performance was predicted in terms of the average societal cost per injury, using computer simulations and transformations from injury measures to societal cost, such as in figure 9. As a result, the average societal cost was determined for each restraint system, as a function of velocity and accident mode. Total societal cost could then be obtained by considering injury frequency, velocity distributions, seat occupancy, and restraint usage. Even with the most optimistic assumptions for belt usage, advanced airbag systems provided superior safety payoff in both front-seat positions, and were thus selected for the RSV. Three-point harness systems were selected for the two rear-seat positions.

The design of the airbag systems is based on principles that have been thoroughly explored in previous NHTSA contracts. The development of RSV restraint hardware from those principles is explained in detail in the paper entitled “Development of Advanced Restraint Systems for Minicars’ RSV,” by Charles Strother, Michael Fitzpatrick, and Timothy Egbert, which is being presented at this conference. To summarize the paper, we may say that these principles emphasize (a) small bag volumes, and hence (b) rapid inflation, (c) separate bag compartments for control of head and torso motions, (d) a force-limiting, energy-absorbing reaction surface, (e) a simple pyrotechnic inflator, and (f) a crushable knee bolster. Basically, the airbag is not relied upon to absorb occupant kinetic energy; rather, it is a load distribution device that quickly fills the gap between the occupant and the restraint-mounting surface, and then starts to decelerate the occupant quickly before he has used up any appreciable stroking volume. The reaction surface (the steering wheel for the driver system, and the dash for the right front-passenger system) is attached to the vehicle structure by means of mechanical force limiters, which allow the reaction surface to stroke inside the compartment at prescribed constant force levels. This stroking feature tends to shave the peaks off of the compartment deceleration pulse, and to transmit an efficient square-wave pulse to the occupant. The restraint can thereby work with a very nonideal crash pulse, as is required for low frontal structure aggressivity. (It also makes the restraint systems much more adaptable to a wide variety of vehicles.) Finally, and perhaps most importantly, the knee bolster controls lower torso kinematics, thus obviating the need for a lap belt (which would be difficult to use). The front-seat restraint systems are shown in figures 16 and 17.

As a result of these features, the RSV restraints have been shown to provide crash protection for the full anthropometric range (including out-of-position children in the right front seat) to 45 to 50 mi/h. System performance with 50th-percentile occupants has been demonstrated in three car-crash tests to date, and for the full anthropometric range in 80 sled tests.

The rear-seat restraints have the appearance of a conventional three-point harness system with retractor, as would normally be found in front seats of current production vehicles. However, two simple design changes have
been made: (a) the webbing exhibits drastically reduced stretch, although it has the same appearance and dimensions of standard webbing, and (b) simple force-limiting devices have been inserted between the belt and the anchorages. In conjunction with a slight change in the belt geometry, the performance of the system ranges from 35 to 44 mi/h for 6-year-old children to 50th-percentile males. A slightly different restraint design, involving manual belt adjustment instead of the retractors, produced somewhat higher performance, but was not selected because the inconvenience could lead to either misadjustment or nonuse.

In side-impact protection, it is apparent that the airbags will have little if any effectiveness, and the effectiveness of belt restraints is questionable at best. Therefore, other protective schemes are required. Basically, these rely on (a) softening the impact between the occupant and the compartment interior, (b) maintaining an adequate living space, and (c) keeping the occupant inside the compartment. The first of these features is provided by substantial padding on the inner door panel—approximately 5 inches in the shoulder area and 4 inches in the hip area. While thicker padding could be used in both areas, crash test experience indicates that it is not required, and vehicle architecture shows that it is not desirable. The second feature (maintenance of living space) is provided by the stiff side structure described previously: the strong foam-filled sills, the three foam-filled lateral sill supports, the strong shut faces around the door opening, the crash pins in the door, and the foam filling in the door. Finally, the third feature (occupant retention) is provided primarily by a novel side-glazing concept. In particular, side glazing is fixed to the door frame, and consists of a single layer of glass bonded to a thin layer each of Mylar and polyvinyl butyrate. The Mylar/PVB membrane is secured to the door frame, so that
when the glass breaks at impact, the membrane surface retains the occupant and cushions any head strikes that might occur. In addition, adequate padding is provided on all interior surfaces.

Rear-impact protection is augmented by a unique head restraint, in which essentially conventional seats are attached to the roof structure via a transparent membrane. This membrane allows the seats to be adjusted, and does not ordinarily provide any support to the seat back. In a crash environment, however, any tendency of the seat back to collapse is prevented by the ability of the head restraint to carry membrane forces. Similar membranes are provided in the rear seat, which is made coincident with the rear bulkhead. In a 40-mi/h collision by a Volvo, exemplary protection was provided to the front-seat occupant, while rear-occupant protection was adequate.

For rollover protection, the emphasis is placed on keeping the occupant inside the vehicle, and providing suitable padding for any interior impacts between the occupant and the compartment. Again, occupant retention is provided by the fixed side glazing and the head restraints, in addition to the features that are present to keep the doors closed (that is, the hinges, latches, and crash pins). The roof structure is strong, but substantial crush would not generally be unacceptable, on the basis of the accident statistics that indicate that ejection, rather than roof crush, poses the significant threat to the vehicle occupants.

FEATURES OF THE MINICARS RSV

Foremost among the features of the Minicars RSV are the low weight, low emissions, low fuel consumption, and high safety performance. These have been discussed previously, and need not be repeated here, so this section will focus on other vehicle features.

Vehicle Architecture

Vehicle architecture is highlighted by a transverse, rear-amidships engine configuration. The body type is basically a two-door hatchback sedan, as shown in figure 18. The doors are unique in that they are hinged at the roof, thus producing a "gullwing" door configuration. Designed to produce the most efficient frontal and side crashworthiness, and to maximize the ease of entry and exit, these doors open fully with only 16 inches of clearance between the RSV and an adjacent vehicle. See figure 19.
The Minicars’ RSV features the exterior dimensions of a U.S. subcompact, and the interior dimensions of a U.S. compact, as can be seen in table 4. The interior space features a 2+2 seating arrangement, with the adjustable front seats accommodating 5th-percentile females through 95th-percentile males, and the rear seats accommodating small children through 50th-percentile adult males. The luggage compartment, located in the front of the car, holds approximately 11 cubic feet of luggage, while an additional 2 cubic feet of luggage volume is located on the rear package shelf, accessible through the hatchback.

### Powertrain

The Minicars’ RSV features a four-cylinder, in-line, single overhead cam, stratified charge Honda Accord engine. With a displacement of 1597 cubic centimeters, and an output of 68 horsepower at 5000 rpm, the Honda Accord reaches 60 mi/h in less than 16 seconds, and similar performance is expected from the RSV, due to the similarity in weights between the two vehicles. The engine is coupled to a 5-speed manual transmission—a combination that should provide the RSV with 31 mi/gal in the city and 39 mi/gal on

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**Table 4. Comparison of weight, size, and accommodations**

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Weight (lb)</th>
<th>Fuel economy combined (mi/gal)</th>
<th>Length (in)</th>
<th>Width (in)</th>
<th>Height (in)</th>
<th>Wheelbase (in)</th>
<th>Luggage volume (ft³)</th>
<th>Front width/headroom/leg room (in)</th>
<th>Rear width/headroom/knee room (in)</th>
<th>Total interior volume (ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSV</td>
<td>2 190</td>
<td>34</td>
<td>170</td>
<td>70</td>
<td>55</td>
<td>104</td>
<td>13</td>
<td>2×25.4/37.0/40.5</td>
<td>2×3.5/37.7/29.0</td>
<td>86.8</td>
</tr>
<tr>
<td>Maverick (4-door)</td>
<td>3 166</td>
<td>24</td>
<td>194</td>
<td>71</td>
<td>53</td>
<td>110</td>
<td>12</td>
<td>48.5/37.8/40.6</td>
<td>52.5/37.0/27.5</td>
<td>86.2</td>
</tr>
<tr>
<td>Pinto</td>
<td>2 562</td>
<td>30</td>
<td>169</td>
<td>69</td>
<td>51</td>
<td>95</td>
<td>6</td>
<td>2×20.5/37.3/41.2</td>
<td>2×16.5/35.3/24.0</td>
<td>59.0</td>
</tr>
<tr>
<td>Honda Accord</td>
<td>2 045</td>
<td>36</td>
<td>163</td>
<td>64</td>
<td>52</td>
<td>94</td>
<td>11</td>
<td>2×20.5/36.5/41.3</td>
<td>51.5/34.0/24.5</td>
<td>57.9</td>
</tr>
</tbody>
</table>

*Estimate.
SECTION 3: INDUSTRY STATUS REPORTS

the highway, for a combined fuel economy of 34 mi/gal. These figures represent a slight degradation in the Honda Accord fuel economy, based on the larger exterior dimensions of the RSV. Emissions data for the Accord are: 5.9 gal/mi CO, 0.79 gal/mi HC, and 1.47 gal/mi NOx, although it should be pointed out that various compromises are possible among acceleration performance, fuel economy, and emissions. The fuel capacity is approximately 8.5 gallons, with a rubber ATL storage cell being used to prevent leakage in crashes.

Electronics

The RSV electronics were developed by RCA Laboratories, and one of the many features is an onboard noncooperative FM continuous wave radar, utilizing a printed circuit tapered array antenna. Producing 25 milliwatts at a frequency of 10.5 GHz, the system has a range of about 90 feet. Since this type of radar generally measures range only, range rate is determined by processing the difference in up and down IF frequencies. Special antenna design minimizes the return signals from side modes, thereby minimizing the sensitivity to such false targets as roadside sign posts and bridge abutments, traffic in adjacent lanes, and so forth.

Range and range rate information from the radar are fed into an onboard microcomputer, which performs a “consistency analysis” on these signals to eliminate any residual false targets (overhead bridges and signs in particular). Furthermore, the microcomputer uses a signal input from the speedometer to calculate, in conjunction with the range and range rate, the degree of danger of a collision. The action that results, if any, is dependent on further inputs to the microcomputer, such as steering wheel angle, which allow the microcomputer to weigh the probability of a serious accident against the likelihood of a false alarm. While much more development is possible in this area, the algorithm used in the microcomputer could allow the system sensitivity, and the potential false alarm rate, to be adjusted for driver impairment, or day/night or wet/dry conditions, and so forth.

The radar/microcomputer system is designed primarily as a driver aid; that is, to provide the driver with information or warnings, rather than taking the driving function upon itself. If, however, analysis of target range and range rate, in conjunction with RSV vehicle dynamics, indicates that a serious collision is unavoidable, the brakes are activated automatically. This is done by dumping accumulator pressure directly into the brake cylinders (bypassing the master cylinder) to obtain maximum braking system response.

In less dangerous circumstances, the microcomputer issues a warning to the driver. This requires a special flexible-format display, on which can be written alphanumeric messages that relate to either hazard or malfunction conditions. In normal operation, however, the display shows numerical indications of fuel level and engine speed, in addition to an analog bar indication of vehicle speed. If the driver wishes, he can select a status mode which shows more detailed information, such as water temperature, oil pressure, distance traveled, and so forth. Either of these modes can be interrupted temporarily by hazard messages such as “following too close,” or diagnostic messages such as “battery fluid low.” This flexible format display eliminates the need for conventional dashboard instruments, thus allowing cost reductions as electronic systems become ever cheaper.

With the radar and microcomputer in the car, it is a simple matter to make an “intelligent” cruise control, which operates in the conventional way unless the RSV comes up behind a slower vehicle. Based on radar inputs, the microcomputer calculates a safe following distance, and adjusts the distance between the two vehicles as a function of the speed of the lead car.

With the precipitous decline of electronic prices by 1985, it is possible to provide other sophisticated electronics at low cost. For example, the RSV contains a Citizen’s Band radio and AM/FM stereo cassette combination.

Running Gear

The Minicars’ RSV features a four-wheel independent suspension. MacPherson struts in
The front and Chapman struts in the rear are provided, using Fiat X1/9 suspension components. A Fiat X1/9 rack and pinion steering gear is also used. The suspension and steering geometry is basically that of the Fiat X1/9, but was adjusted slightly during the course of handling system development by Systems Technology, Inc.

The braking system hydraulics consist of a master cylinder, booster, electric pump and accumulator, and a 3-channel (independent front, select low rear) antiskid system, all of which are manufactured by ITT-Teves of Germany. Fiat X1/9 calipers and enlarged X1/9 rotors comprise the remainder of the RSV four-wheel disk brake system. Braking system installation and testing was performed by the University of Utah.

In 1985 production, the RSV would probably utilize fiberglass wheels. At present, however, the wheels are made of spun aluminum, and are specially configured to maintain the Fiat X1/9 offset (to promote maximum wheel-bearing life), and to accommodate the enlarged brake rotors. The tires are 175/65 R15 Advanced Concept Tires (ACT) manufactured by Firestone. These tires can be operated in the deflated condition, which allows the car to be driven up to 100 miles at freeway speeds before tire replacement/repair. This feature eliminates the need to carry a spare tire, and effectively does away with road-side tire changes.

Plastic and Glass Systems

As discussed previously, superior crash energy management is provided by rigid polyurethane foam. The crush strength of this foam, formulated by the Monsanto Research Corporation, can be readily "tuned" by adjusting the foam density, which ranges from about 2 lb/ft$^3$ to 4 lb/ft$^3$. Through holes punched in the sheet metal boxes, the foam is poured in place, by way of an Admiral production foam machine. While the energy management foam has two components (resin and isocyanate) the machine has been configured to handle three components if necessary. The foam machine is capable of pouring 50 pounds of foam per minute, in precisely controlled quantities.

The bumper foam was also formulated by Monsanto Research Corporation. This semi-rigid polyurethane foam has a density of about 4 lb/ft$^3$, which allows the RSV to have a front bumper that weighs only 13.3 pounds. The rear bumper weighs about 5 pounds. These weights compare to 130 pounds for the front and rear 1974 Pinto bumpers.

The front and rear portions of the exterior body surfaces are provided by way of a flexible body glove. Also formulated by the Monsanto Research Corporation, the body glove is made of a flexible polyurethane resin, reinforced with fiberglass cloth. Both the front and the rear portions of the body glove are fabricated in single large pieces, which are then fastened to the structure in much the same way as conventional sheet metal fenders. While these pieces are currently hand-made, by 1985 it is expected that Reaction Injection Molding (RIM) will be used for such parts. Currently, however, techniques do not exist for integrally reinforcing RIM parts (with chopped glass fibers, for example), so hand-fabricated fenders, deck lids, and so forth, must be used as analogs for RIM parts at the present time.

These plastic exterior parts provide superior property damage protection for the RSV. In particular, barrier impacts at 10 mi/h in the front and 5 mi/h in the rear can be sustained with no damage. (This applies to all components, not just those that are safety-related.) The estimated no-damage capability for pole impacts is 4 mi/h in the front and 2 mi/h in the rear.

For barrier impacts at speeds above 10 mi/h, the structure aft of the bumper starts to incur permanent damage. However, at speeds less than 20 mi/h, this damage is limited to a module that is attached to the remainder of the structure with eight bolts. Consequently, the module may be easily replaced at low cost, once again helping to minimize repair costs.

Minor parking lot dents are mitigated, if not eliminated, by the front- and rear-body glove sections. The soft front-end also helps to cushion an impact with a struck pedestrian. The hood geometry is designed to provide a nearly optimum trajectory for such impacts, to minimize pedestrian injuries.
The RSV glazing is provided by Sierracin/Sylmar, an automotive supplier. The windshield is conventional, except that the interlayer includes a vacuum-deposited, electrically conductive gold surface. In addition to reducing the transmission of thermal energy through the windshield, the gold coating permits the windshield to be defrosted electrically. The side glazing consists of a single layer of tempered glass, with a Mylar/PVB membrane fixed to the door frame, as described previously. This glazing is also gold tinted, but is not defrosted. The back light is simply gold-coated tempered glass, as are the rear-quarter windows.

The total visibility from the driver’s eye point is 325° (in a horizontal plane). This good visibility is provided by thin roof pillars, a large glass area, clear head restraints, and the absence of belts dangling from the roof. Conventional windshield wipers are employed in addition to a back light wiper.

Forward lighting is provided by Cibie Z-beam headlights, which are covered to prevent the accumulation of such things as dirt, mud, and snow, to improve aerodynamics, and to provide the smoothest possible contact surface for struck pedestrians.

Ventilation is provided by a blower that is common to the heater and the air conditioner (if installed as an option). Air inlets are provided near the base of the windshield, with three individually controllable vents being located in the dash. Sliding transparent side panels open in the doors for ventilation, communication, and for paying tolls. Exhaust fans located just aft the rear seatbelt attachments provide flow-through ventilation, by evacuating air from the compartment to the exterior, through exhaust ports located adjacent to the tail lights.

These various features are provided to enhance the marketability of the RSV, which is an important consideration in demonstrating that national goals for safety, fuel economy, and emissions can be compatible, and can all be met with a producible, relatively economical product.

The Present State of Japanese Automotive Industry from the Viewpoint of Safety Technique Development

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INTRODUCTION

In reporting on the present state of the Japanese automotive industry at the Sixth International Experimental Safety Vehicle (ESV) Conference, we would like to look back upon how ESV’s were developed in Japan and to touch upon various technical subjects in the area of safety techniques that will be taken up in the future.

ESV DEVELOPMENT—PAST AND PRESENT

Since the ESV development program advocated by the U.S. Government was proposed in 1970, countries throughout the world have participated in the program in various ways, making efforts to develop their own ESV’s.

In Japan, the same program was advocated as a governmental program by the government office concerned; Nissan, Toyota, and Honda participated in it. The ESV’s of Nissan and Toyota were completed at the end of 1973. They were tested by the Japan Automobile Research Institute in Japan, while in the U.S. they were tested by the Ultra System Corporation. Honda subjected its ESV only to internal company testing.

The results of the tests conducted by such appropriate organizations have already been published, and the ESV development program has attained its specified objectives. The ESV development teams of participating companies have been disbanded and the programs have been terminated.
However, even after completion and testing of the ESV’s, various studies have been continued on the analyses of ESV’s. The results of such studies have been published or presented by the organizations concerned and parts of the systems developed in relation to ESV’s have been made subjects of further study and development as subsystems. One example of such a subsystem is the air bag as an occupant protection system, which the Society of Automotive Engineers (SAE) and others have discussed.

EVALUATION OF ESV DEVELOPMENT

The ESV development project is considered to have reached its goal to the extent that light has been thrown upon difficulties involved in technical achievements and upon requirements for attaining the target.

ESV development, however, may be regarded as inclined toward the development of specific techniques because of the far-reaching objective of discovering technical possibilities. Experimental attempts were made to achieve vehicle performance of an extremely high level. These attempts proved successful only under tightly controlled conditions, and few vehicle system elements were provided for feedback to production vehicles.

It is believed, however, that the know-how gained and the partial structures developed in these attempts have proved very helpful to production vehicles.

Because technical development and general progress toward improved vehicle safety should be going on continually, various modifications on production vehicles cannot necessarily be attributed to the ESV development efforts. However, know-how that came from the starting point of an ESV idea, or the level of know-how raised by ESV development efforts had resulted in various technical developments. Basically, such developments have been made in the areas of (1) vehicle body construction, (2) occupant protection, (3) accident avoidance, and (4) warning systems. To be specific, the resultant products are:

- Improvement in body deformation characteristics
- Improvement in seatbelt webbing characteristics
- Fuel leakage prevention technique
- Higher brake performance
- Improvement in controllability and stability
- Improvement in visibility
- Improvement in operating efficiency
- Warning systems

In addition, a great deal has been accomplished indirectly in the following technical fields:

- Stimulus to and promotion of studies concerning safety in human engineering applications, and so forth
- Improvement and accumulation of experimental and evaluation techniques concerning the general subject of safety
- Enlargement of safety facilities such as a J-turn test course, and more complete testing equipment

Furthermore, the international exchange of information, which proceeded along with ESV development, has contributed toward the opening up of undeveloped technical fields and toward the acquisition of techniques in new fields. This led to further development of the technical abilities of many individual engineers. Also, the fact that the international exchange of information has been useful in improving vehicle-safety consciousness and settling the vehicle-safety concept cannot be disregarded.

CIRCUMSTANCES OF JAPANESE AUTOMOTIVE TECHNIQUES

In light of the aforementioned development of affairs concerning ESV’s, and as a prerequisite to the consideration of safety hereafter, we would like to touch upon the problems currently confronting the Japanese automotive industry.

The first and greatest problem for us is that of emission control standards that have been progressively tightened year by year. We are now at the stage where the final deliberation is being made over the 1978 target emission control standards corresponding to those in the U.S. Clean Air Act of 1970.
In seeking the technical means of meeting the target emission control standards, consideration should be given to minimizing the following: resultant deterioration of vehicle operation performance, increase in fuel consumption, increase in vehicle weight, and increase in cost. Along with quality stability, reliability, and safety assurance, these are important matters requiring extremely great efforts.

At the same time, a target of still greater reductions in road traffic noise levels has been indicated, presenting as serious a technical development problem as that of emission control.

Needless to say, the social demand for conservation of natural resources and energy saving is growing stronger in our country. In line with this new conservation mentality, the Ministry of Transportation has begun publishing the fuel consumption figures for the various makes of automobiles, providing makers with a strong impetus to continue their efforts to improve fuel consumption ratios. In such a situation, the promotion and effects of automotive safety measures in Japan are most noteworthy.

We wish to point out that not only have improvements been made in automotive safety, but also the fullest possible safety measures have been implemented throughout the entire motor vehicle environment, with every succeeding year showing better and better results.

Following are the motor vehicle safety measures recently effected by law (secondary revision of 1972 long-term program plan of motor vehicle safety standards in Japan).

- Accident avoidance
- Installation of wind-shield defrosting system
- Defroster control system and its identification
- Side visibility
- Reduction in injury and damage
- Door latches and door retention performance
- Seat anchorage strength
- Augmentation of seatbelt system
- Installation of side light and side reflector
- Fog lamp performance
- Break-upon-impact interior mirror
- Shock absorption by seat back
- Shock absorption by instrument panel

The number of vehicles registered in Japan at the end of 1975 was 17 million passenger cars and 11 million trucks and others; the number of vehicles newly registered during the same year was 2.7 million passenger cars and 4.3 million trucks and others. These figures would indicate that the safety measures described above will not necessarily have immediate impact; still, the number killed and injured in traffic accidents has been decreasing remarkably in recent years.

Improved vehicle safety may have made a partial contribution to such a trend, but the real reasons are considered to be the completeness of traffic safety facilities, the reinforcement of traffic control by police, the thoroughness of safety training, and a heightened safety consciousness among the general public.

Furthermore, it cannot be overlooked that from the viewpoint of vehicle safety performance, the automobile inspection system and periodic maintenance system required by law in Japan are contributing greatly to accident prevention. Broad safety measures must be established on the basis of cost/benefit. Even when the scope is limited to automotive safety, an adequate analysis of cost/benefit must also be carried out.

In Japan, the analysis of automotive accidents, which is necessary for cost/benefit analysis, has only recently gotten under way. It is expected that this type of analysis will become more substantial in the future. A review of the related laws and regulations, based on such analyses, will be taken up hereafter.

It is anticipated that, by furthering the international exchange of information, a more effective approach to safety improvement will be found although the traffic environment, of course, varies from country to country.
FUTURE SAFETY TECHNIQUE SUBJECTS

The following are considered to be the most important safety technical subjects or development areas after the ESV project.

General

The emphasis in safety technical development has shifted from vehicles like ESV's to the area of subsystems. Motor vehicles designed and produced exclusively for safety will not always meet social needs, and so our study is being directed toward an overall target that includes natural resources conservation and energy saving. The Nissan GR-I is an example.

Occupant Protection System

We expect the implementation of two effective measures to insure the wide use of the seatbelt system, which is the most important of the occupant protection systems. One measure makes the use of seatbelts mandatory or promotes their use through training and public relations; the other is the technical development of a seatbelt system that is easier to use. A continuous-loop belt system and built-in belt retractor housing are now being developed for the latter measure.

The air bag system is considered inferior to the seatbelt system in many ways, including cost/benefit. The cost and reliability of this system are questionable; it takes up space normally required for the glove box, and it creates difficulty in housing the air conditioner in compact models. We are looking forward to the evaluation results of the air bag system that was being sold by GM as an optional item.

Body and Compartment Construction

There is a strong demand for decreased vehicle weight in our country. Rather than concentrating on reinforcement of body and passenger compartment construction, emphasis in automotive technical development will be placed on a means of lessening vehicle weight, with safety, durability, and noise/vibration prevention maintained at the present level.

A decrease in vehicle weight, leading directly to energy saving and natural resources economy, will, in some cases, be regarded as more important than the reinforcement of vehicles for greater safety, which does not have tangible effects that are easy to evaluate.

Pedestrian Protection

Pedestrian protection through improved body structure was examined as part of the ESV development program, but this proved to be difficult because of severe technical limitations.

For pedestrian protection, flexibility of outside rear-view mirrors is compulsory by Japanese law. In the future, emphasis should be placed on technical development for accident prevention by improving the driver's visibility, especially at night.

Vehicle Brake Performance and Maneuverability

Constant efforts have been directed toward improvements in brake performance. Safety performance in the case of defective brakes should also be considered with respect to cost/effectiveness, when compared with the automotive inspection system and periodic maintenance system.

An automobile braking system augmented by radar has been developed; however, as we know, radar does have the problem of target discrimination. For this reason it is difficult to decide whether the radar input should perform as one of the primary sources for braking application or only as a warning system.

At our current stage of development the addition of this radar capability is quite expensive.

For maneuverability, efforts should be made to improve evaluation methods and to raise the target performance, although these are difficult problems.

Concerning run-flat tires, it is required that a punctured tire be perceived fully and
immediately. The development of a warning device for this purpose may also be necessary; however, many practical problems remain unsolved.

Visibility and Light System

From the standpoint of accident prevention, the development of related techniques and a thorough review of the related laws will be required. A particularly knotty problem which remains to be solved is how to increase the luminosity of automotive lights at night and at the same time meet the requirements for a nonglare effect.

CONCLUSIONS

Now that the ESV development project has achieved its objectives, it is time for us to redefine the goals of future international ESV conferences after completion of the Research Safety Vehicle (RSV) development program.

We have no definite proposals at the present time concerning precisely what the future of the international ESV program should be. Generally, the agenda for the future should include questions regarding methods for evaluating safety characteristics and proposals for the standardization of measurements. For such matters, it is considered necessary that, as a prerequisite, related standards be internationalized to the maximum possible extent, apart from laws and regulations that must be particularized according to the traffic conditions of individual countries.

It is clear that a decrease in the number of traffic accidents and casualties can be attained not only through improvements in vehicle safety performance but also through proper maintenance of the traffic environment, reinforcement of traffic control, and wider dissemination of traffic training. From this point of view, in order to promote careful and effective safety research and to review related laws and regulations, an analysis of accidents is essential. Together with this analysis, international unification and standardization of methods for accident analysis will also be required.

The ESV development project has achieved much in the way of clarifying the technical possibilities of passenger cars. On the other hand, the question of truck safety has yet to be seriously considered.

The fact that the international ESV program has met its objectives is an accomplishment the Japanese automotive industry considers worthy of great praise, and we are grateful to the program promoters and participants for their efforts. We would like to continue working together to further the international exchange of information and techniques.

Status Report of Alfa Romeo S.p.A.

presented by DOMENICO CHIRICO
Design Manufacturer
Alfa Romeo

Alfa Romeo's activities in the Experimental Safety Vehicle (ESV) program have been oriented predominantly towards systematic research in the field of active safety, but without lack of consideration for occupant-impact protection.

The importance of active safety is quite evident and therefore does not require any particular comment. However, it is obvious that if the research can provide wider safety margins, regarding, for example, roadholding, braking performance, and other similar "handling" capabilities, then the vehicle can attain improved tolerance to driver inputs that may be below average ability.

In the area of occupant packaging, sled testing of an inflatable belt restraint system has been completed at speeds up to 32.5 mi/h using human subjects.

A force-limited air belt restraint system for the front seat passengers of subcompact cars capable of providing 50-mi/h protection has been developed and tested.
The comparative effectiveness of conventional three-point belt systems and air cushion restraint systems is being evaluated by subjecting dummy and cadaver occupants to full-scale car crash tests.

Development of a driver air cushion system for the small car capable of providing 50-mi/h protection has been completed and research to evaluate and to improve the performance of energy-absorbing steering columns is continuing.

THE FUTURE

I would like to focus now on the fourth and final element—the future. Let me list a few areas that require our continued attention in the days ahead.

We need to evaluate advanced propulsion systems in integrated test vehicles to assess future goals in fuel economy. We also need to evaluate the integrated technology required to achieve fuel economy goals for the family-size car, as well as evaluate goals for safety and fuel economy for nonpassenger vehicles.

As part of our cooperative activities, there is also much to be gained by sharing studies to define the complex interrelations among the variables associated with economics, manufacturing, marketability, safety, and air quality. We must also pursue further development of cost/benefit methodology and application of these analyses to critical problems such as vehicle aggressiveness and pedestrian protection.

Overall, we have recognized the need for continually assessing future automotive requirements as a basis for planning and decisionmaking in meeting our broad social, economic, and environmental challenges. As we proceed to expand our integrated vehicle activities, we will welcome your inputs and look forward to continuing cooperation with you under the auspices of the international ESV program and future conferences.

I will be following the balance of this program with a great deal of interest, and I wish you well as you proceed with your own specific programs. We share an important mutual interest: I look forward to even greater results from our efforts in the future.

Our efforts have been centered around the development and refinement of a mathematical model of the driver-vehicle system that permits this behavior to be studied using a computer.

- Data have been collected experimentally from a baseline vehicle while the vehicle has been driven by drivers having different levels of skill. They have performed typical maneuvers such as passing, cornering, and braking in a curve, to name a few.
- Following a series of refinements, or “tuning” of the mathematical model, the results indicate the computer predictions, in the terms of driver-vehicle behavior, do correlate with the results already obtained experimentally.

With these means, it is now possible to compare the differences between vehicle types being “driven” by the same driver—or to compare driver differences within the same vehicle. This can be done also by freely changing the maneuvering environment in each case.

It should be possible, using these methods, to define a series of open-loop tests that have been found to correlate with the most differing real world road maneuvers, and which are able to show the safety acceptance level of a vehicle configuration.

With these goals, Alfa Romeo has developed research activity, the results of which have been progressively reported at the previous ESV conferences. In 1971, in Sindelfingen, we showed the studies on vehicle behavior in a curve. In 1972, here in Washington, we spoke on lane changing. In Kyoto in 1973, the passing maneuver was our topic. During the 1974 conference in London, we discussed braking in a curve. Tomorrow, during the seminar on accident avoidance, we will talk about our study of vehicle behavior while subject to crosswind gusts on the straightaway, while cornering, and in passing.

In the area of passive safety, Alfa Romeo has been motivated by the ESV program to contribute to a rationalization of occupant protection research. The studies inherent in such a rationalization have been presented in the ESV conferences since 1972, for which we summarize the main results:
• Washington, 1972—The law of the occupant’s deceleration is influenced by the passenger compartment’s deceleration law, but only limited to the average value and to the first harmonic of the passenger compartment deceleration law.

• Kyoto, 1973—The restraints, consisting of 3- and 4-point harnesses, protect the thorax much better than the head, as is well known. These restraints can be integrated with a device known as a “Soft Sallet” which can protect also the occupant’s head during either frontal or lateral impacts.

• London, 1974—The energy-absorbing (E.A.) capability of the structure is not unlimited and the crush of the E.A. structure, required to decelerate the passenger compartment in a tolerable manner, must increase as the impact velocity increases. Therefore, to assure survival at impact speeds above those tolerated by today’s vehicles, an inevitable increase in both length and weight is needed.

• Washington, 1976—During the “Vehicle Structural Properties” seminar we will show the results of comparative frontal, symmetrical, and nonsymmetrical crashes against a barrier. These tests were done with two model vehicles having completely different architecture. The tests show that a nonsymmetrical barrier crash is the best systematic method of representing the majority of real world frontal crashes—both symmetrical and nonsymmetrical—since it assures a meaningful deceleration of the occupant compartment.

FIAT TECHNICAL PRESENTATION

COMM. ENZO FRANCHINI
Director, Safety Center
Fiat Motor Company

INTRODUCTION

In the previous Experimental Safety Vehicle (ESV) Conferences (Washington, 1972 [1], Kyoto, 1973 [2], and London, 1974 [3]) we put increasing emphasis on the importance of the compatibility problem and it is mainly in this direction that our tests have been conducted since the last ESV conference. Compatibility is the capability of the vehicle to coexist—with the minimum possible damage—with other traffic elements. This definition highlights the fact that, as far as possible, the vehicle must be compatible not only with the other vehicles but also with the other road users (pedestrians, cyclists, and so forth) and with the road structures (walls, light and signal poles, guardrails, and so forth). The problem has a range that involves all the points of the road-man-vehicle triangle and requires, from a practical standpoint, that a scale of priorities be set.

PRIORITIES

The priority of themes shall be established on the basis of the accident analysis results, thus enabling them to focus on those accidents which prove statistically to be more frequent and dangerous.

From the official statistics of road accidents in Italy [4], of the 287,000 accidents that occurred in 1974 (fig. 1), other vehicles represent the most frequent obstacle (83 percent), followed by pedestrians (14 percent), and then road structures (3 percent). We shall, therefore, begin by dealing with the compatibility between vehicles.

The vehicles involved range from the small car to the huge truck, but statistics indicate (fig. 2) that when the obstacle struck by a car is another vehicle, it is another car in 58 percent of the cases and a truck in 17 percent of the cases. Compatibility between vehicles must first be investigated as compatibility between cars; this is no small problem by itself as cars of quite different weights are now in the traffic mix.

From the accident analysis conducted by Fiat on 3,000 cases [5], the results show that the mass ratio of colliding vehicles (fig. 3) is already 1 to 1.25 in 47 percent of the cases; as the ratio increases the percentage drops. The cumulative chart (fig. 4) indicates that in 95 percent of the car-to-car collisions the ratio between the masses of the two vehicles reaches 2 as a maximum. For this reason, our
first priority will be to investigate the compatibility between cars with a mass ratio not greater than 2.

The same accident analysis by Fiat [5] indicates that the most frequent accidents (fig. 5) are: front end (60.3 percent), side (23.7 percent), rear end (11.8 percent), and rollover (4.2 percent). The high priority of compatibility in front-end impacts is therefore clearly apparent.

The direction (fig. 6) in which the 1,806 frontal impacts covered by the Fiat investigation [5] occurred is, in 64 percent of the cases, the longitudinal direction (between the 11 and 1 o'clock positions). The oblique direction, from the 10 to 11 and 1 to 2 o'clock positions, occurs only in the remaining 36 percent of the cases. Therefore, compatibility in front-end impacts in the longitudinal direction has the highest priority.

Front-end deformation may be total or partial; the Fiat investigation [5] highlighted the values shown in figure 7. Because the offset impact is characteristic of an aborted overtaking, it is evident that in Italy, where traffic is driven on the right, the percentage of damages to the left side of car fronts is higher than to the right. (For the sake of simplicity, concentrated impacts (against a pole, for example)—which account for only 6.4 percent of the cases—are not included in this figure.)

The investigation showed that deformation involves:

- The entire front-end width in 30.6 percent of cases
- Up to 2/3 of the width in 32.8 percent of cases
- Not more than 1/3 of the width in 30.2 percent of cases

These are three practically equivalent groups, and evaluation must now be combined with the analysis of car-occupant injury severity. Figure 8 shows the numerical values.
recorded for the 1,155 frontal impacts in a longitudinal direction examined in the Fiat investigation [5]. It is apparent that the number of accidents in which there has been at least a casualty is higher when deformation involves two-thirds or the full width of front end (63.4 percent of these two conditions are responsible for 81.7 percent of the fatalities).

From the above discussion it is evident that priority must be given to the study of compatibility in frontal impacts involving the full width or about two-thirds of the front-end.

To complete the analysis, it should be noted that the lower number of fatal accidents were recorded when deformation involved a smaller fraction of the front-end width. This is due to the fact that in the centered collision, crushing occurs throughout the front width to a given depth that is practically identical on each side (fig. 9). In the offset collisions, however, with speed at par, crushing is greater on the struck side. The advantage is that with a deeper deformation depth the average occupants’ deceleration is lower. This is true as long as the passenger compartment remains undamaged, as is usually the case in minor collisions. One disadvantage in offset collisions is the increased probability that the passenger compartment structure, stressed in a concentrated area (particularly the door, the instrument panel, or the dashboard), will yield to the point of reducing the survival space necessary to prevent occupant crushing. This performance prevents the restraint system from operating properly, and restricts the rescue of injured occupants after the accident.

The priorities of the themes highlighted above are:
- Type of obstacle—other vehicles
- Type of vehicles—vehicles with mass ratio not higher than 2
- Type of accident—frontal impact
- Direction—longitudinal
- Deformation extent—entire front or about 2/3 offset

METHODOLOGICAL APPROACH

After the themes of priority have been identified, it is necessary to decide how to evaluate the compatibility of a vehicle, that is:

- Which characteristics are significant?
- Which of these characteristics, or the interaction of some of them, represent conditioning parameters?
- How can such parameters be evaluated?

A vehicle must be investigated, from the compatibility viewpoint, in relation to the twofold role it may perform, namely:

- As a struck vehicle, the damages to its structure and occupants must be limited
- As a striking vehicle, the damages to itself and to its occupants must be limited as well as those to other vehicles and their occupants

IDENTIFICATION OF THE SIGNIFICANT CHARACTERISTICS

To acquire this basic knowledge, it was essential to run systematic, centered, frontal collisions, in a longitudinal direction, between vehicles of different models.

Some sets of tests were run without dummies on board in order to determine, first of all, the vehicles' structural behaviour. The results were presented at the previous ESV conferences.

Table 1 shows a summary of the test reported at the Kyoto Conference [2]. The first conclusions were:

- Impact severity is characterized by two factors: speed and type of obstacle.

Figure 3. Mass ratio of colliding vehicles—Histogram—Fiat accident analysis: 3 000 cases.
The obstacle is characterized by three factors: mass, rigidity, and interface; that is, the car/obstacle mutual influence, regarding their shape and the local distribution of structural stiffness (fig. 10).

A summary of the tests presented at the London Conference [3] is shown in table 2. Of the conclusions, the following are worth stressing:

- Of the three front-end profiles (fig. 11), the more favorable are the backslanted and almost vertical ones.
- Even with mass ratios of up to 1.7, the ESV cars suffered deformations in the front structure only; the passenger compartment remained undamaged. This conclusion is confirmed by the results of the test [6] between the small 1750-pound Fiat ESV and the huge 5270-pound AMF ESV at a mass ratio of 3 (fig. 12).

It was decided to deepen this knowledge by setting up a test program with a 50-mi/h closure speed using standard production cars, each with two dummies on board. These tests would investigate the behaviour of both structures and occupants, because the Fiat Safety Laboratory was moving to new facilities, the tests were run by Dynamic Science, of Phoenix, Arizona. The models selected (table 3) were representative of the entire Fiat production range. Each model was tested against all the others; table 4 shows how the weight ratio spans from 1.05 to 2.35—beyond the previously established ratio of 2. To investigate the influence of closure speed, tests were run at 40, 50, and 60 mi/h for both pairs 128/124 and 132/124.

In all the tests recordings were made of the following measurements:

- Structural behaviour (fig. 13):
  - dynamic and permanent deformations of car exteriors at bumper (A) and hood (B) height

![Figure 4. Mass ratio of colliding vehicles—cumulative chart—Fiat accident analysis: 3000 cases.](image-url)
— dynamic and permanent deformations inside the cars at floor (C) and instrument panel (D) height
— deceleration at some 10 points on car

• Dummies' behaviour (fig. 14):
  — on each dummy (driver and front passenger) tridirectional deceleration of head and chest; load and femurs

The dynamic measurements were recorded in part by umbilical cable and telemetry (fig. 15) and then processed by computer, in part by high-speed movie cameras, and in subsequent study on a micromotion analyzer.
IDENTIFICATION OF THE CONDITIONING PARAMETERS

Much effort went into collecting the single results, comparing them, and calculating and comparing their ratios for an evaluation of their interaction. A stepwise multiple regression analysis was utilized to revise the results and acquire data for the following steps of the procedure. Details are omitted here for the sake of brevity; the conclusions of the investigation are reported instead.

The conditioning parameters resulted in the following:

- The vehicle mass ratio and closure speed are the fundamental parameters for both the structural response and the occupants' response, but alone they are not sufficient and must be associated with other parameters.
- The total vehicle's exterior crush influences the occupants' behaviour and is strictly related to the time of velocity change, dynamic force at vehicle interface, and individual exterior crush.

Figure 6. Percentage of frontal impact cases according to direction—Fiat accident analysis: 3 000 cases.

Figure 7. Percentage of cases according to deformation extent—Fiat accident analysis: 3 000 cases.
Figure 8. Number of cases and casualties in frontal impacts in the longitudinal direction—Fiat accident analysis: 3,000 cases.

Figure 9. Front section deformation in frontal collisions.
### Table 1. Tests presented at the Fourth ESV Conference—Kyoto

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Vehicle A</th>
<th>Speed of each vehicle (mi/h)</th>
<th>Vehicle B</th>
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<td>1 200</td>
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<td>1 800</td>
<td>Fiat 124 reinforced</td>
</tr>
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<td>Fiat 124 reinforced</td>
<td>2 200</td>
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</tr>
<tr>
<td>7</td>
<td>Fiat 130 standard</td>
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<td>Fiat truck</td>
</tr>
<tr>
<td>8</td>
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<td>4 300</td>
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<tr>
<td>9</td>
<td>Fiat 500 reinforced</td>
<td>1 200</td>
<td>Fiat ESV</td>
</tr>
<tr>
<td>10</td>
<td>Fiat 130 standard</td>
<td>3 400</td>
<td>Fiat ESV</td>
</tr>
</tbody>
</table>

- Individual exterior crush can influence compartment integrity, interior space reduction, door self-opening, and the post-crash door-opening effort.
- The total energy to be absorbed is independent of initial/final energy distribution between cars.
- Frontal stiffness and its distribution depends on vehicle design parameters (frontal width and height, bumper location, and local structure force/deflection characteristics); it varies as the crush varies.
- Dynamic force at vehicle interface is strictly connected to frontal stiffness, engine and front masses dynamics can have significant effect on dynamic force.
- Occupant compartment integrity influences the occupants' behaviour; it can be affected by a door collapse, instrument panel support structure deformation, wheel intrusion on the dashboard, and the floor (in our tests no engine intrusion in the occupant compartment occurred).
- Vehicle total velocity change, time of velocity change, and coefficient of restitution influence the occupants' response and are practically independent.
- Occupant compartment decelerations are not sufficient considering the peak values; the entire time history must be considered.
- Dummies' parameters: the Head Injury Criteria (HIC) and chest Severity Index (SI) ratios show a correlation with the square of the vehicle mass ratio and with the square of the closing speed that is good for the driver and less good for the passenger. The

Figure 10. Interface: shape and local distribution of structural stiffness.
EXPERIMENTAL SAFETY VEHICLES

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Vehicle A</th>
<th>Vehicle B</th>
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<td>2 000</td>
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</table>

Table 2. Tests presented at the Fifth ESV Conference—London

Figure 11. Comparison of the three front-end profiles.

Figure 12. Front collision test Fiat ESV/AMF ESV.

chest peak $g$ criteria (FMVSS 208) is more severe than the chest SI. Chest deflection and chest pressure distribution should also be considered. The values of the loads on femurs are hard to correlate with the vehicle mass ratio and closure speed. One must keep in mind that the present parameters are unreliable, because of the insufficient knowledge of basic biomechanics and the unavailability of valid dummies.

- Repeatability: the values of the structural parameters showed repeatable results within 10 percent of the mean values; on the other hand, the values of the dummy parameters showed considerable scatter, on the order of 25 percent (sometimes higher), which is not unusual in normal tests with dummies.

EVALUATION APPROACH

The method outlined so far consists of running direct-vehicle collision tests; this
SECTION 3: INDUSTRY STATUS REPORTS

<table>
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Table 3. Models tested

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<td>132</td>
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</tr>
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</table>

Table 4. Weight ratio

method cannot be used to evaluate the compatibility of a given car model with the numerous models on the road.

The definition of a practically usable method can derive, in our opinion, only from a partially experimental and partially analytical approach. The keystone is the use of a test tool, such as a dummy car equipped with a moving barrier.

TEST TOOL DESIGN

On the basis of the parameters that proved to be conditioning, the test tool design criteria were established as follows:

- Rigid, reusable structure (for Fiat models)
- Variable weight capability (2 000-5 000 lb)
- Load measuring capability (load cells)
- Crushable energy-absorbing face (honeycomb)
- Crush displacement measuring capability (string pots)
- Electrical and visual impact sensors
- Accelerometer and instrumentation provisions
- Redundant data transmission (umbilical/telemetry)
- Flexibility in ballast installation
- On-board abort system

The test tool configuration is shown in figure 16. It is similar to the Society of Automotive Engineers (SAE) and International Standards Organization (ISO) moving barriers; its dimensions are: 4 m (157 in) long, 1.8 m (72 in) wide, and 0.86 m (34 in) high. It has been designed to withstand, under full load (2 270 kg = 5 000 lb), accelerations on 60 g longitudinally, 20 g vertically, and 20 g laterally.

The arrangement of the 4 500-kg (10 000-lb) load cells fixed to the test tool front structure is shown in figure 17. An aluminum plate, which supports a honeycomb block, is fixed directly on each load cell with a hole at center for the pin of a string potentiometer, measuring the crush. The chessboard arrangement of the front face (fig. 18) with 36 rectangles of 200 X 180 mm (8 X 7 in), arranged on four rows and nine columns, allows the crush and load distributions to be measured. It is also possible to detect from the recording (fig. 19) the crush and load patterns during the impact, thus
obtaining the load/crush characteristics to be used later on.

The test tool has been fabricated and checked out in a series of impacts in addition to component tests (behaviour of honeycomb modules, load cells, and string potentiometers under perpendicular and inclined loads) to verify the test tool instrumentation module concept.

In two fixed barrier tests against a flat, rigid barrier (fig. 20) and a shaped, rigid barrier (fig. 21), all instruments performed as expected and the honeycomb modules crashed to the shape of the impacted barriers.

TEST TOOL COLLISIONS

The weight (ballast) and front stiffness (type and length of the honeycomb elements) may be varied in the test tool; the question was to decide what car model should be simulated. The characteristics of the average European car, weighing around 1100 kg (2500 lb), could have reproduced, but it was felt advisable, at this set-up stage, to make the evaluation conditions particularly severe and so we decided to simulate the larger model in the Fiat line, the 130, weighing about 1800 kg (4000 lb), equivalent to the U.S. family car.

The collision tests (table 5) were run against this model that was properly instrumented. After two initial tests at 40 mi/h, the speed was increased to 50 mi/h and maintained in all subsequent tests.

Figures 22 through 25 give the comparisons of the deformations observed for each model in the direct collision tests against the 130, and in the simulated collision with the test tool. The results are generally in agreement.
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h6od edge, etc.) that could represent aggressive elements. For the same test, figure 27 gives the curve of total loads versus time; the values recorded with the load cells agree quite well with those calculated from the measured accelerations. Table 8 shows a comparison of some of the values measured on the dummies of the 128 in the tests against the 130 and the test tool, respectively; it is further proof that reproducibility for structural behaviour is good and fair for dummies’ behaviour.

EVALUATION METHODOLOGIES

The evaluation of the compatibility of one car versus a group of other cars may be carried out using three different methodologies of processing and examination of the results obtained by the test tool. Such methodologies, indicated as A, B, and C, permit a progressively deeper evaluation of compatibility.

Evaluation by methodology A is direct (fig. 28). A collision test is run at a pre-established speed using the car under examination and the test tool on which the most severe characteristics (local aggressiveness, stiffness, masses, and so forth) of the cars in the group have been reproduced (fig. 29). The structural responses of the car under investigation (intrusion in given locations, value of force at interface, decelerations, and so forth) and of its dummies (decelerations, forces, pressures, deformations, and so forth) are recorded.

Such values are compared with the permissible limits; if they are not exceeded it is certain that, up to the test-closure speed, the car is compatible with all the car models investigated (fig. 30). If the limits are exceeded, the car is not compatible with the fictitious model, but could be compatible with almost all the models of the group. In this event it would be more logical to discard the too severe model rather than the car under investigation. If it is desired to develop just one configuration of the test tool, this is the simplest method, although it is reliable only if the result is positive.

The evaluation according to methodology B is partly experimental and partly analytical.

Figure 14. Dummy measurement location.
permits the compatibility to be examined by vehicle pairs and up to the closure speed they are mutually compatible to be determined. However, it does not allow compatibility to be optimized, inasmuch as it is not capable of predicting the consequences of the modifications which could be introduced into a vehicle during the design stage.

Methodology C (fig. 32) is substantially similar to methodology B, because it still relies on the comparison between car pairs, but it is based on the use of sophisticated mathematical models. For car simulation, an attempt was made initially to use some existing digital computer crash simulation programs with four, five, or six masses (fig. 33), but it was found that they were incapable of supplying reliable results. Consequently, a more complex simulation program was set up; a typical model configuration is shown in figure 34. This is a general purpose, lumped parameter, nonlinear, structural dynamics program, capable of analyzing planar and three-dimensional models; the pro-
Instrumentation

area

area

III

I

I

I

Figure 16. Test tool structural configuration.

The work in progress is focused on the following:

- Check and improvement of the methodologies outlined above by statistically comparing the predicted behaviours with the experimental behaviours recorded during the previous phases
- Verification of procedure functionality by using new car models
- Completion of the frontal collision study

The last item deals with direct collision tests for vehicles.
between the different models to acquire basic information on angled (fig. 36) and offset side collisions (fig. 37).

The other important problems of study of side collisions and the study of pedestrian collisions will be tackled successively.

Figure 17. Typical instrumentation module.
Figure 18. Test tool front face.
Figure 19. Test tool load cell forces on row B.

Figure 20. Post-test view against flat, rigid barrier.
Figure 21. Post-test view against shaped, rigid barrier.

Table 5. Test tool collisions

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Car model</th>
<th>Tested car Weight (lb)</th>
<th>Closure speed (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>132</td>
<td>2 798</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>130</td>
<td>3 949</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>126</td>
<td>1 677</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>128</td>
<td>2 363</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>124</td>
<td>2 677</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>132</td>
<td>2 779</td>
<td>50</td>
</tr>
</tbody>
</table>

NOTE: The test tool (weight = 4 000 lb) simulates the 130 model.
Figure 22. Comparison between car/car and car/test tool collisions—126/130.
Figure 23. Comparison between car/car and car/test tool collisions—128/130.
Figure 24. Comparison between car/car and car/test tool collisions—124/130.
Figure 25. Comparison between car/car and car/test tool collisions—132/130.
### Table 6. 128/Test tool collision—comparison of test conditions

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Car/car</th>
<th>Car/test tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle test weight (lb)</td>
<td>2345</td>
<td>3332</td>
</tr>
<tr>
<td>Impact speed (mi/h)</td>
<td>25.22</td>
<td>25.22</td>
</tr>
<tr>
<td>Final speed (mi/h)</td>
<td>10.14</td>
<td>4.14</td>
</tr>
<tr>
<td>$\Delta V$ (mi/h)</td>
<td>35.36</td>
<td>21.08</td>
</tr>
</tbody>
</table>

### Table 7. 128/Test tool collision—crash values measured on the 128 car

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Test against 130 car</th>
<th>Test against test tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum dynamic crush (in)</td>
<td>30.1</td>
<td>30.7</td>
</tr>
<tr>
<td>Average permanent crush, bumper level</td>
<td>18.7</td>
<td>20.0</td>
</tr>
<tr>
<td>Average permanent crush, hood level</td>
<td>14.6</td>
<td>17.0</td>
</tr>
<tr>
<td>Maximum permanent intrusion, floor level</td>
<td>7.6</td>
<td>8.6</td>
</tr>
</tbody>
</table>

### Figure 26. 128/Test tool collision—distribution of maximum loads.
Figure 27. 128/Test tool collision—curve of total loads versus time.

Table 8. 128/Test tool collision—comparison of some of the values measured on the dummies

<table>
<thead>
<tr>
<th>Value</th>
<th>Driver</th>
<th>Front passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>128/130</td>
<td>128/Tt</td>
</tr>
<tr>
<td>Head:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak of the resultant, g</td>
<td>223</td>
<td>192</td>
</tr>
<tr>
<td>Severity index</td>
<td>2 630</td>
<td>2 157</td>
</tr>
<tr>
<td>HIC</td>
<td>2 001</td>
<td>1 590</td>
</tr>
<tr>
<td>Chest:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak of the resultant, g</td>
<td>49</td>
<td>59</td>
</tr>
<tr>
<td>Severity index</td>
<td>385</td>
<td>427</td>
</tr>
</tbody>
</table>

Figure 28. Methodology A.
SECTION 3: INDUSTRY STATUS REPORTS

Figure 29. Test tool characteristics.

1. Maximum aggressivity
2. Maximum rigidity
3. Maximum mass
4. Test tool

Figure 30. Compatibility with the other models.

Model 1
Model 2
Model 3
Model 4
Model 5

Compatibility with models 1 2 3 4
Figure 31. Methodology B.

Figure 32. Methodology C.

Figure 33. Crash simulation programs with 4, 5, and 6 masses.
SECTION 3: INDUSTRY STATUS REPORTS

Figure 34. Typical model configuration.

Figure 35. Occupant model.
Figure 36. Front-angled collision.

Figure 37. Frontal offset collision.
CONCLUSIONS

- The compatibility problem was studied giving priority to the statistically more frequent and severe accident type—the frontal, longitudinal, centered collision—that occurs between cars having a mass ratio of up to 2.3.
- The conditioning parameters have been identified.
- A test tool, consisting of a moving, deformable, dynamometric barrier, has been developed and used.
- Three evaluation methodologies have been formulated which allow progressively more accurate analysis of vehicle compatibility, with remarkable savings in the number (and cost) of the cars that would be required if test collisions were run directly between the different models.
- After completing the study of frontal collisions, research will be extended to side and pedestrian collisions where the concept of compatibility is fundamental.

Bibliography

5. FIAT Accidents’ Analysis (part of the results were published in the bibliographies [1] [2]).


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PRELIMINARY REMARKS

This aerodynamic research, concerning the evaluation by wind tunnel tests of the crosswind effects on the directional capability of different vehicles, was carried out by the Pininfarina S.p.A. on behalf of the Italian Ministry of Transport. It forms part of the Italian programme for the study and the development of Experimental Safety Vehicles (ESV).

The contract was signed on July 20, 1974, and the research was completed by April 1976. A resume of this study is given in the following paragraphs.

Introduction

It is well known that crosswind gusts have important effects on the road behaviour of vehicles, specifically on their “active” or “primary” safety.

Considering that a number of scientific reports dealing with this subject were already available, the first stage of our study took the form of bibliographical research. We found that most of these reports dealt with the following points:

- Mathematical models that determine the vehicle’s road behaviour by calculations [1-7]
- Wind tunnel tests in side wind conditions to gather experimental data of the vehicle’s aerodynamic coefficients [8-14]
- Road tests on vehicles subjected to artificially produced crosswind and therefore of known characteristics [4] and test facilities of MIRA, Daimler Benz, and so forth.
- Theoretical analysis on the man-vehicle system in crosswind conditions

Reports on the mathematical models point out which aerodynamic coefficients have the most weight on the vehicle’s road behaviour...
in gusty conditions; they are the yawing moment coefficient $C_N$ and the side force coefficient $C_Y$.

Experimental values of these coefficients, which can only be easily measured by wind tunnel tests, are shown in wind tunnel test reports. Unfortunately, these experimental data are of limited interest as they concern tests that have difficult correlations, mainly for the following reasons:

- Tests are sometimes made on small-scale models, sometimes on full-size vehicles
- Data come from wind tunnels of different characteristics
- Data concern vehicles of extremely different dimensions and shapes

To get over this lack of comparable data, we decided to concentrate our efforts on a single model and to perform wind tunnel tests on this vehicle and four of its variants: In this way we will gather experimental data coming from the one wind tunnel, data that is related to five vehicles having the same front part and underbody but with five different rear shapes, which are representative of the majority of vehicles currently on the road.

In practice, we proceeded as follows:

- First, we chose a vehicle of middle size, according to European standards, and with a threebox-type body.
- Second, we designed and built four variants of the rear part of this vehicle; this was the easiest modification to improve the vehicle's behaviour in crosswind conditions.
- Third, in our wind tunnel we carried out aerodynamic tests at different yawing angles (from $-5$ to $+40$ degrees, step $5$ degrees) for both the threebox vehicle and for the four variants.
- Finally, we made a comparison between the aerodynamic coefficients measured in the wind tunnel for these five vehicles; but, as this comparison was insufficient to clearly show the differences in response, we decided to study a mathematical model, drawing it from the bibliography and improving it to take into account the aerodynamic coefficients. In this way, we could evaluate the most important parameters involved in the crosswind motion of these five vehicles.

**BIBLIOGRAPHIC RESEARCH**

Reports examined during our research are listed in the references.

It should be noted that, in order to define the mathematical model set up in the last

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**Figure 1. Side center (SC) and aerodynamic center (AC) positions on the 5 vehicles at $\beta a = 30^\circ$.**
stage of our research, we particularly examined two reports [1, 4].

**CHOICE OF THE BASIC VEHICLE AND OF ITS FOUR VARIANTS**

In choosing the basic vehicle we paid attention to the following requirements:

- A well-defined, threebox-type body for which we could design four significantly different types of tail
- Overall dimensions and an interior passenger compartment typical of a middle-size European vehicle

As a result, we chose a Fiat 124 saloon; we subsequently attached the other four tails that we had developed: a semifastback, a fastback, a semi-station-wagon, and a station wagon.

The silhouette of this basic vehicle and of its four variants is shown in figure 1. Figure 2 shows one of these vehicles during the wind tunnel tests.

**WIND TUNNEL AERODYNAMIC TESTS**

The basic vehicle and the four variants were tested in the wind tunnel at yawing angles from -5 degrees to +40 degrees, measuring, by a six-component balance, all the aerodynamic forces and moments acting on these vehicles.

For the sake of brevity, in figures 3 through 6, we show only the results concerning coefficients $C_X, C_Y, C_N$, and $EO$ values (aerodynamic centre position).

**EVALUATION OF WIND TUNNEL TEST RESULTS**

Many varied and interesting observations appeared. For the $C_X$ (drag coefficient, fig. 3), all the vehicles have a great increase of aerodynamic drag at yawing angles $\beta$ from 10 degrees to 30 degrees, which, apart from safety, is unfavourable for fuel consumption. The station wagon vehicle is about 10 percent better than the basic vehicle threebox type. This is because the rear lift and, therefore, the induced drag are very low.

The $C_Y$ (side force coefficient, fig. 4), reached the highest values for the fastback and station wagons, and the lowest for the semifastback vehicle.

Therefore, contrary to what might have been expected, we observed that this coeffi-
cient did not increase with the enlargement of the rear-side area. This was probably due to the wake and the pressure distribution behind the vehicle, which, in crosswind conditions, vary with the changing of the tail type in an unpredictable way.

The yawing moment coefficient $C_N$ increases with the $\beta_a$ to about 20 to 30 degrees and then it decreases.

The value of this coefficient is related to the aerodynamic centre position, that is, the point of application of the aerodynamic side forces $Y$.

Figure 5 also shows that, in the more
critical area—yawing angles $\beta_a$ about 20 to 30 degrees, the fastback vehicle is the best one, as its yawing moment is the lowest one, while the semifastback vehicle is the worst one.

In figure 6 we show the EO values, which represent the longitudinal positions of the aerodynamic centre, measured from the middle of the vehicle wheel base and considered positive if in the forward part of the vehicle. At yawing angles $\beta_a$ from 20 degrees on, the fastback vehicle has an aerodynamic centre position more to the rear than the other

Figure 4. The side force coefficient ($C_{\gamma}$).
vehicles; this is directly linked to the low value of the yawing moment coefficient $C_N$. At low yawing angles the aerodynamic centre position is more to the rear for the station wagon. For the whole range of yawing angles tested, the semifastback vehicle shows the most forward position of the aerodynamic centre.

On further examination of these diagrams, we can state the following:

- At yawing angles of 30 degrees, the aerodynamic side force coefficient $C_Y$ varies from...
a minimum of about 0.21 for the semifastback to a maximum of about 0.27 for the fastback vehicle, with an increase of about 28 percent.

- If we look at the application point of this side force (always at $\beta_a = 30$ degrees), we notice it varies from a minimum of 0.25 meter, in the front half of the wheel base on the fastback, to a maximum of 0.62 meter for the semifastback. As for the yawing moment coefficient $C_N$, the values vary from a minimum of 0.11 for the fastback to a maximum of 0.20 for the semifastback, with an increase of 82 percent.

- The $C_Y$ and $C_N$ values of the other vehicles are intermediate in comparison with those mentioned above.

On the basis of these data and bearing in mind that the dynamic behaviour of the vehicle is linked to the $C_N$ and $C_Y$ values, it is difficult to clearly determine which of these five vehicles would be the safest when moving in gusty conditions.

Figure 6. The EO values.
MATHEMATICAL MODEL OF VEHICLE'S ROAD BEHAVIOUR IN CROSSWIND CONDITIONS AND RESULTS OBTAINED

The theory concerning the dynamics of a vehicle [1] can be summarized as follows:

- The report considered the steady state response of a vehicle due to a side force $Y_a$ and to a yawing moment $N_a$, when applied on the vehicle's centre of gravity. The vehicle is assumed to have two degrees of freedom ($Y$ and $\beta$), while a third degree of freedom (rolling angle) is partly considered to evaluate the load transfer on the wheels and the steering angle due to the rolling angle.

- The vehicle is assumed to move with fixed controls.

- We take into consideration the following parameters:
  - cornering stiffnesses $C$ of the front and rear tyres, expressed as a function of the slip angles $\alpha$ of the tyres, unknown
  - gradients of self-aligning powers (SAP) of front and rear tyres, also defined by the slip angles $\alpha$
  - rolling stiffnesses of front and rear axles expressed as a function of the rolling angle $\phi$ unknown
  - steering angle $\delta$ produced by the rolling angle $\phi$ and also defined by $\phi$
  - aerodynamic side force gradient $\partial C_Y / \partial \beta_a$ defined on the basis of the aerodynamic side force coefficient $C_Y$

- We consider these other parameters to be known:
  - vehicle weight $g$ (kg)
  - load distribution on front and rear axles $G_1P$ (percent) and $G_2P$ (percent), respectively
  - wheel base $WB$ (meters)
  - frontal area $S$ ($m^2$)
  - aerodynamic side force and yawing moment coefficients $C_Y$ and $C_N$ for different yawing angles $\beta_a$

- This calculation is made by iteration, $\alpha$ and $\phi$ being unknown; the following main results were obtained:
  - yaw rate $r$ (rad/s) of the vehicle with fixed controls and due to the gust, covers a circular trajectory when it reaches the steady state condition
  - side slip angle $\beta$ (degrees) of the vehicle during the above-mentioned trajectory
  - bending radius $R_c$ (meters) of the above-mentioned trajectory

The calculations were made for each of the five vehicles in two different load conditions, corresponding to the driver alone and to a full load (five persons). Moreover, the calculations were made for each of the yawing angles tested in the wind tunnel, that is from $\beta_a = 5$ degrees to $\beta_a = 40$ degrees and at different moving velocities from $V = 10$ to $V = 40$ m/s.

Hereafter, we refer only to the results obtained for the bending radius $R_c$ of the circular trajectories covered by the vehicle, in steady state conditions and in load conditions corresponding to the driver alone.

Figure 7 shows that for vehicles having a moving velocity $V = 30$ m/s, the bending radius $R_c$ decreases at the increase of the yawing angle $\beta_a$. Particularly for $\beta_a = 30$ degrees, it varies between the following values:

- $R_c = 576$ meters for the fastback (maximum value)
- $R_c = 530$ meters for the semifastback (minimum value)

Figure 8 shows the values of $R_c$ at different moving velocities ($V$) for a crosswind angle $\beta_a = 30$ degrees. The value of $R_c$ becomes maximum for the fastback and minimum for the semifastback.

Therefore, on the grounds of this examination of the $R_c$ parameter, we can come to the conclusion that the fastback is the best one among the five examined in the steady state response to a crosswind gust. In figure 9 we have shown the trajectories covered by the five vehicles. These different trajectories are the ones covered by the vehicles in steady state conditions on the basis of their different aerodynamic characteristics, for $V = 30$ m/s and $\beta_a = 30$ degrees.

VERIFICATION ACCORDING TO THE REPORT "ON THE SIDE WIND SENSITIVITY OF THE AUTOMOBILE" [8]

Referring to the theory explained in the
above-mentioned report, we calculated the following parameters:

\[-S_d = \frac{1}{m_o} \cdot \frac{1 - n_1}{1 - n_o} \quad (g/kg)\]

This parameter, called the side wind design coefficient, depends on the suspended mass \(m_o\), and on the position expressed in the percent of the wheel base, of the aerodynamic centre \(n_1\), and of the centre of gravity \(n_o\), or,

Figure 7. Trajectory bending radius \(R_c\) at different aerodynamic yawing angles (\(\beta_a\)).
in other words, the main design characteristics of the vehicle.

It is independent from both the moving velocity and the over- and understeering characteristics of the vehicle, which, in turn, depend on the suspension and on the tyres.

The results are shown in figure 10, where it can be seen that, at yawing angles $\beta_a$ higher than 20 degrees, the fastback achieves lower Sd values and, therefore, it is less sensitive to side winds. At yawing angles $\beta_a$ lower than 20 degrees, the station wagon is slightly better.

Figure 8. Trajectory bending radius $R_c$ at different motion velocities (V).
Figure 9. Trajectories covered in steady state conditions by each vehicle.

\[ V = 17.32 \text{ m/s} \ (\beta_0 = 30^\circ) \]
\[ -S_w = \frac{V \cdot r}{Y_a} \quad (g/kg) \]

This parameter is called side wind sensitivity coefficients. It depends on the moving velocity \( V \) of the vehicle, on the yaw rate \( r \) of the trajectory covered by the vehicle due to the crosswind, and also on the aerodynamic force \( Y_a \) produced on the vehicle by the crosswind gust. In order to calculate the \( S_w \)

Figure 10. Side wind design coefficient \( S_d \) at different aerodynamic yawing angles \((\beta_a)\).
values, we used the $r$ values calculated in accordance with those described in the previous paragraph.

In figure 11 we can see that for a crosswind intensity corresponding to a yawing angle $\beta_a = 30$ degrees, and for the different moving velocities we considered, the fastback gives the lower values of the $Sw$ coefficient.

Plotting $Sw$ values at different yawing angles $\beta_a$ for a moving velocity $V = 30$ m/s,
we observe that at yawing angles $\beta_a$ from 20 degrees on, the fastback shows the lowest values of the coefficient $S_w$ (see fig. 12); on the other hand, at yawing angles lower than 20 degrees, the station wagon vehicle and the basic threebox-type vehicle give the lowest $S_w$ values.

This characteristic shows that for sideward gusts that have low intensity compared with the moving velocity, the threebox and station

Figure 12. Side wind sensitivity coefficient $S_w$ at different aerodynamic yawing angles ($\beta_a$).
wagon vehicles are less affected by the side wind, while, for sidewind gusts that have high intensity, the fastback is the one that suffers less.

Since these high intensity gusts are the most dangerous for any vehicle’s safety, we must conclude (in accordance with indications given by the parameters $S_d$ and $S_w$ of the Japanese report) that the fastback is the best, followed by the station wagon and the semi-station-wagon.

**SUMMING UP AND CONCLUSIONS**

In order to evaluate the sidewind gust effects on the directional capability of vehicles with different rear-body shapes, we proceeded as follows:

- We chose a basic threebox-type vehicle and designed four other different tails for the semifastback, fastback, semi-station-wagon and station wagon versions.
- These five vehicles were tested in the wind tunnel to determine the values of all the aerodynamic coefficients, at yawing angles $\beta_a$ from 0 to 40 degrees for each one.
- We compared the aerodynamic coefficients of these five vehicles and we realize that, although the $C_N$ diagrams show that the fastback is the least sensitive to the aerodynamic yawing moment, this parameter is probably insufficient to evaluate either the different sensitivities of the vehicles to side winds, or their different road behaviour.
- We calculated the trajectories covered by the five vehicles, in steady state conditions, as a result of crosswind gust. This procedure, rather complicated in relation to the number of parameters involved, allowed us to calculate the bending radius $R_c$ of the trajectories covered by the five vehicles, and to conclude that, among the five vehicles tested, the fastback is the best one in crosswind conditions as it covers a trajectory with the highest bending radius.
- Finally, we made a further comparison of five vehicles, using the parameters $S_d$ and $S_w$ that were used in the Japanese publication [8]. The comparison of these parameters also confirmed that the fastback is the best one in sidewind conditions.

In conclusion we can say that:

- Wind tunnel tests allow us to measure some useful coefficients, particularly $C_N$, which is the most indicative coefficient of the sidewind sensitivity of a vehicle.
- A simple comparison of different vehicles can be made using the $S_d$ coefficient (sidewind design coefficient), which depends on the vehicle mass, the position of the aerodynamic centre, and the centre of gravity, but it is not dependent on either the moving velocity or the over- or under-steering characteristics of the vehicle. This parameter must obviously be kept as low as possible.
- A more complicated comparison of different vehicles can be made by taking into account the vehicles’ aerodynamic characteristics, their centre of gravity, and their neutral steer points (NSP), by calculating the bending radius $R_c$ of the trajectories covered by the vehicles in steady state conditions or their sidewind sensitivity coefficient, $S_w$.

These parameters are probably the most indicative ones of a vehicle’s directional behaviour in crosswind conditions; in fact, even if a vehicle’s behaviour in crosswinds on the road is always transient, it is already known from theory and experimental results that the vehicle deviations in these conditions reflect the direction and intensity of those found in steady state conditions.

- We must exclude simple comparisons among different vehicles, such as their side areas or their side centre positions. As we saw from the tests, the fastback, at least in this particular case, was better than the station wagon even if the latter one had a bigger side area. Figure 1 compares the side centre position for the five vehicles with aerodynamic centre positions for $\beta_a = 30$ degrees, and we saw that, while the side centre position moves back as the rear side area of the vehicle is increased, the aerodynamic centre position varies in an unpredictable way and it is not correlatable to the side centre.

- We must dismiss the temptation to indicate which one of the tails is the best to deal
with sidewind sensitivity. These tests have clearly shown that the aerodynamic coefficients, and particularly $C_V$ and $C_N$, depend on the wake pattern and specifically on the location on the vehicle’s rear surface where the airstream detaches from the body.

From wind tunnel test experience, we know this airstream separation point can easily be changed by detailed modifications, and we can, therefore, suppose that by employing this technique it will be possible, within certain limits, to make any vehicle rear shape more or less sensitive to side winds.

Consequently, we believe that it could be of great interest to carry out systematic research in order to study the aerodynamic effects produced by detailed modifications on the rear part of the body.

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Status Report of the German Automotive Industry

GUNTHER BRENKEN, D. ENG.
Managing Director
Association of the Automobile Industry, Inc.

PAST HISTORY
Paraphrasing a German expression, one could say of the invitation issued in 1970 by
the U.S. National Highway Traffic Safety Administration (NHTSA); “America called, and they all came running.” The then Federal Transportation Minister, Georg Leber, was informed by the German automobile industry that it would participate in the Experimental Safety Vehicle (ESV) program. By the time of the Second ESV conference, October 1971, in Sindelfinger, Germany could already present its own ESV. Over the years, all the German manufacturers of passenger cars have participated in the five ESV conferences held to date: they have presented reports, participated in the discussions, and they have exhibited new ESV developments. The makers of parts and accessories have also expressed their interest, and they participated in the conferences and exhibitions.

At the fourth ESV Conference, held in Kyoto, Japan, in March of 1973, it already had become clear that the development stage for complete ESV’s was at an end, and this became self-evident by June 1974, when the fifth Conference met in London. The suggestions for improved active and passive vehicle safety that had been presented at earlier conferences by the various manufacturers and research institutes, largely in response to, or as variations on, ESV themes set by the Americans, had been implemented, by and large. Today, many of those ideas can be found in actual production models. But neither researchers nor car builders are yet completely satisfied. Legislators are under public pressure to issue new laws or to amend the old ones. But in many areas we still do not have the needed scientific foundations from which to proceed. That is why, at the end of the fourth ESV Conference, a call went out for thorough-going research, which was confirmed at the fifth ESV Conference in London. Above all, research is needed in the following areas in order to obtain information that is specific and can be applied to automobile design:

- Resolution of biomechanical relationships
- Systematic analysis of accident statistics
- Creation of uniformly applicable and comparable testing methods, particularly in regard to test dummies

The automobile industry cannot solve these problems all by itself. Efforts were resumed to close the gaps in our knowledge regarding these specialized areas. This conference will show to what extent these efforts have been successful.

SPECIALIZED RESEARCH

In the course of research, it became evident that there are still many territories “with blank spots on the map” that remain to be explored. One should start in an area that can yield important results. These can tell us where constructive leverage should be applied, which is the right place to start, and they can save us from needless expenditures by letting us start at the right place and with the best tools. In Germany, specialized research is carried out by scientific university institutes, as well as by the automobile industry itself; the latter research is extensive and is partially supported by the government.

Accident Research

A great number of German institutions are concerned with accident research. In order to obtain an overview, the Association for Automotive Technology Research (FAT) commissioned one of the institutes of the Technical University in Berlin to analyze current accident research programs. The Federal Highway Administration supports efforts at coordinated research in various specialized fields. In addition, there is a large number of separate investigations under the direction of various research groups created at the initiative of car manufacturers; outside consultants are called to assist in these investigations.

The new accident report forms used by the police since January 1, 1975, have contributed a certain intensification of data input to the official national statistics of the Federal Government; but, of necessity, this service can provide only fragmentary indications in regard to the evaluation of vehicle safety. Under these circumstances, the investigations begun in 1969 by the HUK Association under

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1Report of the fourth ESV Conference, p. 621.
the independent initiative of the automobile insurance companies take on particular significance; they provide massive quantities of data on many topics and furnish statistically valid, detailed evaluation of accident and personal injury risks.

To date, German automobile insurers have analyzed some 50,000 automobile accidents involving passenger injury. Thanks to these studies, it is possible to keep to a minimum the unavoidable delay between accident investigation and the computation of results that are relevant to safety considerations. In addition, these studies provide for the first time a before-and-after analysis, in actual practice, of various safety devices. Increasingly, accidents involving only uninjured passengers have also been included in the more recent HUK studies; these are of course decisive if one is to assess the practical effectiveness of safety devices.

Future developments are sure to entail an increase in the percentage of accidents caused by local vehicles and of accidents involving pedestrians, bicycle riders, and motorcyclists. In Germany, this category of road users already contributes close to 50 percent of all accident fatalities, and this percentage will appear to grow as automobile passengers profit from the improved protection afforded by more effective safety devices. On-site investigations of accidents in this category are carried out by interdepartmental teams in Heidelberg, Hannover, and Berlin on behalf of the Federal Institute for Highway Research.

Beginning in 1975-76, German insurance companies that write accident policies have maintained a census of all accidents involving injury to pedestrians. Up to now, about 35,000 such accidents have been reported. These studies, for the first time, are providing a comprehensive survey of accident sites, local highway construction procedures, faulty attitudes of drivers and pedestrians, as well as correlations between the nature of pedestrian injury and type of accident. German automobile insurance companies have also completed a study of 2,000 accidents involving motorcycles and mopeds; the results of this study will be presented in 1977. In addition, a study has been undertaken that covers bicycle accidents.

The effectiveness of the seatbelt has been proven beyond any doubt. Supplementing conclusions gained in emergency clinic and on-site studies, German automobile insurance companies have completed an analysis of 1,000 accidents resulting in serious passenger injury. In order to prevent the possibility of negative selection, all reports of accidents involving passengers using seatbelts were included without regard to gravity of injury during a 2-month period.

Other research concentration has been on lateral and rear collisions and compatibility. Emphasis is also placed on the study of driver attitudes and of the degree to which drivers make actual use of the active safety devices at their disposal for accident avoidance. This is rendered more difficult by the fact that this question can, in general, only be judged on the basis of detailed knowledge regarding the actual course of the accident. As yet, there is only very little information available in this domain; this prevents effective correlation with test results. It is to be hoped that these difficulties will be overcome, at least in part, as properly evaluated accident data become available. In this connection, it is important to obtain findings that have across-the-board validity and are not tied to one particular case.

In matters of accident research, it is generally true that particular study goals can best be achieved by coordinated analysis of the results of in-depth research and scientifically valid statistical analysis, that is, when within a multiphase analysis, one well-defined category of accidents is subjected to in-depth analysis bearing on specific problems. The elaboration of such accident data, however, is very labor intensive and requires continuous accident analysis. On the one hand, the individual sets of data must be circumscribed in order to remain goal oriented; on the other hand, their collection should be as encompassing as possible since new technical developments create novel conceptual perspectives from which already existing accident investigations might have to be reviewed. In addition to offering improved techniques for the analysis of accidents in actual practice, a list of requirements for future, concrete, accident research criteria provides a significant basis for the coordinated development of traffic safety procedures.
The various ESV conferences have significantly promoted a goal-oriented exchange of experiences in regard to statistical accident data. Nonetheless, there is much that can still be improved. Work is now done in many countries on identical problems, without one nation knowing what the other is doing in this regard. In the interest of a practical utilization of accident research results, it would be extremely useful if contact between the various national research groups were already begun during the project stage; this would greatly speed up exchange of information about project goals and, later, about research results.

One of the real problems in evaluating accident statistics is the lack of usable, uniform, international terminology. Although substantially standardized categories have been established, many basic concepts, such as type of accident, classification of accident gravity, and data on speed and on form of collision, still lack uniformity. Proposed solutions of this problem have been submitted. But rapid international coordination of accident research can be attained only by setting up a permanent working group in which the principal research units would be represented and in which unified guidelines can be discussed and information on work in progress can be exchanged.

The international bodies concerned with accident research should give priority to the formulation of standard definitions in order to insure comparability and applicability of the data presented by the various nations.

Biomechanics

All efforts for the improvement of traffic safety aim at protecting people from injury or, at least, limiting such injury as much as possible. For automobile manufacturers, this means that technical safety devices must be tailored to human characteristics, and that presupposes a knowledge of man’s mechanical resilience as well as particular attention to the forces that impinge on the car passenger and on the road user outside the car during an accident.

The present knowledge of worldwide biomechanical research is still not sufficient to answer the following essential questions:

What are the human load limits? One designates as load limits those mechanical magnitudes (acceleration, force, moment, and derived magnitude) that inflict damage to specific parts of the body (bone fracture, organic lesion, and so forth). Be it noted that, to a degree that has not yet been determined, these values depend on such specifically human parameters as sex, age, anthropometry, and weight distribution.

What are the appropriate lesion criteria? Lesion criteria designate the boundaries between acceptable and unacceptable injury, and they should be represented by mechanical data (AIS, OIS, and so forth) as well as by mechanical magnitudes.

What are appropriate protection criteria? One designates as protection criteria the values of mechanical load limits measured on test dummies. The test dummy is thus a measuring instrument used as part of test technology to check the effectiveness of security devices in representative tests. An automotive engineer needs prescribed protection criteria so that he can check adherence of his safety devices to these criteria by the use of test dummies.

Protection criteria should be determined as follows:

- Establish load limits using animals, corpses, or volunteers, and evaluate each accident.
- Determine lesion criteria. This can be derived from the load limits or, directly, through accident analysis.
- Determine protection criteria. On the one hand, the protection criteria must insure that the lesion criteria are adhered to, and on the other hand, they must be practicable for the automotive engineers from the point of view of test technology.

The tasks described here can be resolved only through the interaction of engineering science and medicine. The German auto industry has, therefore, been cooperating for several years with medical institutes in order to draw closer to the solution of these problems. Thus, for instance, tests for the determination of load limits have been run since 1973 by the Institute for Forensic Medicine for Heidelberg University.

Dynamic tests are carried out with corpses.
that are secured by safety belts. At the present stage of these investigations, head-on collision of vehicles is being simulated. The first results of these experiments were presented at the 18th and 19th Stapp Car Crash Conferences. The engineering know-how required by these studies is provided by the German automobile industry through a working group of the Association for Automotive Technology Research (FAT).

In 1976, the Federal Highway Construction Administration (BAST), acting on behalf of the Government of the German Federal Republic, initiated the establishment of a Research Association for Biomechanics. The working group "Biomechanics" mentioned above joined this association as representative of the German automobile industry. The aim of the research association is to develop lesion and protection criteria. The German automobile industry hopes that its participation in these investigations will insure direct correlation to the automobile and, when appropriate, rapid incorporation into mass production.

Passenger Protection

The purposes of the restraining system are to save the passenger from being projected against rigid elements of the car's interior and to apply the softest possible brake to his velocity at the instant of collision. The problems can be solved by correlation between the deformation of the vehicle structure and the restraining system.

The automatic three-point seatbelt has been clearly shown to be the most effective and, at the same time, the most economical restraining system among the various types of safety belts available today (fig. 1). This belt adjusts automatically to the proper length, regardless of sitting position and body size. The push buttons for these belts have been standardized in Germany. They are coded in red, and only four models have been authorized.

For those passengers who do not want to exert themselves, there already exist "passive" seatbelts. One such passive system consists of a shoulder belt and a knee pad (fig. 2). Other passive belt systems were demonstrated by several manufacturers at the fourth and fifth ESV conference (fig. 3).

The German automobile industry does not share the basic conviction that the air bag constitutes a passive restraining system suited to all types of accidents. It merely furnishes supplementary protection in certain situations if coupled with other familiar restraining systems.
Much attention has been devoted to restraining systems for children. The following minimum requirements have been formulated on their behalf:

- The system must be strong enough to withstand a 50-km/h head-on collision with a wall (standard test for weight corresponding to that of children).
- It must be simple to install and remove.
- The weight of the restraining system must not impose any additional load on the child (forces of inertia of the child’s seat). The child’s seat must be anchored separately to the vehicle, the child himself is firmly held in his seat.
- The movement of the “child dummy” in a standard test must be so limited that no contact occurs with any rigid element of the car’s interior.

The following systems are under debate for children in the various age groups:

- For infants up to the age of 1 year, weighing less than 9 kg, a solid shell in which the baby is held in a prone position. The shell is anchored in accordance with the requirements listed in figure 4.
- For young children between the ages of 1 and 3, weighing 9-17 kg, a child’s seat in which the child’s head and body are braced laterally (fig. 5).
- For children between the ages of 3 and 10, weighing 17-35 kg, a child’s restraining system consisting of suspender straps with a very wide lap strap or small deformable safety bench.
- For children taller than 1.40 m, a three-point seatbelt.

As a matter of general principle, children under the age of 12 should be seated on the
EXPERIMENTAL SAFETY VEHICLES

rear seat; in Germany this is prescribed by law.

In the general public's mind, head rests are regarded as complements of seatbelts in case of head-on collision. But, in fact, the head rests are part of the safety system for rear-end collision, while the seatbelt belongs to the system for frontal and lateral impact and for overturning of the car.

One tends to overestimate the injury-reducing effect of head rests. There is no justification for demanding the head rest as an indispensable adjunct of the seatbelt; in a head-on collision the backward force is not as violent as the one impelling forward against the belt. Accident studies show no instance where lack of a head rest caused throat or neck injury to any strapped-in passenger. A correctly designed and properly adjusted head rest does offer protection in case of rear-end impact.

Safety systems are necessary and must be used. Continuing public awareness of this fact requires effective dissemination of pertinent information. Unfortunately, one has to overcome preconceptions and human inertia. Technical journalists and psychologists should cooperate through the mass media in order to persuade the public that:

- Seatbelts are worth the small effort of fastening them.
- Seatbelts should be used even in city driving.
- The structural collapse features of vehicles have little effect if the passenger is not strapped in.
- Technical safety devices are useless by themselves without human cooperation.
- The chances of survival are five to six times greater inside the vehicle than out (when passenger who have been catapulted outside the vehicle survive, it is by pure chance).
- An unconscious passenger can do nothing for his own rescue. With a seatbelt, his chances of escaping injury, and therefore of helping himself, are much greater.

Automobile Body Design

In the course of developing Experimental Safety Vehicles (ESVs), various structural elements were subjected to head-on collisions against brick walls at speeds up to 80 km/h. Later studies, however, have shown that this was not necessary. In Europe, requirements regarding the vehicle's body are stipulated by the tests prescribed by the Economic Commission for Europe (ECE):

- Head-on collision with solid wall at 48 km/h
- Ninety-degree lateral impact on stationary vehicle of object weighing 1 100 kg at 35-38 km/h
- Rear-end impact on stationary vehicle of object weighing 1 100 kg at 35-38 km/h
- Roof cave-in test on vehicle firmly held by appropriate device; impact by an object (60 percent of vehicle's net weight); impact velocity: 2.7-3.3 m/s

All tests are carried out with empty vehicles. After each test, the following requirements must be satisfied:

- Deformation of the passenger shell must not have exceeded a certain value.
- All doors must have remained closed during collision.
- It must be possible to open without tools a sufficient number of doors to rescue all the passengers.
- Rigid elements in the passenger space must not have constituted danger of injury for the passengers.

The vehicles produced by the German automobile industry satisfy these requirements.

In order to be able to meet the above conditions with due regard to economy of energy and raw materials, and in order further to reduce the risk of injury to passengers, even more attention will have to be given, when designing future vehicles, to devising structural sheet-metal elements such as hood, trunk lid, wheel components, fenders, and doors that will absorb deformation energy.

In the past, attention has been given mainly to collisions with stationary obstacles or with equivalent vehicles. But in the future, the matter of "compatibility" will also have to be included in the investigations. Here is what we mean:

When two vehicles of different types are involved in the same accident, it is particularly important that their design be standard-
ized in regard to type of construction, structure, and restraining system. This is the only way to prevent the passengers of one of the vehicles from suffering more serious injuries than those of the other vehicle. This compatibility problem is one of the principal themes in today’s research efforts. The goal is to design vehicles in such a manner that the safety devices in vehicles of different types involved in an accident will have the greatest possible protective effect on all the passengers; at the same time, the cost of these devices must not exceed an economically justifiable figure. The level of usefulness of a safety device can be gauged by the monetary equivalent of the injuries from which it will protect passengers.

This balancing of optimum effectiveness against minimum overall cost can only be achieved by establishing the needed basis for future test procedures and evaluation criteria; these will have to take into account the acceptable physical human load limits—that are not yet fully known.

Pedestrian Safety and Automotive Engineering

Since 1972, there has been a clearly discernible trend in the distribution of injury risk among the various categories of road users: The percentage is going down for automobile passengers, while growing for the unprotected category, pedestrians and cyclists. By 1973, in Germany, the number of fatalities in the second group had already exceeded that of the first group. This trend persists, and it will grow in the years to come owing to the improving passenger safety devices being developed by automotive engineers.

In our country, it is the pedestrians who are at a particular disadvantage. Their share of traffic fatalities is about 40 percent; in the cities it can range up to 70 percent. Within the pedestrian category, children under 15 are in special danger, and the age group 5 to 8 has the highest accident rate. One also notes the disproportionately high incidence of accident victims among aged pedestrians.

That is why, in Germany and certain other countries, accident research has been focusing on collisions between vehicles and pedes-
automobile manufacturers with several problems. The standard height for impact studies prevalent in today’s European car design is above 425 mm, as a rule. In the future, a solidity test for bumpers will be included in the prescribed procedures, and since the impact forces must be transmitted to the automobile’s structure, the standard bumper height essentially determines the positioning of the bearing elements of the vehicle’s body. Heretofore, the value resulted from the arrangement of axles, engine, and longitudinal runners of the body. A change, therefore, implies impinging on the basic underlying conception of the automobile. If the basic layout is left unchanged, the lowered position of the bumper requires that it be connected to the bearing elements of the automobile’s structure by additional elements able to absorb impact forces and bending moments. This signifies increased net weight and higher energy consumption.

But a much more critical consideration is the regulation which applies in the important U.S. market; under this regulation, the bumper must be tested for stresses at heights that are considerably above those contemplated in Europe. The standard height is set in the 400-500-mm range. These values were selected in the United States to provide for the type of car prevalent there with characteristic, rather long overhang, front and rear. It is a matter of not wanting to change basic designs, and also preventing potential damage to the cars by steep inclines, such as the ramps that sometimes lead to garage entrances. No consideration was given to pedestrian safety and still remain cost-effective for the United States as in Europe because of the difference in traffic patterns and make-up.

There is still no sufficiently reliable answer today to the question whether automobile engineering can make any real contribution to pedestrian safety and still remain cost-effective. Research efforts should be expanded to cover as many cases as possible; this might determine which elements of a car’s front determine pedestrian injury patterns, and whether possibilities exist for optimum shapes and materials. In any case the concept of considering only the height of bumpers seems problematic. In this domain, standardized regulations are needed for Europe and the United States. This development has given new stimulus to the public’s long-standing demand for standard automobile bumper height. Contrary to recent expectations, the task that seemed so easy at first can hardly be solved on short notice in view of the overriding factors: “passenger safety, automobile design and European-American standardization. It is commendable that American authorities, too, have initiated a study program to tackle this question.”

Vehicle Dynamics

The German automobile industry has already reached high levels in the domain of automobile dynamics. Work continues toward further improvements. Research emphasis, for instance, is on step function of the steering angle. No impulse has come from the ESV program that would be useful in this connection; nor would one expect such an impulse in the future.

STANDARDIZATION OF TECHNICAL REQUIREMENTS

In addition to the two international bodies, ECE and European Community (EC), there are now national authorities of varying importance. Each issues safety and emission regulations in its own country, and the scope of the regulations varies with each authority’s importance.

This situation causes enormous expense for the vehicle manufacturers because, in some cases, widely divergent regulations govern the same subject matter; in certain cases, these regulations have not even been based on any cost analysis.

It is therefore of great urgency that all these laws be brought into harmony. We welcome the support for ECE step-by-step standardization expressed by the United States in regard to testing procedures and technical requirements; we hope very much that this initiative will lead within the foreseeable future to concrete results, and that this will bring about the coordination of ECE and U.S. regulations strongly desired by automobile manufacturers.
The efforts of the ECE and EC have already created examples of standardized regulations.

The following points are of special importance:

1. Formulation of a long-range program establishing priorities based on cost analysis
2. Uniform deadlines for the application of regulations to automobile types already in production and to newly developed ones
3. Legislative procedures that provide for preannounced goals and for coordination with industry at appropriate time intervals
4. Step-by-step replacement of national regulations by international statutes; forgoing of any new separate national legislation

SUMMARY

This presentation could not have enumerated all the areas in which the German automobile industry has labored successfully in the past 2 years in the interest of better vehicle safety and thus also in the interest of ESV development.

Automobile dynamics have been further explored and progress has been made toward accident prevention. Numerous constructive devices have already been incorporated into new models or are on the verge of realization which result in more secure and easier driving, improved safety under unfavorable weather, and comfortable riding characteristics.

Beyond that, efforts have been made to improve cost analysis of safety measures and to establish precise criteria by which to gauge the effectiveness of new devices.

For the next few years—until about 1985—the following problems will be at the center of research efforts, as they have been in the past:

- Accident investigations
- Biomechanical studies
- Passenger safety
- Response of new vehicle types under collision conditions

Working together with the automobile industry, legislators should intensify their efforts to achieve unified regulations and test requirements, for instance, in regard to test dummies; they should set target dates for new statutes well in advance of actual implementation.

Even though we may be giving the impression that we are up against a sort of sound barrier, the development of even safer motor vehicles will continue, for with the aid of technology, engineers have the ability to break through even the sound barrier.

Governments have the task of formulating laws for the protection of the people and of society. This obligation is universally recognized. It should apply not only to automobile design but also to other safety factors. This might well include road construction where considerable improvements can be achieved, as is evident from a comparison of accident frequencies on federal highways and on side roads.

Passenger safety could also be enhanced more effectively by means of improved traffic control and road construction than by the techniques of automotive engineering.

These days, with ever more complex traffic problems, and with travel that transcends national boundaries, legislators should give automobile manufacturers adequate advance notice, that is, at least 5 years. That way, good solutions could be translated into actual practice with much less friction than has been the case in the past.

We urge NHTSA to direct its efforts along these lines in the interest of improved international relations.

The Contribution of Volkswagen to the Research Safety Vehicle Program

DR. WOLFGANG LINCKE
Volkswagenwerk AG
Research and Development
in addition to technical ones have been discussed. More and more the question has arisen whether the safety requirements postulated and their technical solutions are still economically feasible. Seen from this point of view, we welcome the fact that the Research Safety Vehicle (RSV) Project has dealt with safety research in the wider context of system analysis. In this respect, phase 1 of this project is of special significance insofar as it incorporates an analysis of all basic problems of transport technology, accident statistics, and economy as well as their correlation to safety technology. Although phase 1 ended 18 months ago, and phase 2—the design of vehicles—is about to be completed, it seems appropriate to report on the most significant results of phase 1 as this is the first ESV conference held since its completion. The following will be a brief report on Volkswagen's contribution to phase 1. Our work was based on the principles shown in figure 1, centering around cost/benefit analyses. The basic data for these analyses were derived from analytical studies of automobile use and accidents and from technical considerations concerning accident avoidance and crashworthiness.

AUTOMOBILE USE AND ACCIDENT ANALYSIS

The first question to be answered in the course of this work was, "What will traffic and accidents be like in the mid-1980's?" Today, I can do no more than give a brief summary of our answers to this question, which are based on detailed studies in various fields.

1. Far beyond the period covered by this prognosis, the automobile will continue to be the most important means of transportation in the United States as well as in Europe. The significance of mass transportation will increase only locally.

2. The numerical and structural development of the population as well as the development of settlement structures will cause both the total number of motor vehicles and mileage to increase.

Table 1. Accident type and impact location in 1973 and the prognosis for 1985 for the United States

<table>
<thead>
<tr>
<th>Accident type</th>
<th>1973 U.S. (percent)</th>
<th>1985 U.S. (standard estimate in percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ran off roadway</td>
<td>5.9</td>
<td>5.6</td>
</tr>
<tr>
<td>Hit a fixed object</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Hit another object</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Car vs car</td>
<td>66.5</td>
<td>66.8</td>
</tr>
<tr>
<td>Car vs truck</td>
<td>11.1</td>
<td>11.0</td>
</tr>
<tr>
<td>Multiple vehicle</td>
<td>10.8</td>
<td>10.5</td>
</tr>
<tr>
<td>Other</td>
<td>3.6</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Impact site:

| Front                  | 50.3                | 50.3                                   |
| Right                  | 11.9                | 11.5                                   |
| Left                   | 13.8                | 13.8                                   |
| Rear                   | 21.5                | 21.9                                   |
| Other                  | 2.5                 | 2.5                                    |

1 RSV-Phase-I-Final Report, Vol. I-III, Nr. PB244-634, PB244-635, PB244-636, DOT HS-801 624, DOT HS-801 625, DOT HS-801 626, prepared by Volkswagen for DOT Contract No. DOT-HS-4-00843.
3. The mass distribution of the vehicles used for transportation will change under the influence of the energy supply situation.

4. Even if we assume extreme developments in the number of motor vehicles, population density, and road systems, accident patterns will not change significantly.

This last statement was made by us in cooperation with the Highway Safety Research Center (HSRC) of the University of North Carolina. It is based on a projection model. Table 1 shows some of the outstanding results.

In principle, therefore, we were able to project the efficiency and economy of safety measures for the target year 1985 based on an analysis of today’s accident situation. However, we found the accident data available to be both inexact and unsatisfactory for several reasons:

- There is little standard statistical material.
- The size of the samples is limited.
- Accident studies are performed according to different codes (PIC-AIS, TAD-VDI).
- Errors are committed in estimating vehicle speeds.
- Statistical data are inconsistent.
- There is bias caused by regional differences.
- There is bias caused by variations in the depth of the studies.

In order to support our findings despite such difficulties, we had to use sophisticated methods such as sensitivity analyses.

### TECHNOLOGICAL SAFETY PROBLEMS

#### Crashworthiness

We covered the following sets of problems from the theoretical, design, and experimental angle (see fig. 2):

- The effect of frontal, lateral, and rear impacts at various test speeds on weights and cost
- The compatibility problems raised by vehicles of differing type and mass

Again, accident statistics emphasized the significance of the second set of problems named. In the course of our work in connection with phase 1, we developed a theoretical concept of compatibility (fig. 3) that guarantees occupant safety both in the smaller and in the bigger vehicle over the entire statistically significant range of mass ratios and closing velocities.

This concept does not involve any basic changes of either the geometry or the design principles of a vehicle. Our work on the problem of compatibility was based on systematic analyses of data obtained from today’s motor vehicles (figs. 4, 5) from which we derived some basic laws of similarity. We shall hear more about this work at some later time in the course of this conference\(^2\) [1].

ACCIDENT AVOIDANCE

Based on accident statistics we compiled the following list of priorities:

- Vehicle response to steering input
- Braking in a turn
- Straight-line braking performance
- Vehicle steering characteristics on a constant radius
- Visibility
- Rollover immunity
- Crosswind immunity
- Steering returnability

In order to draw up test specifications that were characteristic of the situations named above, we applied the procedure illustrated in figure 6. We concentrated on open-loop procedures as far as possible in order to eliminate, as much as possible, the influence of the driver. Porsche AG, Zuffenhausen, cooperated in drawing up these test specifications.

COST/BENEFIT ANALYSES

All the individual studies mentioned up to now have supplied us with the data base for our cost/benefit analysis. The following approach was used:

- The absolute benefit of safety measures was not taken into consideration. Instead, we concentrated on finding combinations of safety measures that would yield maximum benefit at a given cost (consistent measures).
- Sensitivity analyses were used to demonstrate that combinations of this nature are hardly affected even by a grave lack of precision in the input data.

Both these principles [2, 3, 4] are illustrated by figure 7, which is based on two assumptions concerning the societal cost figures of an injury or death in motor vehicle accidents (table 2).
Figure 4. Effective interior occupant compartment distance versus vehicle mass (curb weight) using European vehicles.
Figure 5. Deformation stroke in frontal fixed barrier impact versus mass for various types of vehicles at $v_0 = 30$ mi/h.

Figure 6. Approach to the development of vehicle handling criteria.

- Accident statistics
- Determination of the most frequent accident situations
- Definition of suitable closed-loop test procedures
- Correlation of test results
- Determination of vehicle characteristics as criteria for handling performance
- Data rating
- Preparation of specifications
Figure 7. Total benefit per car and associated consistent test conditions. (All velocities are closing velocities for impacts with movable barriers.)
## EXPERIMENTAL SAFETY VEHICLES

<table>
<thead>
<tr>
<th>References</th>
<th>Monetary value of one fatality</th>
<th>Monetary average value of one non-fatal injury</th>
<th>Ratio fatality nonfatal injury</th>
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<tbody>
<tr>
<td>“Economic Analysis of the Occupant Crash Protection Standard.” Staff Report, Office of System Analysis, NHTSA, April 1971.</td>
<td>$43,000</td>
<td>$2,200</td>
<td>19.5</td>
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<tr>
<td>Mackay, G. M. “Cost/Benefit Consideration of Restraint Systems.” 1973.</td>
<td>£23,000</td>
<td>£2,000</td>
<td>11.5</td>
</tr>
<tr>
<td>Helms, E. “Folgekosten der Straßenverkehrs unfälle 1968 nach Schadensarten.” Zeitschrift für Verkehrssicherheit 17, Nr. 4. 1971.</td>
<td>308,000 DM</td>
<td>4,820 DM</td>
<td>63.9</td>
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<tr>
<td>Niklas, J. “Nutzen/Kosten-Analyse von Sicherheitsprogrammen im Bereich des Straßenverkehrs.” Schriftenreihe des VDA, Nr. 7. 1970.</td>
<td>120,000 DM</td>
<td>1,340 DM</td>
<td>99.5</td>
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<tr>
<td>Traffic Safety Memo No. 113, NSC. July 1974.</td>
<td>$90,000</td>
<td>$3,700</td>
<td>24.3</td>
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<tr>
<td>VW Study. 1974.</td>
<td>$83,000</td>
<td>$5,300</td>
<td>15.6</td>
</tr>
</tbody>
</table>

Table 2. A comparison of societal cost figures of fatal and nonfatal injuries according to various authors

Along those lines our cost/benefit analyses supplied us with a number of consistent measures for the improvement of crashworthiness (see table 3). Each set represents the maximum benefit attainable in each vehicle at the cost figure stated. In accordance with the RSV concept of compatibility all test speeds given are closing velocities in a collision with a movable deformable barrier (MDB). Generally, the decision on which a set of test specifications is to be used will be based on nontechnical considerations.

We do hope, however, that through our contribution to the RSV Project we have helped to make it clear that technical considerations can go far towards creating a rational basis for decisions of this nature.

Volkswagen has selected set B of table 3 to use in their preliminary design work in connection with the RSV Project, mainly because the cost/benefit curve showed a local gradient of nearly 1 (see the last-but-two column of table 3), indicating that the benefit is ideally superior to the cost.

Similar considerations may be applied to accident avoidance measures (see fig. 8). They illustrate that legal regulations regarding costly pieces of equipment, such as adjustable headlights or distance warning systems, are rather meaningless.

### Table 3. Consistent test conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Closing velocity in movable barrier test ($V_{COT}$) (mi/h)</th>
<th>Equivalent car (mi/h)</th>
<th>Cost per car ($)</th>
<th>Benefit per car ($)</th>
<th>Local benefit increase per cost unit</th>
<th>Benefit cost ratioa</th>
<th>Reduction of fatalitiesb</th>
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<tbody>
<tr>
<td>Front</td>
<td>53</td>
<td>15</td>
<td>25</td>
<td>30</td>
<td>40</td>
<td>306</td>
<td>7.65</td>
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<tr>
<td>Side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rear</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Active restraint/mandatory use</td>
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<td>53</td>
<td>15</td>
<td>25</td>
<td>30</td>
<td>81</td>
<td>398</td>
<td>1.50</td>
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<td>Combination A</td>
<td>60</td>
<td>15</td>
<td>25</td>
<td>34</td>
<td>114</td>
<td>432</td>
<td>1.25</td>
</tr>
<tr>
<td>Combination B</td>
<td>71</td>
<td>15</td>
<td>25</td>
<td>40</td>
<td>179</td>
<td>511</td>
<td>1.08</td>
</tr>
<tr>
<td>Combination C</td>
<td>80</td>
<td>15</td>
<td>40</td>
<td>45</td>
<td>289</td>
<td>598</td>
<td>0.53</td>
</tr>
<tr>
<td>Combination D</td>
<td>85</td>
<td>32</td>
<td>47</td>
<td>48</td>
<td>588</td>
<td>698</td>
<td>0.33</td>
</tr>
</tbody>
</table>

aWithout significance for overall economical considerations.
bPer 10,000 cars and per year. These were compared with production state cars without restraint.
Figure 8. Decision on active safety cost-effectiveness.
Several tables and figures have been left out from this text. However, the main points are as follows:

**Table 4. Most important vehicle characteristics**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body style</td>
<td>Sedan (2 or 4 door)</td>
</tr>
<tr>
<td>Overall length (in)</td>
<td>181-193</td>
</tr>
<tr>
<td>Overall width (in)</td>
<td>69-73</td>
</tr>
<tr>
<td>Overall height (in)</td>
<td>53.5-54.3</td>
</tr>
<tr>
<td>Wheel base (in)</td>
<td>106</td>
</tr>
<tr>
<td>Tread (in):</td>
<td></td>
</tr>
<tr>
<td>Front</td>
<td>56.7-57</td>
</tr>
<tr>
<td>Rear</td>
<td>56.7-57</td>
</tr>
<tr>
<td>Number of passengers</td>
<td>4 (5)</td>
</tr>
<tr>
<td>Front</td>
<td>2</td>
</tr>
<tr>
<td>Rear</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Gross vehicle weight (lb)</td>
<td>4 000 (max.)</td>
</tr>
<tr>
<td>Distribution (percent F/R)</td>
<td>50.5/49.5</td>
</tr>
<tr>
<td>Curb weight (lb)</td>
<td>3 000 (max.)</td>
</tr>
<tr>
<td>Distribution (percent F/R)</td>
<td>60/40</td>
</tr>
<tr>
<td>Useful load (lb)</td>
<td>1 000</td>
</tr>
<tr>
<td>Fuel tank capacity (gal)</td>
<td>20.0</td>
</tr>
<tr>
<td>Engine:</td>
<td></td>
</tr>
<tr>
<td>SAE horsepower</td>
<td>100</td>
</tr>
<tr>
<td>Transmission</td>
<td>Automatic/manual</td>
</tr>
<tr>
<td>Tire information:</td>
<td></td>
</tr>
<tr>
<td>Tire size</td>
<td>165 SR 14</td>
</tr>
<tr>
<td>Tire pressure</td>
<td>27/25.60</td>
</tr>
<tr>
<td>Brakes:</td>
<td></td>
</tr>
<tr>
<td>Front</td>
<td>Disc</td>
</tr>
<tr>
<td>Rear</td>
<td>Drum</td>
</tr>
<tr>
<td>Power assist</td>
<td>Yes</td>
</tr>
<tr>
<td>Steering</td>
<td>Safety steering system</td>
</tr>
<tr>
<td>Additional equipment</td>
<td>Passive restraints, pedestrian protection</td>
</tr>
</tbody>
</table>

**RSV DESIGN**

In accordance with the data sheet (table 4), Volkswagen has presented one possible way of realizing the specifications and principles promulgated by them in their work on the RSV Project (see figs. 9 and 10). Nevertheless, we have to emphasize the fact that, in our opinion, the system in its entirety is far more significant than its realization in any one selected spot, even if that spot was selected very carefully.

**PERSPECTIVES FOR THE FUTURE**

Even in retrospect the results of phase 1 of the RSV Project still are extremely significant as a basis for future safety research. Although this report has merely dealt with Volkswagen's contribution toward that project, we think it is appropriate to say that the work performed by the other participants also concentrated on the important aspects of system analysis, in many respects confirming our conclusions, in others, supplementing or diversifying them.

Here again, on behalf of Volkswagenwerk AG, we repeat our suggestion that, in addition to the interesting and necessary work on the subsequent phases of the RSV Project, the basic research begun under phase 1 should be continued systematically and should, if possible, be summarized and made available for discussion.

One further step in this direction is the project “Engineering Model of Future Motor Vehicles.” The goal of this project is to develop a comprehensive engineering model of future motor vehicles that will provide a realistic and uniform basis for developing safety requirements and assessing their future effects.
Figure 9. RSV frame.
LITERATURE


Status Report by the United Kingdom Motor Vehicle Industry

MR. J. J. HOLLINGS
Society of Motor Manufacturers and Traders Ltd.

INTRODUCTION

In drafting this report on behalf of the United Kingdom automobile industry, the Society of Motor Manufacturers and Traders compared the themes of previous conferences with the theme of this conference and noted that the circumstances under which we meet in 1976 are different from the previous meetings. The world is slowly recovering from a major depression that, at the time of our last meeting in London, in June 1974, was already with us although the depth of the recession was then only being signalled.

One effect of this depression, particularly in a number of European countries including the United Kingdom, is to remind us of the need for economy. In this climate, safety takes on new aspects, as does the search for
energy reduction and environmental protection. Doubtless this was the concern behind the concept called the S3E—Safety, Energy, Environment, and Economy. Indeed, this point was made by the Administrator of the National Highway Traffic Safety Administration (NHTSA) at the June 1974 conference, when he stated:

We must also consider the environment and the economy. All three areas are factors in the future design of vehicles, and we must keep them in mind as Research Safety Vehicle (RSV) proceeds. In discussing safety, energy, environment, and economy, I have called this concept the S3E.

The United Kingdom automobile industry has concluded that today the most important of these three is economy, that is, the economical use of materials and fuel to reduce the impact of increasing cost to its customers.

This progress report relates the views of the United Kingdom automobile industry on the four objectives, and outlines the current situation in the United Kingdom.

![Figure 1](image1.png)

**Figure 1. Trend of new vehicle registration in the United Kingdom for 1970-75.**

SAFETY

As can be seen from figure 1, the vast majority of the vehicles sold in the United Kingdom market during the last 5 years fell between the engine capacities of 1 000 cc and 2 000 cc. Figure 2 shows that the kerb weight of current vehicles is from 620-1 240 kg (1 365-2 730 pounds) with most being well below 1 000 kg (2 200 pounds). The majority are thus considerably smaller and lighter than the RSV programme for a 3 000-pound (1 364-kg) safety car.

In Europe, international governmental collaborative research has been going on since 1970 under the aegis of the European Experimental Vehicles Committee (EEVC). We make no apology for quoting from the foreword of the paper presented by the Chairman of the EEVC at the 1974 conference. He stated:

Research to improve the safety of vehicles had been carried out internationally for some time. Government administrators in collaboration with industry have started investigations to standardise regulations which differ from each other, and also to make recommendations for the highest possible level of safety, using available techniques, whilst remaining acceptable for production. This facilitates the sale of cars between nations, and at the same time improves their safety. Without underestimating this continuing work, some Governments have initiated more advanced research, eventually to be used to strengthen regulations to give safer vehicles. Any gain in safety must be achieved within reasonable limits of cost, weight and dimensions.

Furthermore, account must be taken of the special difficulties for small, light vehicles and the problems of their compatibility on the road with larger, heavier vehicles.

Manufacturers have been carrying out their own safety developments and the results of some of this work, where they relate to the EEVC recommendations, are shown in tables.

1 The emphasis has been added by the authors.
EXPERIMENTAL SAFETY VEHICLES

1-3. It will be seen that in a number of cases the results are encouraging.

The United Kingdom industry is continuing to study the objectives and test methods of the EEVC. There is no doubt that this organisation is formulating test procedures and acceptance criteria that are appropriate to the European cars below 3 000 pounds kerb weight. So far indications are that the recommendations are practicable and would not have an unacceptable effect on the total vehicle price providing the benefits can be demonstrated.

For these reasons the United Kingdom industry is not pursuing the RSV concept further but is following the EEVC objectives. However, it should be noted that one manufacturer has supplied three vehicles from its 1974 experimental safety vehicle (ESV) model range to the NHTSA. The manufacturer has participated with Calspan Corporation in the test programme. This comprised a 90-degree, car-to-car side impact at 48 km/h (30 mi/h) and a head-on impact between the British SRV-1 and the AMF 2 ESV at a closing speed of 96 km/h (60 mi/h). Both tests were understood to demonstrate compliance with expected performance (figs. 3-6).

Occupant Protection

In recognition of the proved performance and demonstrated cost-effectiveness of safety belts in saving lives, the United Kingdom, together with most other European countries and a number of other developed areas of the

Table 1. 48-km/h frontal barrier impact tests

<table>
<thead>
<tr>
<th>Item</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test type:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) 30°</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Offset right hand 1/2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Offset right hand 1/3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dummies:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Restrained</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Instrumented</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fitted—front right hand</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fitted—front left hand</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fitted—rear right hand</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Fitted—rear left hand</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>EEVC recommendations:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compliance with biomechanical tolerance limits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head—&lt;1 000 Severity Index (SI)</td>
<td>O</td>
<td>O</td>
<td>X</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>O</td>
<td>—</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Chest—&lt;60 g - 3 ms</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>O</td>
<td>—</td>
<td>—</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Femur—1 700 lb (7.6 kn)</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>O</td>
<td>X</td>
<td>—</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No bursting open of doors during impact</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Possibility of opening at least one door without tools after collision</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Possibility after collision of removing complete dummies</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>No fuel spillage or fire</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>Tank empty but no damage to tank or lines</td>
</tr>
</tbody>
</table>

*This criterion taken from the 1974 report but since lowered by EEVC WG-4.

NOTE. O = compliance with recommendation; X = failure to meet recommendation; — = no information.
world such as Australia and the Province of Ontario in Canada, have enacted, or will shortly enact, laws requiring the wearing of safety belts. Table 4 shows the status of the safety belt-wearing laws of such countries.

One result of the increase of belt wearing has been that European car manufacturers have had to put increasing emphasis on the comfort of the wearer in addition to the protection criteria.

Some of the customer problems that have been found by United Kingdom manufacturers are as follows:

- Diagonal strap rubbing the neck, especially for smaller occupants

Table 2. Rear impact tests

<table>
<thead>
<tr>
<th>Item</th>
<th>Test vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile barrier weight test (kg)</td>
<td>1 1 1 1 1 1 1</td>
</tr>
<tr>
<td>Impact velocity (km/h)</td>
<td>50 50 48 48 50 35 35 35 35 35</td>
</tr>
<tr>
<td>EEVC recommendations:</td>
<td></td>
</tr>
<tr>
<td>1. No bursting open of door during impact</td>
<td>0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>2. Possibility of opening at least one door without tools after collision</td>
<td>0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>3. Possibility, after collision, of removing complete dummies</td>
<td>- - - 0 0 - - - -</td>
</tr>
<tr>
<td>4. No fuel spillage or fire</td>
<td>0 0 0 0 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>

NOTE. 0 = Pass; - = no information.

Table 3. Roof tests

<table>
<thead>
<tr>
<th>Item</th>
<th>Test vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test type:</td>
<td>1 2 1 2 2 1 1 1 2</td>
</tr>
<tr>
<td>EEVC Recommendations:</td>
<td></td>
</tr>
<tr>
<td>1. No bursting open of door during impact (Type 1 Test)</td>
<td>- 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>2. Possibility of opening at least one door without tools after collision (Type 1 Test)</td>
<td>0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>3. Possibility, after collision, of removing complete dummies (Type 1 Test)</td>
<td>None fitted</td>
</tr>
<tr>
<td>4. No fuel spillage or fire (Type 1 Test)</td>
<td>- - 0 - - 0 0 0 -</td>
</tr>
<tr>
<td>5. Absence of excessive roof crush (Type 2 Test)</td>
<td>N/A 15.8 cms N/A 5 cms 3.6 cms N/A N/A N/A 9 cms</td>
</tr>
</tbody>
</table>

NOTE. 0 = pass; - = no information; N/A = not applicable.
Figure 3. AMF-ESV to British SRV-1 SRV closing speed 96 km/h (60 mi/h).

Figure 4. Posttest result.

Figure 5. Ninety-degree car-to-car impact at 48 km/h (30 mi/h).

Figure 6. Impacted vehicle.

- Lap strap riding too high off iliac crest into abdomen
- Difficulty in connecting and releasing buckle with console-fitted anchorages
- Excessive pressure on the shoulder with emergency locking retractors equipped with conventional retract springs at high settings
- Unacceptable difficulty in coarse adjustment of many static belts and hence dirty, untidy appearance, and slack wearing condition (if used at all)
- Similar problems with retractors with low spring setting (usually introduced to obviate excessive shoulder pressure)
- Lack of provision of means for adjustment of upper anchorage height to suit tall and short occupants
- Interference with access to rear passenger compartment in two-door vehicles

To overcome some of these problems one manufacturer has lowered the “B” post anchorage by some 40 mm, and others have made available anchorage adjusters, which, when fitted, lower the “B” post loop by some 35 mm (this equipment being recommended for persons of below average height, especially small females) as seen in figures 7 and 8.

Another manufacturer has under review two designs of “B” post adjustments, shown in figures 9 and 10. These allow the wearer to easily select alternative positions for the upper anchorage without the need of tools. Figures 11-13 show a British vehicle that is
### Table 4. Summary of European seatbelt, anchorage, and wearing legislation

<table>
<thead>
<tr>
<th>Country</th>
<th>Front seats</th>
<th>Rear seats</th>
<th>Legal approval</th>
<th>Belt-wearing aspects</th>
<th>Estimated effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Belt type</td>
<td>Number required</td>
<td>Date</td>
<td>Belt type</td>
<td>Anchorage</td>
</tr>
<tr>
<td>Austria</td>
<td>L+D or L#</td>
<td>2</td>
<td>1.10.72</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Australia</td>
<td>L+D*/(L)</td>
<td>2(1)</td>
<td>1.1.74</td>
<td>L or L+D</td>
<td>L or L+D</td>
</tr>
<tr>
<td>Belgium &amp; Luxembourg</td>
<td>L+D</td>
<td>2</td>
<td>1.4.71</td>
<td>NR</td>
<td>TBE</td>
</tr>
<tr>
<td>Switzerland</td>
<td>L+D/(L)</td>
<td>2(1)</td>
<td>1.1.71</td>
<td>TBE</td>
<td>TBE</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>L+D/(L)</td>
<td>2(1)</td>
<td>1.1.69</td>
<td>TBE</td>
<td>TBE</td>
</tr>
<tr>
<td>West Germany</td>
<td>L+D/(L or D)</td>
<td>2(1)</td>
<td>1.1.74</td>
<td>NR</td>
<td>2(1)</td>
</tr>
<tr>
<td>Denmark</td>
<td>L+D*/(L#)</td>
<td>2(1)</td>
<td>1.7.69</td>
<td>2.1.78(?)</td>
<td>Nat or E</td>
</tr>
<tr>
<td>Spain</td>
<td>L+D</td>
<td>2</td>
<td>11.11.74</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>France</td>
<td>L+D/(L or D)</td>
<td>2(1)</td>
<td>1.4.70</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>L+D or D</td>
<td>2</td>
<td>1.1.65</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Italy</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Ireland</td>
<td>L+D or full or D</td>
<td>2</td>
<td>1.6.71</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Norway</td>
<td>L+D*/(L)</td>
<td>2(1)</td>
<td>1.1.71</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Netherlands</td>
<td>L+D or L</td>
<td>2</td>
<td>1.1.71</td>
<td>L+D*</td>
<td>Outer only</td>
</tr>
<tr>
<td>Sweden</td>
<td>L+D*/(L)</td>
<td>2(1)</td>
<td>1.1.74</td>
<td>L+D*</td>
<td>Outer only</td>
</tr>
<tr>
<td>Finland</td>
<td>L+D/(L)</td>
<td>2(1)</td>
<td>1.1.71</td>
<td>1.78(?)</td>
<td>E or Nat</td>
</tr>
</tbody>
</table>

### Legend
- **D**: Diagonal-type 2-point position
- **(1)**: Mid front or rear seat position - where present
- **(?)**: Expected but not certain
- **?**: Exact day/month not known
- **@**: Date at which data given are correct.
- **E**: ECE Regulation 14 (Anchorage), Regulation 16 (Belts)
- **TBE**: Required but details to be established
- **E**: E Mark accepted if endorsed with National Approval Number
- **x**: Local maximum during publicity campaign
- **L**: Lap if centre seat position present
- **NR**: Not required
- **ADR**: Australian Design Rule
- **BSI**: British Standards Institution
- **av**: Average
- **o/s**: Outside cities
- *****: Locking retractor (or inertia) reel
- **L+D**: Lap and diagonal or “2-point” belt
- **Nat**: National Approval, e.g., BSI, etc.
fitted with a guide for the seatbelt that can be used, at the discretion of the occupant, to lower the run of the seatbelt across his/her chest. The guide is mounted in a frangible fitment so that under impact conditions the load is taken directly by the upper anchorage. Tests indicate that there is no measurable increase in the forward movement of the occupant during the impact.

Figures 14 and 15 show the arrangements in two new British cars where the lap portion of a running-loop belt is anchored to the seat ensuring a snug, comfortable, and anatomically correct fit. Another British vehicle was introduced in 1970 with both lower and upper anchorages on the seat.

It is most important that regulations which strictly control the design of motor vehicles should not preclude such developments that have the objective of overcoming real problems faced by the vehicle user. In Europe this has been the case where even now it is very difficult to obtain approval in all countries for designs that are different from the common state-of-the-art at the time the regulations were written.

As would be expected, the increase in compulsory belt-wearing requirements has given rise to a very high fitting of emergency locking retractors (inertia reels). Indeed, some British manufacturers now fit only this type of seatbelt as standard, other manufacturers have them as standard on some models and as options on other models.

Further development continues on passive belt-wearing systems. No current model of British car yet incorporates such a system, but it is known that a number of British manufacturers have systems under development.

Alternatives to the passive seatbelt-wearing system include the automatic cushion restraint system that consists of a pad held in...
SECTION 3: INDUSTRY STATUS REPORTS

problem by manufacturers’ design staffs. The Common Market countries, including the United Kingdom, are expected shortly to be mandating the EEC Directive 74/483 on External Projections of Motor Vehicles. It will be recollected that the problems of pedestrian impact were a feature of the demonstrations at the United Kingdom Government’s Transport and Road Research Laboratory during the 1974 conference. We are pleased to note that a paper on this subject is being presented by a major British manufacturer in the seminars.

Figure 9. This design provides a two-position anchorage. The main unit is recessed into the vehicle side structure and fixed in place by means of a standard 7/16" diameter bolt, and two lighter fixings. The existing seatbelt bracket is attached to a torque plate that can be plugged into either location. The release button permits its removal and relocation to the alternative position.

Figure 10. A vertical member and spring-loaded anchorage bracket make up this unit. It can be attached to the side panel assembly by means of a standard 7/16-inch bolt. The anchorage bracket may be depressed and then adjusted up and down the member, automatically locking on release in the most suitable position. In this example the seven alternative anchorage positions are 19 mm (0.75 inches) apart and provide an overall travel of 114 mm (4.50 inches).

light contact with the occupant’s chest together with a knee restraint. In an emergency the pad is locked into position. This system was demonstrated at the 1974 conference and is becoming of increasing interest to manufacturers and operators of urban delivery vehicles in countries where compulsory seatbelt-wearing laws operate (experience of this device forms the subject of a paper to be presented at one of the seminars).

Another occupant protection development is the new generation of laminated safety glass which was demonstrated at the 1974 conference and is now fitted as standard to a new British vehicle. This glass, known as “Twenty-Twenty,” incorporates a tempered inner layer, which fractures under impact into finer fragments spreading more extensively to present a smoother surface that causes less severe lacerations of the face and scalp. Figure 16 illustrates the more rounded shape into which the glass deforms on impact.

Pedestrian Protection

In the European countries up to 40 percent of all road deaths are pedestrians. More and more attention is thus being given to this
Figure 11. This illustrates a further example of the problem of persons of short stature, that is, the belt bearing against the neck, presenting an uncomfortable situation.

Figure 12. One manufacturer’s solution to the problem shown in figure 11. The belt can easily be removed from the guide by the occupant. In event of impact the guide pulls away from fixing.

Figure 13. Further detail of the installation shown in figure 12.

ENERGY

In all countries, road transport of people and goods is essential to the creation of national wealth, and road vehicles depend upon petroleum fuel because of its high energy density.

The world is using up its fossil fuel store at an increasing rate, but, because the fuel cannot be replaced, it should be conserved until science has learned to replenish our resources, converting the sun’s energy into a usable range of fuels for transport and other purposes.

Conservation programmes must emphasise efficient and appropriate applications of the different forms of fuel. For example, electricity, however generated, is efficiently and appropriately used for domestic and industrial application. It is not suitable for transportation, except perhaps for railroads, whereas liquid fuels, such as are derived from petroleum, are the most appropriate for road vehicles due to their high energy density and ease of handling within the existing distribution system. For this reason petroleum fuels
should be conserved for road transport and for portable power applications.

Coal and gas are most readily applied to stationary installations and are not well suited to portable uses. Exotic fuels such as hydrogen are not readily adapted to road use but could more easily be used in future for stationary applications.

If petroleum-based liquid fuels were to be conserved for road transport and other appropriate applications, the period would be considerably extended during which road vehicles could operate on the same principles as are in use today.

Depending on the extent to which this policy is applied, the period before alternative fuels become essential to road transport will be extended by a factor of up to five, since road transport uses less than one-fifth of the world’s consumption of petroleum products and dedication of all those products to road transport and portable power use could extend the availability of those products by the amount indicated.

Adopting a different hypothesis, if all use of petroleum products for road transport were to be reduced by 25 percent, this would result in a reduction in overall petroleum use of about 4.5 percent, which is virtually insignificant in total oil resource conservation terms. It is clear that reductions in the use of petroleum products for other than road transportation purposes must be the first concern of world energy conservation programmes.

At the same time, it is clearly highly desirable to conserve transportation energy as a contribution to overall energy conservation programmes, both for economic reasons and to defer the need to change to more expensive
Examples have been shown here for the United Kingdom, the Common Market countries, the United States of America, and Japan. From the table we see that the Common Market and the United Kingdom have a similar pattern of road fuel use, that is, in 1975 about 0.29 tonnes of gasoline per annum per person. In the United States the consumption was 1.35 tonnes per annual per person, that is, 4.66 times the European average.

Fuel conservation in the United States becomes a matter of concern for the rest of the world. An objective of 40-percent saving has been proposed, and it is interesting to see that in 1975 this would have been 127 million tonnes, almost equal to the whole of the road fuel consumed by the 250 million people of the EEC plus the 105 million people of Japan.

Against this background the Research Safety Vehicle programme is highly significant with its emphasis on economy of operation and use of energy. It has been stated elsewhere that the energy consumed to manufacture a car such as the RSV will be...
approximately one-tenth of the total energy used as road fuel during the lifetime of that car. Vehicle weight is the principal factor governing the total amount of energy used to construct and propel the car, and for this reason it must be concluded that every effort should be made to reduce the weight of future cars. To this end each legislation requirement that may add weight should be very carefully evaluated for its effectiveness since it will inevitably cause a fuel penalty.

ENVIRONMENT

Exhaust Pollution

In accordance with other member countries of the Common Market, the United Kingdom has adopted the exhaust emission regulations applicable to petrol-engined motor vehicles as established by the United Nations Economic Commission for Europe and now incorporated in the relevant EEC Directive.

Background to the Air Pollution Problem in the United Kingdom

A survey by the United Kingdom Department of Industry during 1972 (shown in table 6) identified sources of pollutants.

Table 6. United Kingdom air pollution sources

<table>
<thead>
<tr>
<th>Source of pollutant</th>
<th>CO (%)</th>
<th>HC (%)</th>
<th>NOx (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>48.7</td>
<td>37.7</td>
<td>20.9</td>
</tr>
<tr>
<td>Domestic</td>
<td>24.4</td>
<td>Very low</td>
<td>4.6</td>
</tr>
<tr>
<td>Industry</td>
<td>9.7</td>
<td>40.6</td>
<td></td>
</tr>
<tr>
<td>Town gas process plants</td>
<td>0.1</td>
<td>Very low</td>
<td>34.0</td>
</tr>
<tr>
<td>Petroleum refineries</td>
<td>2.6</td>
<td>21.7</td>
<td></td>
</tr>
<tr>
<td>Power stations</td>
<td>14.6</td>
<td>Very low</td>
<td>40.5</td>
</tr>
</tbody>
</table>

From this table it can be seen that there are other sources than transport that are contributing significantly to pollution of the environment. Legislation to reduce motor vehicle pollution was introduced in the United Kingdom in 1972. The full effects of this will not be seen until the 1980’s, but we believe that it will make significant reductions in the proportion of pollutants contributed by road transport; therefore, it is considered that more stringent measures, beyond those recently agreed in Europe, cannot be justified.

The United Kingdom motor industry is of the firm opinion that, prior to any further lowering of the limits, there is good justification for the establishment of a European air quality standard against which future regulations should be determined. It should be this
approach that justifies required emission regulation levels and the timing of their introduction.

If regulations were to be introduced for a further reduction in exhaust gas emissions limits without regard for the lead time necessary to establish favourable cost/benefit terms, then, dependent upon what levels may be established, difficulties will be presented to both manufacturer and motorist in that to some extent:

1. Drive quality will depreciate further; a situation unlikely to be tolerated by the customer and which may of itself constitute a safety hazard.
2. Petrol consumption will increase significantly and with fuel costs currently rising at a greater rate than real income, this imposes an additional cost burden upon the motorist, with obvious political implications.
3. Vehicle performance will decrease by comparison with previous model years, and despite the viewpoint in some quarters, performance characteristics are still a major selling feature of a motor vehicle.
4. The initial purchase price of the vehicle will increase.
5. The more complex emission control systems are likely to affect the cost of ownership through increased service charges.

Noise Pollution

The principal pollutant other than exhaust emissions of concern to the automobile industry is that of noise.

Within the EEC, the Government of the United Kingdom continues to press for lower noise levels, and on 5 July 1974, a draft Council directive was published setting out lower noise levels to come into effect on 1 October 1976. In spite of this pressure these lower levels have not been ratified and no date has been fixed for their implementation.

In anticipation of the proposed lower levels, United Kingdom industry carried out the necessary development and made significant capital investment to meet the 1976 date. However, as a result of the failure of the Council of the EEC to publish firm legislation, development in the United Kingdom has generally been put in abeyance because the previously developed noise reduction specifications may no longer be compatible with projected vehicle designs.

Table 7. Existing and proposed legislation to control the noise emitted by new passenger cars

<table>
<thead>
<tr>
<th>Country</th>
<th>Legislation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing</td>
</tr>
<tr>
<td><strong>European Economic Community (EEC):</strong></td>
<td></td>
</tr>
<tr>
<td>Limits in dB(A):</td>
<td>82</td>
</tr>
<tr>
<td>Test method</td>
<td></td>
</tr>
<tr>
<td>Acceleration test in Directive 70/157/EEC</td>
<td></td>
</tr>
<tr>
<td><strong>Japan:</strong></td>
<td></td>
</tr>
<tr>
<td>Limits in &quot;phon&quot;</td>
<td>84</td>
</tr>
<tr>
<td>Equivalent to dB(A)</td>
<td>-</td>
</tr>
<tr>
<td>Test method</td>
<td></td>
</tr>
<tr>
<td>Equivalent to EEC</td>
<td></td>
</tr>
<tr>
<td><strong>United States (most stringent State requirement):</strong></td>
<td></td>
</tr>
<tr>
<td>Limits in &quot;phon&quot;</td>
<td>80</td>
</tr>
<tr>
<td>Equivalent to dB(A)</td>
<td></td>
</tr>
<tr>
<td>SAE J986a</td>
<td></td>
</tr>
</tbody>
</table>

[a] EEC and SAE limits are both based on acceleration tests, but there are significant differences in the test conditions, notably the distance of the microphone from the vehicle path, which is 7.5 m (24.6 ft) in EEC and 15.2 m (50 ft) in SAE. The effect of the differences varies from one model to another, but in general noise levels recorded in SAE tests are 4-6 dB(A) lower than in EEC, except for certain high-performance cars that are tested in first gear for SAE as opposed to second gear for EEC.

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The present status of noise legislation within the EEC is that a proposal is being considered that would maintain generally the reduced noise levels set out in the Council's draft, but introduction would be deferred until 1980, provided the noise levels are confirmed by October 1976.

In the United States there are no comparable Federal construction regulations although the EPA is known to have test proposals under consideration. However, many States and cities have local legislation. In addition there are "in use" standards amongst which are the "Interstate Motor Carrier Noise Emissions Standards." These standards for both drive-by and stationary tests came into effect on 5 October 1975 and are understood to be strictly enforced.

Table 7 gives a comparison of the legislation in the EEC (Common Market), Japan, and one American State's requirement (that are considered the most stringent).

Considering the long experience of noise control legislation in Europe, it seems unfortunate that the United States is developing unique legislation. It would seem logical and highly desirable that EEC and United States legislation should be harmonised, preferably based on the International Standards Organisation (ISO) and United Nations methods.

ECONOMY

Earlier in this report we drew attention to the importance of the 1,000-2,000-cc vehicle class. The objectives of the EEVC programme and continuing developments in safety-oriented legislation together with pollution control measures all tend to add weight to the automobile. However, the opposite pressures of economics and energy conservation are forcing weight reductions on the industry, thus, weight control is becoming of paramount importance.

Reduced vehicle weight results in lower running costs, so an overall vehicle design aim is to produce the lightest vehicle that current technology will allow. Weight reductions are generally accompanied by cost reductions. Opportunities to save weight are created in many ways. More sophisticated design analys

sis methods can show areas where savings can be made, but more obvious methods involve the use of alternative materials.

One of the most promising recent developments involves the use of high-strength low-alloy steels (HSLA) and investigations are proceeding in several companies. Many questions need to be answered before HSLA can be directly substituted for mild steel. Investigators are trying to establish differences in welding behaviour, corrosion resistance, work hardening, crush behaviour, and so forth. It would appear that a large number of panels could eventually be made in HSLA with considerable weight benefits and few cost penalties.

There are other ways of reducing weight, the easiest being, of course, the use of lightweight materials such as aluminum and plastics.

The use of aluminum in place of cast iron or steel can, in some cases, reduce cost. This is where the initial cost of material is offset by the lower fabrication cost, but, unfortunately, this only applies in a limited number of cases. Aluminum dye casting can result in cost savings because less machining is required, and higher production rates are possible.

The benefits of good weight control are improved performance, fuel economy, cost savings, and in the case of load carrying vehicles, maximum payloads. Thus weight control is becoming increasingly important for emission control and fuel economy.

CONCLUSIONS

Safety

In Britain, 75 percent of vehicles recently registered have an engine capacity between 1,000 and 2,000 cc. They have weighed between 800 and 1,200 kg compared to the target of 1,364 for the 3,000-pound RSV. It is for this reason that the EEVC proposals, rather than those for the RSV, seem to most British manufacturers to be more suitable to European conditions.

When tested in accordance with the proposed EEVC procedures, many current cars can meet most of the requirements if suitably strengthened.
The wearing of seatbelts is the most cost-effective way of saving lives. Many European countries have made seatbelt wearing mandatory, and all manufacturers continue to make considerable improvements in the comfort and convenience of seatbelt wearing.

Energy

Many alternative fuels have been considered for motor vehicles but none is able to match petrol or diesel fuel for energy density and convenience. For example, solid or gaseous fuels and electricity are more suitable for stationary applications. For this reason we recommend that petroleum fuels should be reserved for road transport and other portable power applications.

Vehicle weight is probably the single most important factor affecting energy consumption both in the manufacture and use of vehicles.

Environment

Emission control legislation in the United Kingdom and Europe will not show its full effect on air quality until the 1980's as older cars are replaced. When this process is completed the contribution of motor vehicles to air pollution will be very much reduced relative to other sources. For this reason the need for further reductions in automotive pollution standards should be fully demonstrated before proposing to increase their severity.

More severe emission levels would be likely to result in increased fuel consumption.

Vehicle noise controls are based on different test methods in Europe and the United States, giving different meanings to the indicated values. We recommend that the test methods should be internationally standardised on those developed by the ISO.

Economy

Vehicle weight reductions give economies in running costs and the consumption of materials. In Europe, car weights are already substantially below those of American models, and vehicle manufacturers will continue to give high priority to weight control. We recommend that government agencies in all countries review current and proposed legislation to ensure that its effect on vehicle weight is minimised.

Effect of High Pressure Hydraulic Systems on Primary Safety

M. J. J. DE LASSUS
General Delegate of Citroen Car Corporation

INTRODUCTION

During the previous international conferences on Experimental Safety Vehicles (ESV), which Citroen closely took part in from the beginning, our company steadily reported on its work in progress and its experiments, performed with the agreement and financial assistance of the French Government, according to the program it established in 1968, entitled “Experimental Safety Sub System” (ESSS). This program was based on the study of subassemblies and partial structures of European-type light vehicles and the restraint systems that can be fitted to them.

The resulting cost/efficiency of this realistic and rational program enabled us to immediately apply the developments of research and experimenting to our mass production vehicles (GS-CX). Our research especially concerned itself with the difficult problem set for vehicles with small overall length by the optimum absorption of energy in cases of frontal impacts. It is, therefore, worth remembering that from now on, automobile customers have the opportunity to take advantage of this acquired knowledge.

In view of the targets set by the ESV program, it seems advisable today to leave the field of passive safety and briefly show, in a technical film, the devices adopted by Citroen that have been perfected and developed to increase the qualities of active safety in their
suspended in practice since 1953, in a field that gives our production a particularly individual character.

First, our automobiles possess exceptional qualities of road-holding, thanks to a highly increased road grip due to the possibility of reducing, by approximately 50 percent, the specific frequency of suspension when compared to the frequency of a standard suspension with metal springs. This also improves the comfort of the passenger.

As for braking, the fitting of a high pressure circuit and appropriate controlling of its delivery allows, together with an optimum determination of braking power with a minimum of response time, an adjustment as perfect as possible for proportioning the braking force on the front and rear axles according to the implied loads.

And last, the mastery of hydraulic engineering, always working with the presence of a high pressure source, enabled Citroen to work out a power steering where both the steering-turning force and the return to a straight line of steering are a direct function of the speed, thus contributing to driving without effort at very low speeds (parking, town maneuvering) and to optimum road-holding during highway use. On the most unfavorable roadbeds, this is accomplished with the help, if necessary, of an alteration in compact and full-sized vehicles. These devices include the use of hydraulic engineering applied to suspension, braking, and, for some of our models, to power steering.

However, I have to emphasize the three following advantages that have resulted from our unceasing technical development, never

Figure 1. More than 2,000,000 vehicles are equipped with high pressure hydraulic systems.

Figure 2. Pump pressure and discharge.
As far back as 1953, high pressure hydraulic systems have been used in mass production on the rear axle suspension of the “15 Six H” vehicle. High pressure hydraulic systems have been applied since 1955 to the suspension and brakes of such vehicles as the DS, SM, GS, CX, and to the brakes of some light trucks, as well as to the power steering and gear shifting of some of these vehicles. Constantly improved, these systems benefit from our experience in building more than 2 000 000 vehicles and they have reached the highest level of quality and reliability (fig. 1). Furthermore, it is essential to point out that the whole of these technical attainments (at present demonstrating perfect reliability) is the result of research work, developments, and testing that lasted for a long time but enabled very important progress in the field of vehicle active safety and quite reasonable terms of cost/efficiency.

PRESSURE SOURCE AND PRESSURE ACCUMULATION

The engine of the vehicle actuates a variable flow high pressure (HP) pump which is fed from a tank by a type of mineral oil and forces it into a main accumulator through a pressure regulator.

When the pressure in the accumulator reaches 170 bars, cut-off occurs, and then the pump discharges, without pressure, into the tank (fig. 2).

During use, when the pressure in the accumulator drops to 140 bars, cut-in occurs and the pump discharges again under pressure into the accumulator. A safety valve enables feeding by priority “front brake” and “steering” functions (fig. 3).
USES OF HIGH PRESSURE HYDRAULIC SYSTEMS

Ground Connection—Suspension

Each one of the independent wheels is connected to the body by means of a hydro-pneumatic device whose volume of pre-compressed gas is submitted to pressure changes according to the vertical load on the wheel (fig. 4).

The great flexibility obtained with gas springs, combined in the hydro-pneumatic unit with a system of valves providing immediate damping, allows a natural frequency of suspension approximately two times lower than that currently achieved with metal springs.

Having achieved great suspension flexibilities, the height of the vehicle would be particularly sensitive to load changes; an automatic level-compensating device makes up for the effects of these changes by modifying the volume of fluid left in the hydro-pneumatic components (fig. 5).

The automatic height control by keeping the level of the vehicle and the ground clearance constant provides the maintenance of the qualities of comfort and of road-holding whatever the load conditions. The ground clearance can be manually adjusted by means of a lever within the driver’s reach (figs. 6, 7).
A middle position increases the clearance under the body by approximately 40 mm, thus allowing driving on some difficult roads. A high position increases the clearance under the body by approximately 100 mm. This position can be used especially for driving at low speeds through particularly difficult spots. This position also enables an easier tire replacement.

Braking

The feeding of the four disc brakes, controlled by a small travel of the pedal, allows reducing the time of response of the braking system. The pressure on the brakes reacts on the pedal, and thus achieves a constant ratio between the effort on the pedal and the pressure acting on the brake components. The braking power is not proportional to the pedal travel, but only to the force applied to it by the driver (fig. 8).

As front- and rear-brake circuits are independent, on the European-type vehicle the rear-brake circuit is fed from the rear suspension pressure, thus relating directly the maximum braking pressure on the rear axle to the load that is applied to it (figs. 9, 10).

In the case of maximum braking, the pressure supplied for front brakes will be the
pressure prevailing in the front-brake accumulator; for rear brakes, the pressure prevails in the rear suspension. It is possible to split these two circuits according to the standards in force in the interested countries.

Declutching Control

The control cylinder, connected to the pedal, generates a low pressure that controls a high pressure balancing device, integral with the receiving cylinder. This system allows a reduction of approximately 40 percent in the force required to activate the clutch pedal and of 15 percent of its travel (fig. 11).

Power Steering with Power-Centering Device

The control unit achieves the assistance of the rack and pinion according to the impulse given to the steering wheel. A centrifugal governor adjusts the return-to-straight-line system and the steering force according to the road speed.
speed of the vehicle. This force is also dependent upon the rotation angle of the steering wheel. At low speed, the force required for steering the wheels is negligible, and they come back by themselves to a straight line when there is no more force applied to the steering wheel, even when the vehicle comes to a standstill. This salient feature provides great ease in parking maneuvers, as well as an increase in safety when driving with low adherence of the wheels. The return-to-straight-line system gives the vehicle a good trajectory holding, even on a steep-sloping road. This centering in a straight line gives the impression of a vehicle guided by a rail, all the more as the vehicle is running rapidly (fig. 12).

For every position of the steering wheel, the steering is not influenced by the external forces applied to the front wheels, for instance, the bursting of a tire, or an unbalanced left hand/right hand braking. The combination of these exclusive features allows a low steering ratio (2-1/2 revolutions of the steering wheel from stop to stop) that enables the driver to react faster and more efficiently in case of emergency (fig. 13).

Brake Anti-Locking Design

When braking efficiency is no longer influenced by the consumption of fluid under pressure, it is easier to use an anti-lock device since the problem of re-feeding brake components during actuation of the anti-lock device is avoided.

CONCLUSIONS

- The very high pressure used permits the use of small size components.
- Gas springs under high pressure have a small volume.
- The working parts being separated by a film of oil constantly under pressure have an almost unlimited lifetime.
- The contribution of high pressure hydraulic systems to the field of primary safety can be summed up in the following manner:
  - An extremely high level of comfort, and the possibility of backing up components that require appreciable strength, thus reducing considerably the user's fatigue
  - A very good road-holding capacity even in very bad driving conditions

Figure 13. Citroen CX vehicle: A synthesis of engineering applications of high pressure hydraulic systems.
— A particularly fast response time of the braking control, although not a fierce one
— Good brake efficiency despite the most difficult circumstances
— Possibility of fast vehicle maneuvering thanks to quick steering response
— Maintenance of the steering angle selected by the driver no matter what the external circumstances

Peugeot Status Report

JACQUES A. DESBOIS
Directeur des Etudes
Automobiles Peugeot

The London conference marked the outcome of the correct formulation of safety problems and technical guidelines for resolving them. Henceforth, the objective is to state the solutions more precisely and apply them to these various problems, while taking account of economic contingencies. This implies, among other things, the research and development of technologies and the choice of test and judgment procedures.

In Europe for instance, the recent symposium of the European Economic Community (EEC) in December 1975 retained the European Experimental Vehicles Committee (EEVC) proposals as the basis for future European regulations in 1980-1985.

There is, however, still much to be done. Although the mechanisms of frontal impact and the various protective measures are well known, it is not the same with lateral impact, compatibility, and pedestrian and cyclist protection.

On this basis, the activity of Automobiles Peugeot in the field of safety has carried on within the following framework:

- The French Government’s research programs: the Actions Thematiques Programmes (Subsystems Joint Research Program) already described by Mr. Frybourg
- The activity of the laboratory for physiology and biomechanics managed by Dr. Tarriere in association with Renault
- Our own works
- The works performed with our CCMC partners to bring out the most efficient objectives on a European basis on as large a scale as possible.

These four achievements complement each other; so as to make the examination easier, we shall quote guidelines for studies, guidelines for future regulations and main results for each research field.

FRONTAL IMPACT

Nearly 10 years ago, we began to study three-point belt protection. Compulsory belt wearing on the road was decided as early as July 1973 by the French safety authorities and has already contributed to the saving of many human lives, reducing the severity of collisions, and slowing the increase of road accidents involving people. These results encourage us to carry on with our work in improving belt protection.

Technical Standpoint

- Investigations of frontal structures whose deformation in various types of frontal impacts provide an optimum protection level for belted occupants. This work is performed within the framework of the French research program.
- Study of the influence exerted by belt characteristics upon the protection level: rigidity, initial play, and anchorage geometry.
- Improvement of belt comfort; for example, the study of constant-stress retractor, and our work aimed at reducing buckle-opening difficulties.
- Determination of actual accident severity by means of the two characteristic parameters, namely, speed variation and vehicle mean deceleration, and the selection of the frontal impact test procedure. This work confirms our choice of the 30-degree fixed-barrier impact as the only test procedure representative of frontal accidents.
• On the same subject, participation in the founding of a national photolibrary whose utilisation should permit estimating accident violence on a nationwide basis by viewing photographs of vehicles taken according to an accurate procedure. The first results are promising. We hope for international cooperation to exchange necessary information based upon preliminary knowledge of each vehicle's performances in conventional impacts at various speeds.

• Finally, we carry on busily with our biomechanical research, especially concerning head and thorax tolerances. Relating to this, we earnestly urge the various experts to come to an agreement, if possible on a worldwide basis, on the definition of dummies, the criteria to be measured, and the tolerance thresholds; an immediate agreement is needed, however, even if it is to be modified in the long run, to avoid the prevailing uncertainty that now prevents any actual progress in vehicle safety.

Regulations

The various regulations now in force both in Europe and in the United States deal with the strength of belt anchorages, belt components, steering column rearward displacement, energy absorption by the steering wheel, and interior fittings. These heterogeneous regulations are to be replaced by a synthetic regulation in the near future.

In this connection, it should be kept in mind that last May, France presented the ISO Sub-Committee 12 on “Restraint Devices” with a draft synthetic impact test standard based on one prepared by the EEVC working group 2. It is to be noted that France, in fact, had already entered upon this course through the publication, in the Journal Officiel of October 17, 1975, of a synthetic test standard for child safety seats.

LATERAL IMPACT

We have completed the work presented in 1974 in London and manifested it in our Safety Synthesis Vehicle (VSS).

1. The sample of lateral collisions that we have gathered is now big enough to permit correct evaluation of the actual impact conditions as well as their severity: we shall present the state of our knowledge tomorrow during the seminar on “Accident Analysis.” It must be stressed that the results presented at the fifth ESV conference in London, among others relating to speed variations and impact geometric conditions, are fully confirmed. Moreover, we should soon be in a position to estimate the speed of barrier impact that results in occupant contact; thus we might express the severity of lesions as a function of actual impact severity.

2. The current state of our biomechanical knowledge will be described by Dr. Tarriere. It must be noted that the head-neck segment of the currently proposed dummies is in no way adapted to the lateral impact configuration.

3. A compromise between the level of reduction achieved for occupant compartment intrusion and the level of protection provided for interior walls is being investigated. In order to appreciate the results of the quality of protection, we simulate lateral collisions between modified vehicles relative to reference vehicles involved in a severe real accident.

Although the lateral impact is not as well researched as the frontal impact, we find it is still possible to improve vehicle performance and we suggest the following approach for regulations in this field:

• In the near term, improve the resistance to side intrusions, for instance, by having the doors act as a chain anchored to the front and rear pillars.

• In the midterm, limit the specific aggressiveness of any new car. To this effect, we shall carry out a collision test between two identical types as proposed by the EEVC working group 2, and we shall check the compatibility between the frontal and lateral structures of the vehicle.

• In the long term, the mechanism of lateral
impact will perhaps be known sufficiently to enable us to substitute a deformable moving barrier for a vehicle to act as an obstacle.

PEDESTRIAN PROTECTION

Since the fifth ESV conference, held in London, our knowledge of pedestrian protection become more precise; our multidisciplinary investigation shows that:

- The most severe injuries are caused by the impact of the head on the vehicle.
- The injuries caused by second impacts against the ground appear less severe than it was first supposed. The impact speed is generally not very high, and there is probably interposition of arms in a certain number of cases.

For these reasons, we have given priority to the study of possible improvements in the dash zone and the installation of the windshield frame.

Our investigation also shows that the bumper has no major influence on severe or fatal injuries of pedestrians, the most severe injuries being those to the head, but in the absence of regulation, the average height of bumpers must not be increased.

The United States applies safety standard 215. We believe that in the other countries and, in particular, the ECE of Geneva, it would be wise to quickly adopt a regulation on the basis of ISO standard 2958. It is only after a comparison of all the studies undertaken on this item a second step could be bumper height to protect vehicles during light impacts while monitoring pedestrian safety.

CONCLUSION

We have briefly expressed our trends and our results regarding the most important items for us: frontal impact, side impact, and pedestrian protection.

We believe that a certain number of provisions could be adopted for protection in the case of frontal impact: 30-degree impact procedure, protection system by belts for the front passengers, and protection criteria. A regulation based on a synthesis test (in the spirit of safety standard 208, or the French proposal to the ISO) could ensure great progress towards occupant safety by applying only what is possible without trying straight away to obtain perfection.

The study of side impact still requires more work on impact procedure, the test means, and the performance criteria to be retained in a standard.

If the ESV/RSV conferences have produced very interesting comparisons on the solutions to be provided for the problems arising from safety, it has, however, appeared absolutely necessary to treat simultaneously all the consequences of cars on the current environment. Numerous synthesis conferences are organized on this item: Interagency Task Force in the United States, European Symposium in Brussels, and the United Nations Environment Program (meeting held at the beginning of October 1976 in Paris). We wish that an international organization could be created to space correctly these conferences in order to balance the participation of experts from the whole world.

I do not want to end my presentation without pointing out a study that we have undertaken on the protecting of rear passengers in frontal impact and allowing them, at the same time, complete freedom of movement, contrary to belt protection.

Certain governmental officials may be tempted to extend simply and solely the compulsory wearing of belt to rear seats.

However, this does not appear obvious to us for at least three reasons. First of all, the use of the rear seats is quite variable; the users are in diverse age and size, and, finally, the risk of injury is a little less for rear passengers than for front passengers even when belted.

We have achieved a passive protection system integrated to the passenger compartment and favouring the comfort of individual transport. A film on this achievement will be shown tomorrow morning during the seminar entitled “Structure Properties and Occupant Protection.”

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Our example should be considered as an attempt to safeguard the service rendered by the vehicle while protecting the passengers. We wish that regulations could be limited only to specifying requirements for performance, and that the choice of technical solutions adapted to the types of vehicles would be left to the manufacturers.

Renault Status Report

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Since the first meeting in Paris in January 1970, Renault has participated faithfully, actively, sometimes critically, but always constructively, in all international Experimental Safety Vehicle (ESV) conferences.

During the period of 1970-1976, Renault not only attended the meetings of the ESV program, but contributed to most of the international meetings dealing with the protection of automobile occupants in collisions—meetings such as those of the National Motor Vehicle Safety Advisory Council, the Society of Automotive Engineers (SAE), and notably the Stapp Car Crash Conference (STAPP), the International Research Committee on Biokinetics of Impacts (IRCOBI), the American Association for Automotive Medicine (AAAM), Occupant Protection, and so forth. Let us note, if only to be complete, that some of the work presented was well received, and, indeed, rewarding.

This active participation in international debates on occupant protection represented for Renault an important allocation of intellectual, material, and financial resources. In fact, since 1970, approximately 100 persons each year have worked on the various research programs; the expense involved has amounted to approximately 70 million francs per year, and the total investment in test methods for 6 years has risen to 17 million francs.

All of this work, research, study, and testing was conducted with the strict logic that was demonstrated during the second ESV meeting at Stuttgart in 1971. This logic involved studying first chronologically, then simultaneously, all kinds of accident statistics, national and international; intensive multidisciplinary investigations of on-the-road accidents; theoretical, biomechanical, and technological research; the study and formation of subgroups to answer problems that arose; and finally to the study, building, and testing of a complete vehicle, the BRV. Our aim for the BRV was to try to synthesize solutions discovered in terms of industrial and economic reality and to represent a kind of pre-Research Safety Vehicle (RSV). Parallel to this work, an extensive test program was developed to analyze the behavior of many different types of vehicles in varied impact conditions: barrier, offset, point of impact, and speed.

Part of the research work was conducted under contracts from the French Government, within the framework of "Actions Thematiques Programmees." Under this program, about 20 contracts for a total of 7.8 million francs were awarded, of which at least 50 percent of the financing was underwritten by the industry.

Renault's participation in the extensive safety research program was not confined to the scientific field. Realizing that "real world safety" is not entirely commercial, at least on a large scale, but that it would be nevertheless intolerable to do nothing in the face of the epidemic of automobile accident fatalities, we believe that only regulation can lead to progress in the protection of road users. Regulation puts manufacturers on equal footing to meet a minimum level of protection, and it makes the occupant the involuntary, or not completely aware, beneficiary of this protection.

In this regard, regulation must first be effective, and to that end, must take account of reality. Regulation must also be socially acceptable, and to that end must be selected judiciously from the various types of accidents to be considered and the level of protection to be attained.

In this spirit, Renault also participated in the international harmonisation to define future regulation, supplying the knowledge
we had acquired either in the form of research results, or proposed test methods and judgment criteria. But this participation did not exclude criticisms of certain tendencies either to regulate an area so that the legislator simply has the satisfaction of having regulated, or to accord more importance to the details of the regulation (accuracy of measurement, test conditions, and so forth) rather than to the actual foundation of this regulation. This latter tendency is both troublesome and unnecessarily costly, and is akin to the case of a machine that punches holes to one thousandth of a millimeter in diameter, but one centimeter next to the location where the hole should really be.

What is the use of regulating in detail a particular type of collision where such regulation involves vehicle modifications and difficulties in conducting the test under the conditions prescribed by law, if no one, or almost no one, is killed or injured under the prescribed conditions, which rarely, if ever, occur on the road?

It is, therefore, with this same regard for effectiveness and realism that we take this opportunity to specify once again the conclusions we have arrived at on the principal subjects still being debated today.

THE TYPES OF TESTS

We have often stated and written, and continue to do so today, that the only logical method is to deal with accidents in the order of their statistical importance, and that effectiveness will depend on the realism with which they are analyzed and treated.

Frontal impact

If we take the case of frontal impact, we see, for example, that most of the detailed international statistics (one is surprised at the relatively low input of data from the United States) show that the great majority of accidents, about 70 percent, are asymmetrical collisions. It therefore seems strange to us to emphasize progress in occupant protection for this type of collision by retaining a symmetrical test and increasing the test speeds to heighten severity. We uphold the position of the CEVE, presented in London in 1974, which abandons the orthogonal, therefore symmetrical, frontal test in favor of an asymmetrical collision at 50 km/h. We point out, in passing, that among the possible approaches to carrying out such a test we are firmly convinced that the test that achieves the best severity compromise for structure-severity for the restraint system, to come as close to reality as possible, is the frontal impact against a fixed barrier at a 30-degree angle. Progress first must be achieved at this stage, and only then can an increase in the test speed be envisioned.

We devoted our work to a detailed analysis of the behavior of vehicles and restraint systems in this type of impact, and the results of this work will be presented during the seminar on "Crashworthiness." Our studies on the distribution of fatalities with relation to impact severity have shown us that the Equivalent Barrier Speed (EBS) method of classification (based on the amount of energy dissipated only by the vehicle under study, without considering the characteristics of the obstacle) could only result in an erroneous understanding of reality. Also, we have developed an analysis method based on speed variation and the average deceleration of the vehicle studied, which necessarily implies an understanding of the characteristics of the obstacle. This method, applied in our accident investigation, has shown us that 95 percent of frontal impacts that involved fatalities or severe injuries were produced for a speed variation equal or lower than 70 km/h.

We then designed, built, and tested an experimental vehicle, whose goal was to verify the possibility of protecting automobile occupants in an asymmetrical collision against a fixed, 30-degree angle barrier, at an impact speed of 70 km/h, and to do this with an acceptable cost increase.

The very favorable results of this test, conducted by Calspan laboratory under contract to the National Highway Traffic Safety Administration (NHTSA), showed us that we can consider our research work accomplished on this point even if the technological solutions are not yet all industrialized today, particularly for pretensioned belts.
The only difficulty remains in the choice of active or passive restraints. While we do not consider it our place to take a position in this political choice, we must once more affirm that, contrary to what some uninformed people still insist, the air bag provides a gain in protection performance only in the case of the pure orthogonal frontal impact and for an occupant well centered in his seat.

Moreover, it seem important to again point out that contrary to numerous claims, the air bag is not the best solution for small vehicles. In fact, small vehicles by definition have only a short stopping distance, and the time necessary for air bag inflation is incompatible with the time required to halt the movement of an occupant in the passenger compartment with a realistic restraint force. In the best of cases, about 35 ms are necessary for the air bag to activate, and during this time nearly 400 mm of the vehicle was deformed at 50 km/h, while a pretensioned seatbelt can easily be activated within 15 ms therefore after only 180 mm of vehicle deformation, still at 50 km/h.

Lateral Impact

We could next go on to review all the types of tests anticipated to criticize them, but that would take too long and be out of place here. It is more important to understand the spirit in which this criticism is made. If, for example, we nevertheless say a few words about what is anticipated in the United States regarding lateral impact, we could show evidence of another error into which regulation easily falls—choosing a type of test because it is easy to perform. The test with moveable, flat, rigid, and high barriers—even though 80 percent of all lateral impacts are car-to-car collisions—has absolutely no chance of being close to reality. This resembles the case of a man who having lost his keys under a broken street lamp looks for them under the next lamp because it is lit, and it is easier to look for something in the light.

However that may be, the more knowledge about this type of collision increases, the more we are convinced that if high levels of protection in this type of collision are to be achieved, the technological solutions will be of huge consequence for the automobile: weight, price, exterior bulkiness, and decrease in service provided. Moreover, it is certain that to be effective it will not be enough to reinforce the structure but there must also be the means to limit occupant acceleration. This cannot be done without sacrificing passenger space and increasing weight and cost.

It is thus more important in this case than in any other to attack the problem in a realistic way in the choice of the test mode and in the setting of severity levels and judgment criteria. It is also necessary to be aware that to want to take too great a step right away can lead to either dooming numerous existing vehicles, or to postponing the effective date. A middle approach exists, which consists of subjecting entirely new vehicles manufactured after a certain date to regulation.

The route proposed by the CEVE in London to establish a control test for this type of impact seems to us, here again, realistic and pragmatic. Without waiting for the ideal test method that would be realistic, simple, and repeatable, the impact test between two identical vehicles can already permit achieving progress while encouraging manufacturers to improve not only lateral resistance but also to reduce frontal aggression. During this time, the development of a deformable and appropriately shaped movable barrier could proceed calmly.

The Laboratory of Physiology and Biomechanics of the Association Peugeot-Renault has conducted scrupulous investigations on this type of accident within the framework of our inquiry. An important point of this work will be presented during the seminar on “Analysis of Accidents.”

JUDGMENT CRITERIA

Unanimity is now almost complete on the judgment of control test results by criteria, whether they be called injury or protective, measured on anthropomorphic dummies. But here, too, the way certain criteria have been defined and levels set can be criticized. Regarding the head, for example, the Head Impact Criteria (HIC) is an attempt to formulate the Severity Index (SI) as defined for impact condi-
tions, without any relation to what can happen inside an automobile, and its value did not have the same biomechanical meaning as has since been attributed to it. Even if the HIC achieves a better compromise between the deceleration level and the duration of the impact, the value adopted, identical to that of the SI, does not seem to be based on solid biomechanical data. It seems to us desirable and possible to define a new criterion, which could be called Head Protection Criterion (HPC), whose limit, calculated by the HIC method, would be set at 1500. We do not propose this value by chance, or because we do not know how to obtain the value of 1000. We know today, in fact, how to experimentally obtain results much lower than these values under conditions clearly more severe than the 50-km/h impact. We propose 1500 because, during the course of biomechanical research conducted by our physiology and biomechanics laboratory (in collaboration with Assistance Publique Francaise and the Institut de Recherches Orthopediques, and to be presented during the “Biomechanics” seminar), we have become convinced that this value is still a survival limit.

One could counter this position saying that even though 1500 is a survival limit, 1000 is still better and probably saves even more occupants. There can be many answers to this type of argument, and always in a practical and realistic spirit. The first is that it is better to have a judgment criterion perhaps a little less stringent but for a test covering 70 percent of real world accident cases, than to have a criterion a bit more stringent for a test that involves only one-fifth or one-quarter of real world accidents. A second reply is that the technological solutions at the total production level do not have the same industrial availability leadtimes. There again, the realistic course in our eyes is to prefer 1500 today rather than 1000 the day after tomorrow. It can be pointed out in this regard that it is very true that to want too much, too soon, often leads to having nothing for a long time. For example, the desire in 1973 to put into effect an advanced regulation for occupant protection based on passivity and strict protection criteria never materialized because neither the necessary knowledge for success nor the technology required had reached a sufficient stage of maturity. This has had two consequences. The first is that 3 years later, there are no more aggregate tests in the United States than in Europe. The second consequence is that American manufacturers, polarized on the technology of passive restraint systems, have not made the progress in seatbelt technology that they could have.

During this time more and more countries were utilizing, pragmatically, and realistically, that which they had readily at hand—that is, seatbelts, thereby saving many human lives.

EFFECTIVENESS AND COST OF REGULATION

It is disappointing for everyone to find out after the fact that a regulation was ineffective. And it is only today that official studies in various countries have shown the ineffectiveness, or even the unfortunate effect, of certain regulations. Each time that we asked ourselves the reasons behind this ineffectiveness, the answer was always the same: lack of adaptation to real world road conditions. But since the reason is known, why retain an unsuitable regulation? Whatever the reason, and if it can be understood that regulations established in the past with an obvious lack of data did not have the anticipated effect, it is unthinkable that with the methods presently in use and the knowledge already acquired, future regulations may be bound to continue in the same rut as they are today. To be concerned with the cost/effect ratio is first to be concerned with effectiveness.

It follows that that is not enough for choosing a realistic track. Faced with the cost aspect, two different attitudes have appeared. One consists of wanting an all-encompassing protection, even if certain accident cases represent only a small percentage of the total; and in this case, either one wants a sufficient level of protection and the aggregate cost is enormous, or else one wants all the same to limit the aggregate cost and the general level of protection attained is small. A second attitude consists of asking oneself what it is possible to do to affect the maximum number
of road users for a given sum. In this last case, and if it is assumed that by definition one has chosen effective regulations, the best chances are brought together to obtain a good cost/effect ratio. Unfortunately, practice shows that "extra-scientific" elements often enter into the picture to disturb this simple and logical reasoning.

PEDESTRIAN PROTECTION

In another area, pedestrian protection will be, in the future when analyses in progress throughout the world are completed, a problem difficult to resolve technologically. In fact, knowledge already acquired, although incomplete, shows that bumpers are far from being the only determining element, and that the entire front of the vehicle up to the upper part of the windshield may be involved. There again, and because the problem is a difficult one, the formulation of regulatory measures to be taken to increase pedestrian protection can come only from a logical analysis of real world road conditions and meaningful parameters of the mechanics of pedestrian impact and their consequences. For example, we had thought at the beginning of our work that a large vehicle with a high, long, American-type hood would be the most aggressive for a pedestrian. After conducting some tests, it was established that this was one of the best shapes for the front of the car among all those tested.

Once the problem has been discerned, the choices of the levels of protection must be made with great technological and economic realism.

COMPATIBILITY

Very early in the beginning of the ESV program we brought out the problem of aggressivity or of the compatibility of vehicles among themselves. After a phase of analysis of the problem in its physical and mechanical aspects, we entertained thoughts in two directions: to define a method for verification and to define a compatibility level to aim for. This last, far from being achieved as yet, has already shown us that even if the problem is mechanically real its statistical weight still needs to be evaluated. In fact, examination of the distribution of accidents by type of obstacle shows that in France, for example, if 68 percent of frontal impacts occurred between two vehicles, they would only represent 29 percent of the fatalities, while 13 percent of impacts with a fixed and rigid obstacle cause 40 percent of the fatalities, and this for all collision angles mixed together.

BIOMECHANICS

The last field, nontechnological, where progress is still to be made, is that of biomechanics, that is, the field of knowledge of human tolerances of different types of impacts. We have today enough data to begin to do something in this area. But let us say that while we have a good chance of protecting a 50th-percentile, 30- or 40-year old in good health, we are no longer sure of what we are doing for very different sizes or for older persons. This last concern is purely humanitarian and has no relation to any afterthought of cost/effectiveness. In fact, an American study published last year evaluates the cost of a fatality at $170 000 for a 30-year old, and only $500 for an 85-year old! This being the case, we think that although today we have the means to work, it will be necessary in the long term to replace the present thorax deceleration criterion with a deflection criterion and to specify the tolerances for lateral impact.

CONCLUSIONS

These are our principal thoughts, prompted by reflecting on the state of road user protection. But, in truth, it is easy to state that there is nothing new in all this. And that is the most paradoxical. In fact, this means that the continued growth of statistical knowledge, the continued increase in the number of real world accident cases analyzed, the ever-larger number of impact tests conducted, and the ever-greater precision of our

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technological or biomechanical knowledge have only reinforced our conclusions drawn from previous work and permitting the start of research on progress following a sane and realistic, therefore efficient, course. These conclusions concern, for example, the distribution of severity by type of accident, interest in making available analysis methods and accident classifications resting on indisputable physical bases, or the lack of representativeness of certain tests required by regulation.

We are not certain of always being right, but we take great care to verify our conclusions. For this, the road laboratory, that is, our accident investigation, is the safety barrier of our work. We continuously compare our research and test results with what is actually happening on the road, and we constantly try, through theoretical work and tests, to understand and explain what we have been able to find on the road. This has led us to modify some technological components of our vehicles. For example, we have several times redesigned the energy absorber, which equips the retractorless seatbelts of our European vehicles, in relation to our increased knowledge of biomechanics, our test results, and our road observations. We think we have demonstrated that we were not prorearguard combat, and that we know how to be constructive critics. But we know, too, that our role can only consist of providing the results of our research. The final decision does not belong to the industry, and it is perfectly normal that it should be so. However, if the political and economic decisions are difficult to make, this is not a reason for the industry to continue to participate in discussions on points where it has nothing very new to say. We believe that the industry must concentrate its efforts on the problems that are still difficult to solve. Industry can only deplore decisions that take into account neither the reality of the facts, nor logic, nor physical laws. And unquestionably, it is the community as a whole that will bear the economic and social consequences of the decisions made.
Compatibility of Passenger Cars in Road Accidents

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INTRODUCTION

The definitions of passenger car compatibility and engineering concepts designed to achieve compatibility should be evaluated using the following criteria:

- Higher compatibility must result in fewer injuries and fatalities or, at a given injury risk, in higher values of permissible impact speeds.
- A degree of compatibility has to be defined and must be measurable.
- From a predetermined degree of compatibility, characteristics of compatible cars must be evolved.

COLLISION SEVERITY

Road accident investigations reveal that occupant injury risk basically depends on passenger compartment intrusion, which in turn is related to the deformation of structures outside the compartment, and on the "violence" of the crash, which, in physical terms, is obviously described by the acceleration/time curve representing the collision impulse.

This curve can have an infinite number of shapes. Most of them are not recorded and therefore not subject to analysis. But an indirect evaluation of crash violence should be possible using some basic quantities that characterize the impulse curve as a whole. A general analysis of impulse curves, given in appendix I, indicates that the impulse integral, which equals the speed change \( \Delta V \), the mean acceleration \( a \), and the intrusion \( i \) are suitable to describe collision severity.

CORRELATION OF COLLISION AND INJURY SEVERITY

To describe injury severity as a function of collision severity, we used the linear relation

\[
\text{AIS} = a_0 + a_1 \left( \frac{\Delta V}{V_o} - 1 \right) + a_2 \left( \frac{a}{a_0} - 1 \right) + a_3 \left( \frac{i}{i_o} - 1 \right) .
\]

The coefficients \( a_i \) have to be determined from a representative set of accident data, and the relation must comply with a significance test.

Because the representative data set needed are not yet available, we started with preliminary results of accident investigations including 197 unrestrained front-seat occupants and were able to prove significance by a student's test. The coefficients \( a_i \) were determined using the method of multiple regression (appendix II). It is

\[
a_0 = 3.3655 \quad a_2 = 1.5615 \quad V_o = 48.6 \text{ km/h}
\]

\[
a_1 = 1.5989 \quad a_3 = 0.2227 \quad a_0 = 11.05 \text{ g}
\]

\[
i_o = 0.426 \text{ m}
\]

Based on this equation the probable injury severity can be computed from parameters that are either measured on test vehicles or calculated with mathematical models. Primary importance in this respect is attached to the "crush resistance" of car front structures.
A SIMPLE COLLISION MODEL

To simulate the frontal collision of two cars we utilize a simple three-mass model (fig. 1): $m_1$ and $m_2$ represent the essential masses of the cars except those parts accumulated in the contact zone between the cars during the very first phase of the collision, that is, bumpers, front elements of structure, engine, and so on. It is assumed that these parts, $\Delta m_1$ and $\Delta m_2$, are the same fraction of each total car mass ($m_1^{\circ}/m_2 = \Delta m_2/m_2$) and the combined intermediate mass, $m_3 = \Delta m_1 + \Delta m_2$. Therefore, in the moment when $m_3$ has been fully accumulated, its speed is identical to that of the total mass center of gravity. This moment is zero time for the calculation.

Between the masses, two forces $F_1$ and $F_2$ are at work, the characteristic of which is shown in figure 1. Modifications of the front-end crush resistances are simulated by multiplication of the basic function $F(s)$ with factors $p_1$ and $p_2$:

$$F_1 = p_1 F(s_1), \quad F_2 = p_2 F(s_2)$$

The relief line can start downward from any point on the curve depending on the actual crush value $s_1$ resp. $s_2$. The intrusion is assumed as follows:

$$i = 0 \text{ if } s \leq s_0, \quad i = s - s_0 \text{ if } s > s_0 = 0.6 \text{ m}.$$

INJURY SEVERITY AND CRUSH RESISTANCE

The probable injury severity degrees $AIS_1$ (in car 1) and $AIS_2$ (in car 2), calculated as a function of the crush resistance for car 1 for different impact velocities are shown in figure 2 for two cars with equal mass ($m_1 = m_2 = 900$ kg) and in figure 3 for car mass ratio 2 ($m_1 = 1800$ kg, $m_2 = 900$ kg).

As generally expected, the occupants of a heavy car are less endangered than those of a light car. As also expected, a higher impact velocity means higher injury risk. But surprisingly, at high impact speeds, the injury risk can be smaller with unequal crush resistance compared to equal crush resistance and so can be both for equal and unequal car weights.
We consider this to be the consequence of different motions of mass $m_3$. Figure 4 shows the accelerations, velocities, and “crush distances” plotted against time during collisions at 100 km/h. If both cars have equal masses and crush resistances ($m_1 = m_2 = 900$ kg, $p_1 = p_2 = 0.5$) the curves are symmetrical and $m_3$ is in the midposition between $m_1$ and $m_2$ throughout. If the cars have equal masses but different crush resistances ($m_1 = m_2 = 900$ kg, $p_1 = 0.8$, $p_2 = 0.5$) the curves show significant deviations from symmetry and $m_3$ oscillates with high accelerations around the midposition, which, in turn, has considerable influence on the accelerations $a_1$ and $a_2$. They are now temporarily equal to zero and divided into several consecutive impulses. Part of the initial kinetic energy remains in the oscillating system, its final dissipation occurs later, thus increasing the total duration and decreasing the mean accelerations as well as the injury risk.

Figure 2. Injury severity and front-end crush resistance.

The simulation of the standardized fixed barrier impact was performed by introducing into the calculation a very large mass $m_3$. We then determined as a function of $p_1$ the particular impact speed $V_0$ that results in producing but not exceeding an injury severity AIS = 3 and the corresponding crush values (fig. 5). Besides the fairly high impact speeds around $p_1 = 0.1$ that presuppose intolerably large crush, there is for each car mass a local maximum of impact speed combined with a tolerable crush value of approximately 0.5 m, the point in figure 1 where the sharp rise of crush resistance starts. This means that the optimal crush resistance is realized if the “second floor” of the function $F(s)$ is not utilized. As expected, the heavier the car the larger is the optimal crush resistance.

NOTE: $m_1 = m_2 = 900$ kg, $p_2 = 0.5$. 

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SAFETY RESERVES OF HEAVY CARS

As already shown in figure 3, the occupants of a heavy car are exposed to a lower injury risk than the occupants of a lightweight car if the cars considered collide. We have now determined, as a function of \( p_1 \), the impact speeds resulting in a probable injury severity \( AIS_2 = 3 \) for the light car 2, and the correlated injury severities \( AIS_1 \) for the heavy car 1, which are demonstrated in figures 6 and 7. Obviously the crush resistance has little influence on the difference between the injury severity degrees \( AIS_1 \) and \( AIS_2 \).

A NUMERICAL DETERMINATION OF COMPATIBILITY

To make it measurable, we have defined compatibility in terms of physical quantities and introduced a compatibility index (CI) as follows.

When two cars with different masses collide, the larger mass is considered in a certain sense as being aggressive in itself. The likely means for compensation is proper tuning of structure crush resistances. Therefore, a large mass (the heavy car) does not compensate—is least compatible—if it is fully rigid. Let \( V_s \) be the relative speed by which a heavy and rigid car is allowed to impact a less heavy and “crushable” car, under the condition that the energy dissipation capability of the small car is fully utilized, and let \( V_N \) be the corresponding speed by which the heavy car, but with modified and now crushable structure, is allowed to impact the small car under the same conditions (two-mass model). We can then define the compatibility index by

Figure 3. Injury severity and front end crush resistance.

\[ AIS_1 \]

\[ AIS_2 \]

\[ 100 \text{ km/h} \]

\[ 80 \text{ km/h} \]

\[ 60 \text{ km/h} \]

\[ 40 \text{ km/h} \]

\[ 20 \text{ km/h} \]

\[ \text{CRUSH RESISTANCE (} p_1 \text{)} \]

\[ \text{CRUSH RESISTANCE (} p_1 \text{)} \]

\[ 0 \text{ - 1.0} \]

\[ 0.1 \text{ - 1.0} \]

\[ 8 \text{ - 0} \]

\[ 20 \text{ - 0} \]

\[ 40 \text{ - 0} \]

\[ 60 \text{ - 0} \]

\[ 80 \text{ - 0} \]

\[ 100 \text{ - 0} \]

\[ 0.1 \text{ - 0.2} \]

\[ 0.3 \text{ - 0.4} \]

\[ 0.5 \text{ - 0.6} \]

\[ 0.7 \text{ - 0.8} \]

\[ 0.9 \text{ - 1.0} \]

\[ 0.1 \text{ - 0.2} \]

\[ 0.3 \text{ - 0.4} \]

\[ 0.5 \text{ - 0.6} \]

\[ 0.7 \text{ - 0.8} \]

\[ 0.9 \text{ - 1.0} \]

\[ 0 \text{ - 1.0} \]

\[ 0 \text{ - 1.0} \]

\[ 0.1 \text{ - 1.0} \]

\[ 0.1 \text{ - 1.0} \]

\[ m = 1800 \text{ kg, } m_2 = 900 \text{ kg, } p_2 = 0.5. \]
\[ CI = \frac{200}{1_n^2} \frac{V_N}{V_S} \]

We now substitute the energy dissipation criterion and determine \( V_S \) and \( V_N \) so that AIS 3 is not exceeded. Figures 8 and 9 show 3 is not exceeded. Figures 8 and 9 show examples calculated with the three-mass model. The abscissa marks the crush resistance of the heavy car. Low crush force levels result in high compatibility, but again the crush values are intolerably large, as already explained in the context of figure 5.

In figure 8 the values \( m_2 = 900 \text{ kg} \) and \( p_2 = 0.5 \) are fixed, the mass \( m_1 \) has been varied. In general, the CI value slopes down with increasing value of \( p_1 \). Local maxima of CI between 45 and 65 are evident around \( p_1 \approx 0.4 \). This would support the thesis that equal crush resistance for all vehicles could best assure compatibility.

Figure 4. Car-to-car collision.

**NOTE.** Upper display: \( m_1 = m_3 = 900 \text{ kg}, p_1 = p_2 = 0.5 \).

Lower display: \( m_1 = m_3 = 900 \text{ kg}, p_1 = 0.8, p_2 = 0.5 \).
Therefore, we assumed \( p = 0.4 \) for different \( m_2 \) masses and the collision with the upper limit mass \( m_1 = 1800 \) kg was calculated. The results shown in figure 9 lead to contradiction: While \( p_1 \approx 0.4 \) is still optimum if the impacted mass is lightweight, much higher values of \( p_1 \) near 0.8 . . . 0.9 can improve the CI if the impacted mass is increased. Apparently the optimal solution can be found somewhere in between. This needs further comprehensive investigation including the statistical distribution of mass ratios of colliding cars. Crush resistances should be tuned so that the highest CI is associated with the most frequent values of car masses, and restrained occupants have to be included when the injury-collision-severity relation is established.

SUMMARY AND CONCLUSIONS

Compatibility of passenger cars should be evaluated by estimating the probable severity of accident injuries associated with car-to-car collisions.

The injury severity depends on some collision parameters such as variation of car velocity, mean car acceleration, and passenger compartment intrusion.

\( a_T \) and \( a_S \) are not identical. Therefore, the value of the quotient

\[
q = \frac{a_T}{a_S} = \frac{s}{(V_E + V_A - 2V_I)}
\]

generally differs from one which is easily understood by considering the velocity/time plot in figure 10. The numerator of \( q \) is represented by the area below the curve \( v \) hatched to the left, the denominator by the rectangular area hatched to the right. Both areas are equal in size if, for instance, the velocity curve \( V \) is symmetrical to its midpoint \( M \), and then is \( q = 1 \). A sharp velocity descent at the beginning (curve \( V \)) indicates high initial acceleration, then \( s \) is small and \( q \) close to zero. A sharp velocity descent at the

![Figure 5. Barrier impact criteria for AIS = 3.](image)

**NOTE.** \( V_o \) = Barrier impact velocity

\( S \) = Crush distance

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Figure 6. Safety reserves of heavy cars.

NOTE. \( m_2 = 900 \text{ kg}, p_2 = 0.5 \).
Figure 7. Safety reserves of heavy cars.

NOTE. \( m = 1800 \text{ kg}, p_2 = 0.4 \).
Figure 8. Compatibility and crush resistance.

NOTE. $m_1 = 900/1350/1800$, $m_2 = 900$ kg, $p_2 = 0.5$. 
Figure 9. Compatibility and crush resistance.

NOTE. $m_1 = 1800$, $m_2 = 900/1350/1800$, $p_2 = 0.4$. 
Figure 10. Car velocity versus time during collision.

\[ \frac{1}{2} \left( V_e - V_i \right) + (V_A - V_i) \]

**NOTE.**
- \( T \) = Impact duration
- \( V_e \) = Velocity of total momentum.
- \( V_A \) = Initial velocity
- \( V_e \) = End velocity.
end (curve \( V'' \)) indicates high end acceleration, then \( S \) is large and \( q \) close to 2. So the value of \( q \) characterizes the location of the acceleration peak value within the impact event both with respect to time and with respect to displacement or crush distance. The location of the acceleration peak is, in many cases, decisive for occupant loadings, particularly if restraint systems are used.

From road accident data involving unrestrained car occupants the probable injury severity expressed in AIS classifications is related to the collision parameters using the method of multiple regression. The parameters in turn are determined with a mathematical three-mass model from the initial car velocities, the car mass ratios, and the front-end crush resistance characteristics.

A previously defined compatibility index proves useful for assessing compatible crush resistances. Further investigations are needed in particular with regard to restrained car occupants. From preliminary results we conclude:

- Compatibility throughout the entire car population is only achievable if the crush resistances of all cars are tuned to the optimal crush force level combination necessary for the most frequent mass combination of colliding cars.

- Within the range of tolerable crush, heavier cars compared to lighter cars have a safety reserve that is larger, the larger the mass ratio.

- Leveling of the injury risk in cars of different weights by adequate selection of crush resistances is impossible, if equal effectiveness of restraint systems is assumed. Higher risk due to low car weight must be compensated for by higher restraining performance.

- At high impact speeds the injury risk can be smaller in each of two cars with unequal crush resistance compared to cars with equal resistance.

Realistic Compatibility Concepts and Associated Testing

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Research and Development

INTRODUCTION

Because passenger cars are designed to cope with a variety of transport functions, their total population is composed of vehicles differing in mass, structure, and design. In cases of vehicle-to-vehicle collisions between cars differing in this way, it is generally the occupants of the smaller car who are subjected to more strain than those of the bigger vehicle.

It is for this reason that, especially after work started on the Experimental Safety Vehicle (ESV), Volkswagen has been researching the ways and means of improving the compatibility of vehicles differing in mass, structure, and design.

Especially during our participation in phase 1 of the Research Safety Vehicle (RSV) Project, our crashworthiness considerations were dominated by the need to find a feasible concept of compatibility.

This paper contains a survey of the essentials of Volkswagen's RSV compatibility concept for symmetrical vehicle-to-vehicle frontal collisions. The basic goals of our concept are as follows:

1. The structure and restraint system modifications required should be as small as possible.
2. All vehicles designed in accordance with this concept should be as compatible as possible with today's vehicle population.
3. The closing velocity should be sufficiently high in respect to the accident situation.
4. The concept should be applicable to a mass spectrum encompassing nearly all passenger car, vehicle-to-vehicle collisions.

The RSV concept of compatibility developed by VW along these lines guarantees passenger safety in symmetrical vehicle-to-vehicle frontal collisions at closing velocities of up to 71 mi/h and at mass ratios of up to 2, and in a collision against a fixed barrier at
SECTION 4: TECHNICAL SEMINARS

40 mi/h. In all cases of higher mass ratios the closing velocities permissible under this concept decrease with increasing mass ratios.

After our participation in the RSV Project had ended, we were able to prove experimentally, in the course of some follow-up work that this concept can be applied to vehicles of conventional design.

Simultaneously, we started developing a movable deformable barrier that simulates the kinetic characteristics of the frontal structure of a bigger vehicle.

EXPLANATION OF TERMS

Index

1 Small vehicle
2 Bigger vehicle
10 Smaller vehicle in collision with an identical vehicle

20 Bigger vehicle in collision with an identical vehicle
MDB Movable deformable barrier
MNDB Movable nondeformable barrier
c Vehicle-to-vehicle collision (closing)
w Impact against fixed barrier
co Vehicle-to-vehicle collision at $\mu = 1$

Mechanical Values

*a [m/s², g] Acceleration
*v [m/s, mi/h] Velocity
$\Delta v$ [m/s, mi/h] Velocity change
*s [m, in] Stroke
$\bar{s}$ Mean stroke
*m [kg, lb] Vehicle mass
$\mu$ Mass ratio $m_2/m_1$
F [N, lb] Deformation force
$\bar{F}$ Mean deformation force
E [Nm, lb in] Energy to be absorbed in the course of a central straight fully-plastic impact

Figure 1. Wheelbase versus mass for sedans [3].
Figure 2. Distance between bumper and firewall as a function of vehicle mass [3].

Figure 3. Mean deformation force in frontal fixed barrier impacts at \(v_o = 30\) mi/h [3].
FOUNDATIONS

Compatibility of vehicles of differing mass, structure, and design means that force levels and deformation of the structures must be compatible, and that the occupants must not be subjected to strains beyond those permissible according to human tolerance limits. Moreover, the architecture of vehicles must be designed broadly along the same lines to ensure that engineering measures taken to provide compatibility do have the desired effect.

In view of accident statistics, any effective concepts of compatibility must allow for sufficiently high closing velocities over the mass spectrum of passenger car accidents. Finally, we tried to develop a concept that can be implemented in conventional-type vehicles without the use of any exotic materials or unusual vehicle geometries.

For this reason, our first step in developing a concept of compatibility was to investigate the characteristics of today's motor vehicles.

We collected data on vehicle geometry as well as mean accelerations, deformation forces, and strokes in case of a frontal collision with a fixed barrier at 30 mi/h and plotted those data as a function of vehicle mass (figs. 1, 2, 3, 4).

Based on those data, it was possible to draw up some simple rules of similarity [1, 2]. For instance: We found that if two vehicles differing by a mass ratio of \( \mu (\mu \geq 1) \) collide frontally with a fixed barrier, the deformation length will increase by a factor of \( \mu^{1/3} \) (\( \mu = m_2/m_1; m_1 = \) mass of the smaller vehicle; \( m_2 = \) mass of the bigger vehicle) and the deformation forces will increase by \( \mu^{2/3} \).

If two unequal vehicles are involved in a symmetrical frontal collision we may assume that the entire front face of the smaller vehicle will be subjected to the same stress as that of a fixed barrier impact. The contact area of the bigger vehicle, on the other hand, will be less than that of a fixed barrier impact. We may, therefore, assume that the deformation force of the smaller vehicle will be that

Figure 4. Deformation stroke in frontal fixed barrier impact versus mass for various types of vehicles at \( v_0 = 30 \) mi/h [4].
of a fixed barrier impact, whereas the deformation force of the bigger vehicle will be slightly less. We assumed that the mean deformation force of the structure of the bigger vehicle is higher than that of the smaller vehicle by a factor of \( \mu^{1/2} \) [1].

Selection of the Concept of Compatibility

After collecting the basic characteristics of today's motor vehicles, three different compatibility concepts were studied.

- Constant permissible closing velocity independent of mass ratio \( v_c = f(\mu) = \text{const.} \) (concept 1)
- The energy absorption of the bigger and the smaller vehicle is the same \( E_2 / E_1 = f(\mu) = 1 \) (concept 2)
- Constant velocity change of the smaller vehicle at all mass ratios \( \Delta v_1 = f(\mu) = \text{const.} \) (concept 3)

\( v_c = \) Closing velocity
\( E_1 = \) Energy absorbed by the smaller vehicle
\( E_2 = \) Energy absorbed by the bigger vehicle
\( \Delta v_1 = \) Velocity change of the smaller vehicle

The objective of this study was to determine the capacity for energy absorption allowed for by the individual concepts as well as the appropriate closing velocities as a function of the mass ratio \( \mu \).

In this study, we assumed that

- The smaller vehicle's capacity for energy absorption is fully used in the vehicle-to-vehicle collision
- The force level of the occupant compartment of the smaller vehicle and the force level of the frontal structure of the bigger vehicle are adapted, that is, the smaller vehicle's occupant compartment stiffness is higher than that of the frontal structure of the bigger vehicle.

Figure 5 shows the bigger vehicle's relative energy absorption plotted against the mass ratio \( \mu \) for each of the three possible concepts.

As we can see, the relative absorption of energy of the bigger vehicle \( E_2 / E_1 \) (fig. 5) increases with the mass ratio in concept 1, whereas in concept 2 it remains constant (in keeping with the principle of this concept), and it decreases in concept 3.

For each of the three concepts, figure 6 shows the amount of energy absorbed by the bigger vehicle as the mass ratio increases. In this case, this is plotted against the bigger vehicle's capacity for energy absorption when colliding with an identical vehicle.

Figure 7 shows the closing velocity, \( v_c \), that results from the calculations of the
Figure 7. Relative closing velocity versus mass ratio in frontal vehicle-to-vehicle collision for the three different compatibility concepts.

Figure 8. Closing velocity in frontal vehicle-to-vehicle collision and velocity vehicle (2) and the smaller vehicle (1).

relative energies for each of the three concepts plotted against the mass ratio, with \( v_{co} \) representing the closing velocity at a mass ratio of \( \mu = 1 \).

By comparing the three concepts, we find that concept 1 exploits the bigger vehicle’s capacity for energy absorption to the fullest extent. We may state this because at a given mass ratio of \( \mu \) and with the smaller vehicle's capacity for energy absorption fully used, the bigger vehicle, under concept 1, will absorb more energy than under concept 2 or 3, because concept 1 allows for the highest closing velocity.

At the same time, occupant safety is guaranteed at constant closing velocities up to a certain mass ratio. This is only possible because, in case of a collision between two small vehicles of equal weight at \( v_{comax} \), the vehicles’ capacity for energy absorption is used to the limit but the restraint system is not stressed to capacity. This means that the permissible velocity change related to the restraint system must exceed the impact velocity for a fixed barrier impact during which the energy absorption capacity is fully used. Regarding these considerations we decided to investigate a concept that provides passenger safety over a broad mass range at a constant permissible closing velocity.

By means of a multimass model, we calculated the maximum mass ratio as well as the maximum closing speed allowed for by the structure (external compatibility) and the restraint system (internal compatibility) of the concept thus selected.

In this investigation the following points were taken into consideration:

- The increase of the mean deformation force of the frontal structure was assumed to be \( \mu^{1/2} \) (characteristic of today’s motor vehicles).
- We used a rectangular two-level force-stroke characteristic of the vehicle front.
- We assumed realistic deformation distances.
- We also assumed a preloaded restraint system with force limiter to be installed in the smaller vehicle, similar to the system introduced with ESVW II 16I.
- All calculations included effective interior occupant compartment distances.
- The influence of the vehicle’s motor mass, position, and mounting was investigated.
- Furthermore, we assumed that in a vehicle-to-vehicle collision each of the vehicles involved will absorb less energy than in a fixed barrier collision because the contact areas are different. We assumed a maximum energy absorption rate of 80 percent related to a fixed barrier impact.

With the assumptions listed above, the simulated vehicle-to-vehicle collisions performed with this model have shown that both
in the smaller and in the bigger vehicle, occupant safety can be guaranteed for collisions at closing velocities of up to 71 mi/h and mass ratios of up to $\mu=2$ (fig. 8).

Under the conditions just described, both vehicles had a maximum fixed barrier impact velocity of 40 mi/h related to the energy absorption capacity.

If the mass ratio should grow beyond $\mu=2$, the concept demands that the mean deformation force of the bigger vehicle remains constant with increasing $\mu$, and that, at the same time, the velocity change $\Delta v_1$ of the smaller vehicle remain constant (fig. 8).

Table 1. Constant closing and fixed barrier velocities and pertinent velocity changes of the smaller vehicle

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Fixed barrier impact</th>
<th>Closing ($1&lt;\mu&lt;2$)</th>
<th>Change of smaller vehicle ($\mu=2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>53</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>63</td>
<td>42</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>71</td>
<td>47</td>
</tr>
</tbody>
</table>

Moreover, we studied the possibility that this concept of compatibility might necessitate using unusual vehicle geometries, such as an excessively elongated vehicle front in the bigger vehicle. Figure 9 shows, however, that deformation forces increasing by $\mu^{1/2}$ do not cause the length required for the bigger vehicle to increase significantly.

As already mentioned, we found that occupant safety can be guaranteed for fixed barrier impacts at impact velocities of up to 40 mi/h and for vehicle-to-vehicle collisions at closing speeds of up to 71 mi/h for a mass ratio of up to $\mu=2$. In the latter case the velocity change of the smaller vehicle is 47 mi/h at mass ratio of $\mu=2$.

In addition to this, table 1 lists some more compatible velocities determined in the course of simulation computations.

**TESTING**

The tests described on the following pages are intended to demonstrate that the concept of compatibility selected by us may be
Table 2. Test plan: experimental proof of the feasibility of the compatibility concept selected

<table>
<thead>
<tr>
<th>Item</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Test 4</th>
<th>Test 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>A</td>
<td>B</td>
<td>B (This test is run to check the MDB adjustment.)</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>Parameters</td>
<td>Frontal impact of vehicle 1 on fixed barrier at 40 mi/h.</td>
<td>Frontal impact of vehicle 2 on MNDB at (v_c)^a</td>
<td>Frontal impact of MDB on MNDB at (v_c)^a</td>
<td>Frontal impact of vehicle 1 on MDB at 71 mi/h.</td>
<td>Frontal impact of vehicle 1 on vehicle 2 at 71 mi/h.</td>
</tr>
</tbody>
</table>

\(^a\)Depending on the MNDB mass, the closing velocity \(v_c\) given in the table should be such that, in accordance with the concept of compatibility selected, the bigger vehicle will absorb the kinetic energy \(E_2\).

NOTE. Vehicle descriptions:
- Smaller vehicle, Vehicle 1: ESVW II mass 2 200 lb
- Bigger vehicle, Vehicle 2: Ford LTD mass 4 400 lb
- Movable deformable barrier MDB mass 4 400 lb
- Movable non-deformable barrier MNDB random mass

applied to and implemented in vehicles of conventional design. Moreover, we intend to prove experimentally that a movable deformable barrier may be used to simulate the deformation characteristics of one of the two vehicles involved in a collision.

To begin with, we will list general descriptions of the four test procedures on which the tests specified in table 2 are based.

Test Procedure A: Frontal Fixed Barrier Impact

This test procedure is used to establish whether the vehicle will protect its occupants sufficiently in case of a collision with a fixed barrier.

Test Procedure B: Frontal Impact on a Movable Nondeformable Barrier

This test is used to determine the force-stroke characteristic of the deformation zone of the vehicle to be tested by means of the deceleration measured at the movable non-deformable barrier. The characteristics thus approximately determined are used as a basis for adjusting the deformation elements of a movable deformable barrier to simulate the mass of a vehicle and its frontal structure.

Test Procedure C: Frontal Impact on a Movable Deformable Barrier

This test procedure is used to determine the deformation behavior and the degree of occupant safety offered by the vehicle to be tested. The movable deformable barrier simulates the bigger vehicle.

Test Procedure D: Frontal Vehicle-to-Vehicle Collision

A movable deformable barrier merely simulates approximately the deformation behavior of a vehicle. It is for this reason that only with test procedure D, which is expensive, can the compatibility of both the smaller and bigger vehicles be realistically demonstrated.

Description of Test Vehicles

In the tests to be performed, the smaller vehicle will be an ESVW II (2 200 lb) designed for a frontal fixed barrier impact at 40 mi/h [6].
The bigger vehicle will be a Ford LTD (4,400 lb). To ensure that the deformation behavior of the bigger vehicle is favorable towards the smaller vehicle, the engine should be mounted on the chassis frame and should be located as far towards the vehicle rear as possible within the frontal structure. The engine of the Ford LTD is nearly in this position.

Figures 10 and 11 show the ESVW II and the Ford LTD. The pictures are such that the dimensions of both vehicles may be compared qualitatively.

In accordance with the concept of compatibility introduced above, a movable deformable barrier is used to simulate the deformation behavior of the frontal structure of the bigger vehicle, a Ford LTD (total weight 4,400 lb).
Figure 12. Movable deformable barrier.

Figure 12 shows the movable deformable barrier. The force-stroke characteristic is achieved by adjustable deformation elements [7].

The deformation elements mentioned above consist of pipes that buckle during the crash. The buckling force $F$ of these pipes is nearly independent from the closing speed and it is constant versus stroke (fig. 13 [7]). The force level is mainly determined by the wall thickness of the pipes and by the yield point of the material.

Test Results

Test 1: Frontal Impact of the ESVW II on a fixed barrier at 40 mi/h. This test was run to demonstrate that the smaller vehicle will guarantee the safety of its occupants in a frontal collision with a fixed barrier at 40 mi/h (fig. 14).

The test results show that the ESVW II will guarantee occupant safety at 40 mi/h. A detailed description of the test results has been published [6].
Test 2 and Test 3: Frontal Impact of the Bigger Vehicle and of the Movable Deformable Barrier on the Movable Nondeformable Barrier. The movable deformable barrier is used to simulate the frontal structure deformation behavior of the bigger vehicle, the Ford LTD. For this purpose, the deformation behavior of the Ford LTD frontal structure is first determined by test 2 (see table 2). The deformation elements of the movable deformable barrier are then adjusted to the force-stroke characteristics thus determined. The setting is tested by means of test 3.

For both tests, an existing movable nondeformable barrier was used. Its mass is $m_{MNDB} = 3568\text{ lb}$. The total energy to be absorbed by the frontal structures of both vehicles in case of a frontal collision between the ESVW II (mass 1) and the Ford LTD (mass 2) at a closing velocity of 71 mi/h is

$$E = \frac{1}{2} \cdot \frac{m_1 \cdot m_2}{m_1 + m_2} v_c$$

In case of such a collision, the energy to be absorbed by the bigger vehicle is

Figure 14. Smaller vehicle (ESVW II) before and after a frontal fixed barrier impact at 40 mi/h.


\[ E_2 = E - E_1 \]

\[ E_1 = \frac{1}{2} m_1 \cdot \left( \frac{v_c}{2} \right)^2 \]

that is, the smaller vehicle absorbs the amount of energy that it is capable of absorbing at a mass ratio of \( \mu = 1 \) and at a closing velocity of \( v_c = 71 \text{ mi/h} \).

The closing velocity at which tests 2 and 3 are to be run can then be calculated according to the impulse and energy theorem:

\[ v_c = \sqrt{2 \cdot E_2 \cdot \left( \frac{1}{m_{\text{MNDB}}} + \frac{1}{m_2} \right)} \]

Table 3 shows test parameters and results of tests 2 and 3. Figure 15 shows the Ford LTD and the movable nondeformable barrier and figure 16 shows the movable deformable and the movable nondeformable barrier both before and after the test.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Test 2</th>
<th>Test 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m ) (lb)</td>
<td>( m_2 = 4621 )</td>
<td>( m_{\text{MDB}} = 4526 )</td>
</tr>
<tr>
<td>( m_{\text{MNDB}} ) (lb)</td>
<td>3568</td>
<td>3568</td>
</tr>
<tr>
<td>( v_c ) (mi/h)</td>
<td>50</td>
<td>51</td>
</tr>
<tr>
<td>( E_2 ) (10^4 lb-in)</td>
<td>198.7</td>
<td>205.9</td>
</tr>
<tr>
<td>( \delta ) (in)</td>
<td>19.3</td>
<td>21.1</td>
</tr>
<tr>
<td>( F ) (10^4 lb)</td>
<td>10.3</td>
<td>9.8</td>
</tr>
</tbody>
</table>

Figure 15. Ford LTD (4,400 lb) and movable nondeformable barrier (3,568 lb) before and after test 2, which was run at a closing velocity of 50 mi/h.

Figure 16. Movable deformable barrier (4,400 lb) and movable nondeformable barrier (3,568 lb) before and after test 3, which was run at a closing velocity of 51 mi/h.
Tests 4 and 5: Frontal Collision between the Smaller Vehicle and the Movable Deformable Barrier and the Bigger Vehicle. These tests were run in order to prove that occupant safety is guaranteed in case of a frontal vehicle-to-vehicle collision at \( v_c = 71 \text{ mi/h} \) and \( \mu = 2 \). Moreover, test 4 is to establish that a movable deformable barrier may be used to simulate the deformation behavior of the bigger vehicle (fig. 17).

The force-stroke characteristic of the movable deformable barrier in test 4 corresponds to the characteristics derived from test 2. Table 4 compares the strains exerted on the driver of the ESVW II in the course of the two tests. In both tests, the safety criteria of FMVSS 208 were adhered to.

Occupant safety was guaranteed for the driver and front-seat passenger of the Ford LTD as well. As far as their deformation behavior is concerned, the compatibility of

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Test 4</th>
<th>Test 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head (HIC)</td>
<td>894</td>
<td>962</td>
</tr>
<tr>
<td>Chest: ( a_{\text{res}} (g) )</td>
<td>47</td>
<td>59</td>
</tr>
<tr>
<td>Strain ( \sigma_1 )</td>
<td>454</td>
<td>598</td>
</tr>
</tbody>
</table>

Figure 17. ESVW II and MDB before and after the compatibility test with a closing velocity of 71 mi/h.
the two vehicles was established by the fact that during both tests the smaller vehicle's occupant compartment withstood the strain and the space required for survival was thus preserved intact (fig. 18).

SUMMARY

For quite some time now, and especially since work on the ESV started, Volkswagen has been researching ways and means of improving the compatibility of vehicles differing in mass, structure, and design. During Volkswagen's participation in phase 1 of the RSV project, all our considerations on crashworthiness were dominated by finding a feasible concept of compatibility, which should guarantee occupant safety in case of a frontal vehicle-to-vehicle collision at closing velocities of up to 71 mi/h and at mass ratios of up to 2. Moreover, in case of a mass ratio higher than 2 the concept demands that the closing velocity be reduced so that the velocity change of the smaller vehicle remains within permissible limits, always providing that the deformation force of the bigger vehicle remains the same. Furthermore, under the concept of compatibility selected by us we presume that both vehicles will guarantee

Figure 18. ESVW II and Ford LTD before and after the compatibility test with a closing velocity of 71 mi/h.
EXPERIMENTAL SAFETY VEHICLES

occupant safety in frontal fixed barrier impacts at impact velocities of up to 40 mi/h.

The basic principles of this concept are described in this paper. Moreover, it is proven experimentally that this concept can be implemented in motor vehicles of conventional design, even if in this case the smaller vehicle clearly approaches the limits of what is technically feasible. The test consists of a frontal collision between an experimental safety vehicle ESVW II (2200 lb) designed for a frontal fixed barrier impact at 40 mi/h and a serial model Ford LTD (4400 lb). The deformation behavior of the two vehicles came up to expectations. Both the driver and the front-seat passenger of the Ford LTD as well as the driver of the ESVW II "survived" the experiment.

In another test the ESVW II collided frontally with a movable deformable barrier at a closing velocity of 71 mi/h. In this test, both the barrier mass and the deformation behavior of its frontal structure corresponded approximately to the data of the Ford LTD. The data that we collected concerning the deformation behavior of the ESVW II frontal structure and the strain on its driver corresponded to those of an analogous vehicle-to-vehicle collision.

Our future work will be aimed at improving technical solutions as well as performing cost/benefit analyses of the compatibility concept we selected. Moreover, lateral and rear collisions between two vehicles will be included in our considerations.

LITERATURE

Influence of the Shape of Thin-Wall Structures and Structural Elements on the Dynamic Behaviour of the Overall Passenger-Vehicle System during Impacts

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ABSTRACT

It is known that during the collision of the vehicle with an obstacle, shock-like impact forces are acting upon the passengers. This shock-like load can be considered as a transient oscillation process. A corresponding analysis, effected at any defined point of the car, reveals that the basic frequency is superimposed by frequency spectra of differing density and direction. The passenger's body
also constitutes an oscillatory element, which is represented by muscles and bones on one hand, and the embedded organs and liquids with their respective couplings on the other. Mathematical simulatory models for some subdomains are known from pertinent literature.

The frequency spectrum is created during the vehicle deformation phase and transmitted to the passenger through the structural elements, the seatbelt anchorage points, or other vehicle parts. From other research sectors it is known that, with oscillatory stresses, certain frequency ranges are specially harmful to man. It must also be assumed that in case of shock-like impact forces acting upon the passenger, there are some frequency ranges that have noxious effects on vital functions of the human body. Before closely investigating these ranges, it must be determined whether it is possible to influence frequency ranges by corresponding design of the overall structures and of the structural element.

The paper deals with the analysis of typical, realistic thin-wall structures, to be used in vehicle deformation zones. It is proved that the occurring frequency ranges may be influenced, provided special aspects are being taken into consideration.

**FUNDAMENTAL BIOMECHANICAL PRINCIPLES**

Nearly all of the motorized countries have had favourable experience with passenger restraint systems, but examination of the most essential injury mechanisms has confirmed that restraint systems are not yet perfect and have to be continuously improved. The most important step in this context was the increase of the seatbelt usage rate. Because several countries have made the use of seatbelts a law, the injuries caused by seatbelts are of increasing importance [1]. Apart from injuries caused by excessive specific load to body parts, the injuries that are of special interest are those in which passengers show no obvious trauma. It is assumed that the impact of the human body to parts of the vehicle interior can be avoided to a certain degree by the use of the seatbelt.

![Diagram](image)

Figure 1. Factors influencing accident severity.

The accelerations to which the passenger is subjected during an accident are caused by vehicle deceleration that is transmitted to the human body through the restraint system. Man constitutes a three-dimensional oscillatory element that primarily consists of different masses held together by tissues and bones. Mathematical oscillation models for partial optimization by means of calculations are well known and can be found in pertinent literature [2]. They can be considered quite sufficient for the estimation of passenger kinematics, for example, during a frontal collision. More informative, though more difficult to record, would be the effects on the internal organs and their coupling to the other human body parts, however, it must be qualified that neither the organ behaviour nor the coupling interaction are sufficiently known. The identification of the human body can be still more refined by taking into consideration the liquids contained in the organs, such as blood and liquor cerebrospinalis. Quite a number of investigations have shown that the time history, the onset rate, and the frequency of the accelerations acting upon the human body significantly influence the seriousness of the injury [3-20] if this complex system is exposed to shock-like loads.
Extremities

In the framework of this paper no further consideration will be given to extremity injuries as they are less important to the overall degree of seriousness than abdomen, thorax, and head lesions. It should be mentioned, however, that the destruction of bone structures is also influenced by the absorbed energy and the time history [21, 22].

Thorax and Abdomen

A mere deceleration leads to a displacement of organs and liquid columns in the thorax. Vessel pressures increase because of the action of mass load and liquid displacements. This, in conjunction with organ oscillations, results in fissures of the liver and spleen parenchyma, or ruptures and fissures of vessels such as the aorta.

There are various data available concerning the natural frequency of the thorax/abdomen system in the case of external excitation. For the heart and liver, Snyder indicates a value of 6.4 c/s, while Ginguard cites 4 to 8 c/s, and other authors mention 3 to 6 c/s. It can be seen that critical ranges are generally below 10 c/s. Consequently, this range should be avoided during a corresponding load.

Skull/Brain

The reaction of the skull/brain system is similar to that of the thorax/abdomen system, that is, a displacement of the brain matter and of the liquid within the brain cavities occurs.

The most frequent internally acting injury mechanisms are shearing strains caused by the pressure-induced flow of the liquor cerebrospinalis, the evaporation of the latter due to the reduction of its hydrostatic pressure to a value inferior to its vapour pressure limit, and the displacement of the brain matter. The sudden condensation of the cerebrospinal liquor following its evaporation results in extremely high local pressures that may cause tissue lesions.

The natural frequency ranges of the head are more extensive than those of the abdomen and thorax. Critical range indications vary from 3 to 10 c/s, 20 to 30 c/s (Cormann), 20 c/s (Brinn), and 101 c/s (Slattenscheck) to several hundred c/s. (fig. 2).

Figure 2. Summary of the frequency ranges having noxious effects on the human body (collected from pertinent literature).
Summary of the Biomechanical Aspects

The above-mentioned critical frequencies comprise very extensive ranges and coincide in the low-frequency range with basic frequencies of about 7 to 9 c/s, which are determined during vehicle impacts (see Coermann). Due to their strong damping, actual belt systems show a natural frequency of 7 to 9 c/s. Thus the overall "vehicle-belt-driver" system shows a uniform tuning in the resonant range, which should be avoided as much as possible. In the higher frequency range, a load between 20 and 100 c/s seems to be less strong, for no special lesions have been reported. The high-frequency ranges seem to be harmful. It must be examined whether the vehicle structure contributes essentially to these oscillations frequencies and, if so, whether these ranges can be avoided or shifted.

Furthermore, the spectral density of a transient is influenced by the acceleration time history. A square pulse, for example, has a higher frequency than a half-sine pulse. It has been shown that injury seriousness is influenced by differing time history responses [23]. This fact coincides with the ideas concerning injury mechanisms and frequency sensitivity of the human body.

Although sufficient biomechanical data are not always available, the design of automotive structures and elements and the tuning of the vehicle and its restraint system should be done in a way that will avoid harmful frequencies and protect the passengers against excessive energies that could be transformed into other physical conditions such as heat by means of an energy converter.

RESTRAINT SYSTEMS

Air Bag

The number of suitable lab or accident data on air-bag systems is very small compared to that of belt systems.

Because only a very few vehicles with air-bag equipment have been sold by now (90 in the United States, in the first half of 1976, Automobile Revue Nr. 36/1976), this point will not be given further consideration in this report.

Belt Systems

The most frequently used restraint system is the 3-point belt (static or automatic versions). Its belt straps have a relatively high stretching ability and it offers a high degree of damping.

Other belt systems are equipped with so-called energy absorbers, however, it must be assumed that during the design of these elements the influences of the oscillatory system have not been sufficiently taken into account.

In the case of a vehicle crash, the belt system to which the human mass is coupled is excited by the oscillations generated during the plastic and elastic energy transformation. Consequently, the frequency spectrum acting upon the passenger is influenced by both the belt and the vehicle elements, which are directly involved in the elastic and plastic energy transformation.
Figure 4. Tube, oval shell, and box-type test members before and after crash.
SECTION 4: TECHNICAL SEMINARS

OTHERS

As far as other generally known restraint systems are concerned, there is so little information available that they are not going to be considered in the framework of this paper.

STRUCTURAL PROBLEMS

Today's vehicles are generally designed and constructed to permit the transformation of kinetic energies into the plastic deformation of peripheral body sections. The central vehicle part, the passenger compartment, must not be involved in this deformation process but should show only elastic reactions. The deformation characterization of the thin-wall body components is superimposed by elastically or plastically coupled oscillation responses of discrete vehicle masses, such as the engine, chassis, passengers, tank, and so forth.

Consequently, the mass forces acting upon a structural component during deformation are not constant. This fact may have an essential influence on the deformation behaviour of the structural elements.

If these mass forces are relieved at the right moment, the bending moment may decrease, preventing the part from collapsing. Thus, a geometric stabilisation takes place before higher stresses start acting upon the component, and the subsequent folding process goes on without collapsing. The resulting acceleration discontinuities and the relatively long duration of the collapsing process again influence the transient frequency.

DESCRIPTION OF FREQUENTLY USED STRUCTURES

Actual vehicle bodies consist of a system of thin-walled, hollow steel plate parts that are linked by assemblage points and designed as longitudinal members in the front and rear deformation zones.
The majority of today's vehicles have front engines, some versions of which are mounted to the extreme vehicle front so that the drive unit hits the obstacle after a very short deformation path. This results in a considerable discharge of the energy-dissipating structure. Due to this "mass defect," its energy management seems much greater than it is in reality.

Regardless of this fact, we must assume that the corresponding structural components are being and can be designed in such a way that the longitudinal members will absorb about 50 percent of the kinetic energy during a vehicle impact at 30 mi/h without resulting in an increase of weight and production costs.

Thus, the carrying members have to be considered as the most important structural components that essentially influence the oscillation frequency of the passenger compartment.

Specific Energy Management

For reasons of efficiency one will try to arrive at as high an energy rate transformed per weight unit as possible.

This, however, may result in a conflict during the design of parts. The specific energy management capacity of a normal round tube is about 1.6 times better than that of a box-type part. This means shorter deformation paths with identical mass, which suggests a higher basic frequency. Moreover it means that the specific number of folds (number of folds in the function of the volume of the folding segment) is greater than that of the large-area buckling and folding box-type member. This does not mean, however, that the absolute number of buckles and folds is greater with the tube parts. The efficient energy management by means of a box-type part might even necessitate more folds and buckles due to the greater length of the folds with relatively low axial buckling forces.

Figure 3 shows the characteristic dependence of the deformation paths of three test components with identical masses.

Furthermore, due to the short folding and buckling lengths, the amplitude difference in time domain will be smaller with the tube member. The specifically higher energy management of the tube is also to be attributed to the higher deformation velocity per volume unit that, in the case of a 30-mi/h impact, amounts to about 610 s⁻¹ with the first fold and decreases towards the end of the deformation process, resulting in a tensile strength reduction by about 5 percent.
Realistic Elements for Energy Management During Plastic Deformation

Figure 4 shows three characteristic elements, two of which correspond to reality. It must be stated that vehicle parts should be made of two shells; one of which may be a plain sheet plate.

Integral components such as seamless-drawn tubes do exist; however, for various constructive reasons, they cannot be used today. The round profile has been taken into consideration in this comparison because of its homogeneous force transmission and its typical homogeneous buckling strength. The box-type profiles, on the other hand, transmit major forces only through edges and flanges. When exposed to corresponding loads, they react like collapsible struts so that in conjunction with the large-area buckling of its wall, only the formation of big folds is possible. As the round tube part in its actual form can hardly be used in automotive construction, a two-half round shell or oval part has been developed that offers the folding advantages of the tube without complicating production and integration into the vehicle.

All elements could also be used as force-limiting or energy-absorbing devices in a restraint system.

Box-type parts with a side length of 50 mm and a wall thickness of 1.5 mm cannot be considered suitable for use in a motor car. The length, differing load conditions, and efficient force transmission of the part’s cross section should be at least three times as great, with an identical wall thickness of 1.5 mm [29], and this influences the geometric data of selected parts.

Regarding the mechanical aspects of the deformation process, it should be mentioned that buckling does not only occur at the point of impact. Because of the shock waves that are propagated in the metal sound velocity, transverse movements are generated at points far away from the initial point of impact and

Figure 6. Amplitude spectra of the test members with a mass load of $m = 186$ kg and an impact velocity of $V = 2$ m/s.

![Amplitude spectra graph](image-url)
are impeded by the forces of inertia and the buckling strength. With the box-type part, the forces of inertia are relatively great in comparison to the buckling strength.

The buckling strength of a piece of round tube 100 mm in diameter is about four times higher than that of a box-type part of identical length and wall thickness. With the box-type member, this results in major deviations that may be intensified more by reflected waves, finally leading to large buckles and thus an increased collapsing risk.

Because of its additional lever action the elastic or plastic deviation results in higher bending stresses in the deformation area, thus decreasing the deceleration if the mass load is constant during the period. So it must be possible to assign the oscillation analysis of the time-history responses, as recorded during the impact load phase of these parts, to the geometrical shape of the individual part [24].

The different spectral densities of these oscillations act upon the passenger through the vehicle structure and the belt system, and as we have shown in the preceding chapters, their modification may have essential consequences.

It can be summarized that the present three parts are composed of different elements, buckling strengths, force transmissions, and manufacturing possibilities. And it is possible to create new parts by simply joining the elements in a different way. All three elements comply more or less with the request of high energy management and a sufficiently controlled deformation process.

EXPERIMENTAL VERIFICATION

Description of Tests

Tests were effected with elements of the model scale 1:2, using the time-constant model law. The laws of similarity (geometric, time, and force similarity) are being complied
with, except for the forces of gravity. The latter is not feasible for practical reasons, however, because the deviation is small enough to be negligible [28].

During model tests in accordance with the time-constant model law, geometrical dimensions, masses, accelerations, and velocities are scaled down, whereas the deformation period and deformation velocity remains unchanged, as with the full-scale test.

The members are dynamically tested by means of a test car, that has a natural frequency and a frontal impact of about 350 cs.

The vehicle mass can be changed, and in addition it is possible to couple simulated engine masses to it by means of different spring elasticity (fig. 5).

Acceleration sensors of differing limiting frequencies (100 to 1 650 c/s can be mounted immediately behind the member structure to be tested. The acceleration curves are then recorded. During the tests, parameters such as impact velocity, vehicle mass, additional mass, spring elasticity, and test parts could be varied. For load, reference was made on a full-scale 1200-kg vehicle with an impact velocity of 14 m/s. Two parts had to transform 50 percent of the kinetic energy. Consequently, each part of the scale 1:2 model had to be submitted to 150 kg at 7 m/s in order to realize identical load conditions.

The effects of load and velocity changes were ascertained by varying the mass load between 148 and 192 kg and the velocity between 2 and 6 m/s.

Thanks to the vehicle design and the test conditions on the Porsche crash device, which transforms potential energy into kinetic energy and permits easy reproduction of tests, vertical as well as horizontal impact angles of about ±5 degrees occurred. These test conditions lead to scattered results, especially for the box-type members, but they are closer to reality than exact horizontal and vertical tests.

Figure 8. Amplitude spectra of the test members with a mass load of m = 148 kg and an impact velocity of V = 4 m/s.
Oscillation Analysis

The registered time function $a(t)$ was transformed into the frequency range using a Fast Fourier Transformation. This method is commonly known [25, 26].

The Fourier spectrum is defined as follows:

$$ F(f) = \int a(t) e^{i2\pi ft} dt $$

As is generally known, the Fourier spectrum indicates the frequency response of the deformation process. This is quite sufficient for the present investigation: to find out which geometrical shapes and test conditions can influence the frequency of a deformation process. Figures 6 through 12 show a summary of the Fourier spectra.

Interpretation of Test Results

Table 1 shows the most important data of some typical tests. The dependence of the deformation path on the element's shape can be clearly seen, although the difference between shapes B and O is less significant, when compared to shape T.

The evaluation factor $I$ has been calculated by means of the $HIC = \int_{t_1}^{t_2} a(t) dt$ and $SI = \int_{t_1}^{t_2} a^2(t) dt$ (of course, the known HIC and SI limiting values are not applicable in this context). Again, the dependence on the element’s shape becomes evident, as:

$$ b_T > b_O > b_B $$

and:

$$ t_T < t_O < t_B $$

where:

- $b = \text{acceleration mean value}$
- $T, O, B = \text{element shape (tube, oval, box)}$
- $t = \text{time lag}$

\[ ^1 \text{For the HIC index:} \]

$t_1 = \text{an arbitrary time in the pulse}$

$t_2 = \text{for a given} t_1, \text{a time in the pulse that maximizes the HIC.}$

Figure 9. Amplitude spectra of the round tube with an impact velocity of $V = 4 \text{ m/s.}$
This gives a clear idea of the energetic behaviour of the elements.

Six tests were made under identical conditions in order to identify the dispersion. For reasons of clarity, however, one diagram should never comprise more than three curves (figs. 6 to 13). In all the figures the element T shows the greatest participation in the frequency range of less than 50 c/s, followed by the element O, and finally by the element B.

Modifications of the deformation periods by changing the mass load and impact velocity resulted in local shiftings of ±20 c/s. Essential changes are obviously caused by the simulated movable engine mass, which results in an accentuation of the 50 to 100 c/s range.

The shiftings that occur in the high-frequency range of 50 to 100 c/s when changing from the round tube to the box-type parts are explained by the great amplitude discontinuities due to the more intense fold buckling. These frequency ranges have to be avoided because of their possible threat to the passenger's head at loads exceeding 100 c/s (fig. 2), and the resonance frequencies of up to nearly 15 c/s that occur in the passenger's body and head.

The frequency range of 50 to 100 c/s can be avoided by preventing the element from breaking, collapsing, and causing large-area buckling. The range that is inferior to 10 c/s can be reduced and shifted by providing for a relatively high specific energy management, resulting in a high deceleration within a short period.

In compliance with SAE J 211 a, concerning the acceleration measurements of body components, the spectra as shown in figures 5 to 12 have been filtered during registration of the a (t) curve with 100 c/s. A closed examination of the results, however, has revealed that this upper limiting frequency is not suited for a detailed analysis. The subsequent tests with a limiting frequency of 1 650 c/s lead to better results, permitting a more derived evaluation (figs. 14 and 15).

Figure 10. Amplitude spectra of the test members with an impact velocity of \( V = 2 \text{ m/s} \) and a mass load of \( m = 148 \text{ kg} \) plus an additional simulation mass of 38 kg.
Figure 15 shows the amplitude scattering in the frequency range up to 500 c/s, which covers the frequencies of all oval shell parts. The basic frequency of the box-type parts is lower than that of the shell-type and the round-tube parts.

The frequency range of 120 to 140 c/s is specially accentuated in the case of the shell-type and the box-type members. This range approximately corresponds to the buckling and collapsing frequencies of the stiffening elements, the flanges and edges, of both types.

The collapsing length of the oval shell-type parts, however, is essentially shorter than that of the box-type, which results in a shorter overall deformation length requiring increased forces.

In the higher frequency range the amplitude spectrum of the round-tube part shows a peak at about 500 c/s, which might be explained by means of its deformation behaviour.

Under an impact load, the round tube forms four-sided, cycloidal circumferential folds, which originate from eight evenly distributed buckles that are dynamically transverse to the member longitudinal direction. Seven circumferential folds would result in a frequency of about 500 c/s, which corresponds exactly to the test data. The frequency range of 20 to 200 c/s involving the round tube is less than the box-type and shell-type members. This is to be attributed to the absence of nonhomogenous peripheral stiffness with the round-tube part.

The oval shell-type part with its flanges, edges, and tube-like profile shows amplitude peak values between 120 and 140 c/s, as well as in the 480 to 520 c/s range. This is not as marked as that of the box-type or tube members. Thus it can be said that the structural elements have been assigned clearly defined frequency ranges.

In summary, a frequency analysis up to a limiting frequency of 1 650 c/s principally

Figure 11. Amplitude spectra of the round tube with a mass load of \( m = 186 \) kg and an impact velocity of \( V = 4 \) m/s.
permits the tendentious determination of structural component behaviour.

In the 100 to 150 c/s range, stiffness-increasing features in the longitudinal direction of parts, such as the flanges or edges, cause a greater amplitude than a homogenous stiffness distribution that, in the 500 c/s range, has the greatest share in the amplitude due to its dynamic behaviour. Thus, the three tested realistic structures permit a univocal assignment at least within the two frequency ranges of 100 to 150 c/s and 480 to 520 c/s. Frequencies inferior to 20 c/s can only be influenced to a very small degree.

The design of carrying parts causes problems because there are two conflicting objectives: the requirement of as low as possible a g load on one hand, and the necessity of high energy management and basic frequency on the other.

A compromise solution would be a structural element characterized by rapid acceleration increase and a great specific number of folds, similar to the tube, and a simultaneously low acceleration level, as with the box-type part. This would result in a less intense frequency in the range of 20 to 200 c/s and an increase of the basic frequency in the 10 c/s range that, however, cannot be avoided.

SUMMARY

As the shock frequency is essentially influenced by the crash conditions, it seems to be doubtful whether it will be possible to sufficiently influence all frequency ranges by simply modifying the body structure design. It appears more realistic to shift from ranges inferior to 150 c/s to superior ones or vice versa. The range that is inferior to 10 c/s can only be tendentiously influenced. Based on the present test results, one or more filter elements should be provided between the passenger and the vehicle, which, regardless of the input, keep dangerous frequencies away.

Figure 12. Amplitude spectra of the test members with a mass load of m = 186 kg and an impact velocity of V = 4 m/s.
Table 1. Summary of typical test data

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<th>Velocity (m/s)</th>
<th>Static deformation (mm)</th>
<th>Evaluation factor 1</th>
<th>Evaluation factor 2</th>
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Figure 13. Amplitude spectra of the test members with nonconstant mass load of m = 148 kg + 38 kg and an impact velocity of V = 4 m/s.
Figure 14. Amplitude scattering of four half-round-shell-member tests under identical test conditions.

Figure 15. Schematic view of the amplitude spectrum of the test members up to 1 000 cps under identical test conditions.
from man. However, it will be almost impossible to substantially influence the basic frequency or to shift it to ranges of 20 c/s and more, as there are only limited paths available to the vehicle structure and the vehicle interior.

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Safe and Free

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SUMMARY

Owing to its efficiency, reliability, and most favorable cost/efficiency ratio, the 3-point seatbelt tends to be generalized; in Europe, wearing seatbelts is gradually becoming compulsory for front occupants. Is it reasonable to go further and make the wearing of belts compulsory at rear of vehicles, too? The answer is difficult, for:

- Young children, who in 28 percent of the cases occupy these places, cannot be valuably protected by belts.
- Rear seat occupants may adopt most different positions; their number and size vary greatly according to the travel.

Wearing belts would be particularly constraining at the rear of vehicles and less efficient because they would be less accepted, not to mention the trouble created by fastening belts.

No doubt safety shall be the prior aim provided that the automotive transportation qualities will not be ruined; the aim of this presentation is to propose an alternative to the 3-point seatbelt, which is at least as efficient as the latter and much more comfortable. It is a passive protection system fitted into the passenger compartment.

The main results of an impact testing program are also presented; it involved various occupants (men, women, children) adopting different postures, while ascertaining the system’s efficiency. This system provides protection to rear passengers while it does not interfere with the front occupants’ protection.

INTRODUCTION1

The 3-point seatbelt has experienced widespread utilization. Its efficiency was fully demonstrated in numerous laboratory tests and was further ascertained by the analysis of real life accident consequences, particularly in Sweden, Australia, and France.

Then, while facing the ever-increasing number of accidents, authorities in many countries decided to make the use of seatbelts compulsory.

In 1972 it happened in Australia and Sweden, then in France, and recently in most European countries.

French manufacturers believe that the seatbelt has demonstrated its efficiency in affording protection to front occupants.

Peugeot advocated the compulsory use of seatbelts for front occupants when driving outside cities... for the driver’s and the front passenger’s seating position are well defined by two arm chairs. These allow, together with the minimum inconvenience, being adequately restrained for long travels, especially since the adoption of retractors.

1 Text from the film presented at the “Structural Properties and Occupant Protection” seminar.
Would the compulsory use of seatbelts at rear places be a suitable solution?

The manufacturer believes that making the use of back-seat seatbelts compulsory would impose intolerable discomfort to rear passengers... indeed, seatbelts would be a lot of trouble on rear bench occupants, not to mention adults or children may be concerned as well.

One can imagine for example, a mother who drives her children to school every morning. Of course she has to make sure that seatbelts are correctly worn. She checks every time before starting. She spends time applying herself to do it: safety first!

Some of these children are not belted: this is not due to carelessness. Seatbelts are designed to fit grown up people and are not suitable to children of less than 1.30 meters height.

Peugeot is working jointly with the French Institute of Transportation to develop an efficient restraint system for children. The system is not yet available and children are only protected by front seat backs.

The inconvenience of seatbelts at rear places is a fact and not only for children: let’s imagine two businessmen in a taxi; their movements are limited while they once again examine their files before the next meeting.

AN ALTERNATIVE TO THE SEATBELT AT REAR PLACES EXISTS

The reader may think this is not quite serious: have we the right to contest an existing means of protection, for reasons belonging to comfort and convenience? Is it possible to equip rear seats with a restraint system as efficient as the seatbelt in front impact situations?

Peugeot has defined its own solution to the problem while developing a vehicle affording protection to rear occupants. The aim of a back-seat restraint system should take account of:

Figure 1. Operating principle of the child restraint system.
SECTION 4: TECHNICAL SEMINARS

From the Peugeot/Renault Association’s multidisciplinary inquiry it appears that the average occupation rate of back seats is 1.7. Assuming there are three places in the back, the utilization rate of a restraint system at any one of these places is at most, 20 percent.

Nature of Occupants

Again, from the multidisciplinary injury, the results are that age classes may be distributed as follows:

- Under 6, 17 percent
- From 7 to 12, 11.5 percent—bearing in mind that the belt is not appropriate as a restraint system for children in these age classes

Figure 2. Description of the rear occupant restraint system.

Occupation Rate

From the ONSER inquiry (ONSER is the French National Agency for traffic safety) the occupation rates of vehicles involved in road traffic accidents are as follows:

- In 40 percent of the cases the driver was alone.
- In 28 percent of the cases there was another front occupant.
- There were occupants in the rear seat in 32 percent of cases.

Figure 3. Deceleration law of the test sled.
EXPERIMENTAL SAFETY VEHICLES

- 8 percent of the young people from 13 to 17 who can wear seatbelts
- 60 percent of the grown up people

To conclude, let us assume that the seatbelt would be adopted as a restraint system for rear occupants, children representing 28 percent of rear occupants, the actual utilization rate of seatbelts at rear places would be only 15 percent.

Then, compulsory use of seatbelts in the back seat is seven times less justified than in the front.

Severity Level of Accidents

The restraint system shall be designed on account of the actual risk to rear occupants:

- Out of 100 nonbelted front occupant victims, 7 are killed
- Out of 100 belted front occupant victims, 3.8 are killed
- Out of 100 rear occupants, 2.6 are killed

The risk is therefore lower for the rear occupants than for the front occupants; this may be explained as follows.

The analysis of a front impact shows that rear occupants are restrained by the front seat backs.

This only restraint provides a long stopping distance for rear occupants, resulting in low severity, but implies a hazard to front occupants through excessive loads imposed to their seat backs. Then, the driver’s head HIC rises up to 4 450 and the torso deceleration to 70 g.

SELECTING A NONBELT RESTRAINT SYSTEM

Net Protection System

In limiting the rear occupants, trajectory to the front, a possible solution consists of a net installed between the reinforced front seat backs and the car top.

However, in examining occupants' trajectories, one may notice the very dangerous hyperflexion of the head, though injury criteria are met:

\[
\begin{align*}
\text{Head HIC} &= 574 \\
\text{Torso deceleration} &= 40 \text{ g}
\end{align*}
\]

The restraint system shall not involve any head restraint.

Safety Seat

The protection of rear occupants was also considered in reinforcing the front seat anchorages and hinges and equipping seat backs with a receptacle for the occupant. However, occupants are still thrown over the seat backs: for the seat backs, being very rigid and stopping the knees, entail an upward trajectory.

Locating the receptacle nearer the occupants would be the only way to avoid this but

Figure 4. 50th-percentile dummies - maximum levels measured.
would seriously impair rear occupant space. This makes it clear that modification of the front seat back is not a suitable solution.

**PRINCIPLE OF THE PROPOSED RESTRAINT SYSTEM**

Peugeot has experimented with quite a different restraint system for the rear seat. This is a seat especially designed to protect young children. It consists of two parts: the seat itself, attached to the seatbelt anchorage points, and the receptacle located in front of the child, who is thus restrained by a large surface padded with a honeycombed material distributing deceleration forces on the whole torso (fig. 1).

The plastic rigidity of the belt is replaced by energy absorbing devices connecting the receptacle to the seat while limiting the forces applied to the torso. The receptacle is designed so that the occupant's trajectory avoids any impact to the head.

When this system demonstrated its efficiency, Peugeot adapted the principle to adults. The restraint system is attached to the center pillars: it consists of a set of tubes at the torso level (that is, the receptacle) and at the lower member's level (fig. 2).

When an impact occurs, the occupant follows a trajectory at the initial speed of the

<table>
<thead>
<tr>
<th>Table 1. Four 50th-percentile dummies—measured levels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Item</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Head:</td>
</tr>
<tr>
<td>(γ) 3 ms (g)</td>
</tr>
<tr>
<td>HIC</td>
</tr>
<tr>
<td>Thorax:</td>
</tr>
<tr>
<td>(γ) 3 ms (g)</td>
</tr>
<tr>
<td>Femur loads (daN):</td>
</tr>
<tr>
<td>Left</td>
</tr>
<tr>
<td>Right</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Two 50th-percentile male dummies at front, one 5th-percentile female and one child at rear—measured levels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Item</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Head:</td>
</tr>
<tr>
<td>(γ) 3 ms (g)</td>
</tr>
<tr>
<td>HIC</td>
</tr>
<tr>
<td>Thorax:</td>
</tr>
<tr>
<td>(γ) 3 ms (g)</td>
</tr>
<tr>
<td>Femur loads (daN):</td>
</tr>
<tr>
<td>Left</td>
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<tr>
<td>Right</td>
</tr>
</tbody>
</table>
vehicle. The distance between the occupant and the receptacle is about 500 mm, which is covered approximately in 0.08 s, thus banning any coupling with the vehicle during the deceleration phase.

Then, the occupant impacts the restraint system at a speed equivalent to the speed variation of the vehicle. The occupant is restrained at the torso level. The tubes are padded with a composite foam material in order to lessen the effects of contacting the receptacle. The energy created in restraining the occupant is dissipated through flexion and distortion of the tubes, their rigidity being calculated to maintain the torso deceleration under 60 g.

The risk of submarining is eliminated by additional tubes located at leg level. The advantage of this solution is to preserve the quality of protection provided by the system for any location of front seats and for every occupant sizes from 6-year-old children on.

**Test Results**

The quality of protection provided by this system was ascertained through impact testing. The receptacle was placed in a passenger compartment mounted on a test sled. Test conditions were selected as representative of actual impact situations. The deceleration law adopted is an averaging of deceleration laws measured on numerous vehicles in 30-degree front impacts (fig. 3).

Impact velocities are about 50 km/h. We reached 43 km/h at the present state of technology and 54 km/h at the time of the impact with braking simulation beforehand.

**Table 3. Four 50th-percentile dummies—measured levels**

<table>
<thead>
<tr>
<th>Item</th>
<th>3-point seatbelts</th>
<th>Static passive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hybrid II 50th</td>
<td>Hybrid II 50th</td>
</tr>
<tr>
<td></td>
<td>(Right front)</td>
<td>(Right rear)</td>
</tr>
<tr>
<td></td>
<td>(Left front)</td>
<td>(Left rear)</td>
</tr>
<tr>
<td>Head: (γ) 3 ms (g)</td>
<td>−</td>
<td>48</td>
</tr>
<tr>
<td>HIC</td>
<td>−</td>
<td>475</td>
</tr>
<tr>
<td>Thorax: (γ) 3 ms (g)</td>
<td>42</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>46</td>
</tr>
<tr>
<td>Femur loads (daN):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>−</td>
<td>200</td>
</tr>
<tr>
<td>Right</td>
<td>−</td>
<td>740</td>
</tr>
</tbody>
</table>

| Femur loads (daN):           |                   |                        |
| Left                         | −                 | 250                    |
| Right                        | −                 | 550                    |
When four Hybrid II male dummies of the 50th percentile were placed in the vehicle, rear-passenger trajectories were appropriate; their presence did not interfere with front occupant protection: we experienced neither a modification of the torso deceleration nor any submarining. The measured levels are lower than the tolerance levels generally admitted (fig. 4 and table 1).

We also verified the quality of protection of the system with a 5th-percentile woman and a 6-year-old child, front occupants being 50th-percentile males (table 2).

The protection afforded to the legs avoided submarining effects and the results were very good.

They were in a situation where the woman folded her legs and the man is sitting obliquely. We also performed a test where the speed at the moment of impact was raised to 54 km/h by simulating a prior braking: the results remain satisfactory (fig. 5 and table 3).

<table>
<thead>
<tr>
<th>Table 4. Synthesis impact test—measured levels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Item</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Head:</td>
</tr>
<tr>
<td>(γ) 3 ms (g)</td>
</tr>
<tr>
<td>HIC</td>
</tr>
<tr>
<td>Thorax: (γ) 3 ms (g)</td>
</tr>
<tr>
<td>Femur loads (daN):</td>
</tr>
<tr>
<td>Left</td>
</tr>
<tr>
<td>Right</td>
</tr>
</tbody>
</table>
All these results obtained with a test sled were confirmed by a synthesis impact test, performed at 44 km/h. (See table 4.)

CONCLUSION

The results registered with this device demonstrated that the safety belt is neither the only solution nor the best one for back seats. The tests were carried out only at 45 km/h, but the technology may be improved and we reached 54 km/h by simulating a prior braking registered in more than one case out of two.

One may object that we propose a device whose cost is without doubt higher than that of the safety belt. Nevertheless, we have seen that the safety belt cannot be used by 30 percent of the vehicle users, composed of children, so that the cost/efficiency ratio is of the same order.

But it is quite different for the comfort/efficiency ratio. This device offers the best safety without entailing at the same time uneasiness and discomfort.

It would be advisable that the authorities in charge of safety do not treat the problems only by constraining laws; so much more than the speed limitations increase the time passed in the vehicles.

Any physical discomfort in the occupant compartment may have psychological effects on the safety in vehicle driving. That is why the master coach-builder, Pininfarina, has been charged with adapting this safety system to the occupant compartment. (See fig. 6.)

This research should be the starting point of a new approach to car safety that would involve compulsory belt wearing in the front of vehicles but in the back seats a less constraining solution, better adapted to the comfort of individual transport, should be devised.

The Behaviour of Vehicles and Occupants in Asymmetrical Frontal Collisions

P. VENTRE, J. C. RULLIER, and J. P. VEROLLET
Renault Crashworthiness Department

ABSTRACT

Based on the one hand, on the examination of European statistics giving the distribution of hit areas for vehicles involved in frontal collisions, and, on the other hand, the analysis of two cases of accidents drawn from the Peugeot-Renault association's multidisciplinary survey, we are studying the behaviour of vehicles and occupants in asymmetrical frontal collisions, especially with a fixed, inclined barrier, using a theoretical approach with a mathematical model and a practical analysis.

INTRODUCTION

The inclusion of frontal collision tests with a fixed barrier inclined at 30 degrees to the left or the right in American legislation, plus the orientations given by CEVE [1] during the fifth ESV Conference in London in 1974, towards an asymmetrical frontal collision, have highlighted work carried out on analysing structural behaviour and restraining devices in these types of accidents.

Indeed, it is far from obvious that vehicles designed to withstand an orthogonal collision with a fixed barrier are suitable for protecting occupants in an asymmetrical collision. Now this type of accident groups together by far the largest number of cases of frontal collisions.

Studies concerning asymmetrical collisions have been carried out following a logical line: examination of statistics to find out the statistical weight of the problem; analysis of road accident cases to define the important parameters, whether they are favourable or not; theoretical analysis of the problem; and practical analysis based on a large number of tests in various configurations and for several different types of vehicles.
A BRIEF REMINDER OF STATISTICS

Statistical analysis is carried out on two levels: multipurpose investigations representing samples limited to several thousands of cases but carried out thoroughly, and national statistics covering all accidents in a country, representing several hundreds of thousands of cases but with some inaccuracy in the data. The latter can then be compared from country to country, or grouped together in groups of countries, thereby allowing a fairly accurate picture to be had concerning the accident situation for a sample so that its statistical validity and field of confidence for the specialists is in no way ambiguous.

Furthermore, when analysing case by case, the importance of codifying should be noted for the validity of the conclusions drawn from the overall results.

Table 1. European statistics for frontal accidents

<table>
<thead>
<tr>
<th>Accident type</th>
<th>France</th>
<th>Italy</th>
<th>England</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Frontal distribution</td>
<td>25</td>
<td>26.2</td>
<td>25.5</td>
<td>14.9</td>
</tr>
<tr>
<td>Frontal offset lh &amp; rh</td>
<td>57</td>
<td>38.7</td>
<td>22.0</td>
<td>55.2</td>
</tr>
<tr>
<td>Frontal greatly offset lh &amp; rh</td>
<td>13</td>
<td>38.7</td>
<td>37.5</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Collision with favourable results, front-wheel drive vehicle (vehicle A).

Figure 2. Collision with favourable results, rear-wheel drive vehicle (vehicle B).
EXPERIMENTAL SAFETY VEHICLES

In this analysis we are particularly interested only in that vehicle in each accident that underwent a typically offset collision with belted-in occupants.

Collision with Favourable Results

A vehicle weighing 900 kg, having front-wheel drive and a lengthwise engine, with two people correctly belted in at the front, is hit on the front left-hand side (fig. 1) by a vehicle of the same weight with a rear-mounted, rear-wheel drive engine, with two front occupants not belted in (fig. 2).

This accident analysed by our usual methods of determining the speed variation $\Delta V$ and mean deceleration $\gamma m$ [2] is well known to us for we have since reproduced it on three occasions. It was considered interesting because of the violence of the collision ($\Delta V = 50-55$ km/h and $\gamma m = 10-12$ $g$), and the very favourable medical report on the occupants. The driver of the first car only complained of various pains in his left shoulder, back, and left thigh, which may have been due to being restrained by the belt; he was rated Injury Severity Level (ISL) 1 because of a slight wound to his left hand. He was not taken to the hospital.

Figure 4. Collision with unfavourable results (vehicle C).

ANALYSIS OF TYPICAL ACCIDENTS

To become familiar with the important parameters for protecting the occupants in this type of collision, it is possible to compare the results of two accidents under similar conditions but having very different results for the occupants. Both of these accidents were taken from the multipurpose investigation carried out since 1970 by the Peugeot-Renault Association's Biomechanical and Physiological Laboratory.

More often than not, the latter are supplied by data processing on a computer, and the syntheses no longer permit the initial information to be referred to. Europeans have largely used the NATO codification, and there are many and detailed statistics. It is rather surprising that we do not dispose of as much accurate data for the United States.

The data now available in Europe are summarized in table 1. It can be seen that for four European countries, asymmetrical collisions represent on an average two-thirds of all frontal collisions.
The passenger, who was dozing, lost consciousness for a short while, had slight contusions to his face and pelvis, and suffered for some time from cervical pains due to his impacting the driver’s right elbow. He was rated ISL 2 and was kept in hospital for 6 days. In the other vehicle, the passenger was killed outright and the driver, who was polytraumatized, was rated ISL 4.

By examining the accident, and reconstituting it, it was possible to obtain an accurate opinion of those parameters that were important for occupant protection. In spite of the violence of the collision (vehicle closing speed in the order of 120 km/h), the occupants of the vehicle we are interested in had three parameters acting in their favour.

Collision Conditions. Offset collision with a small angle between the lengthwise axes of the vehicles, and an interference over one-third to one-half of the vehicles. This increases deformation of both vehicles’ structures, which may seem a paradoxical favourable factor, but which has as a corollary a reduction in the mean deceleration and an increase in the occupant-vehicle ride-down.

Structural Behaviour. High structural strength in passenger compartment area. It can be noted that the front left-hand door opening was hardly deformed, which bears witness to the high body-side strength and a good distribution of the crushing forces from the front to the back.

Behaviour of the Restraining Devices. Excellent performance of the restraining devices. Wholly maintaining free space in front of the occupants within the passenger compartment, allowed the energy absorbers built into the shoulder belts to be used to their utmost. The five strands of energy absorber material were completely broken (fig. 3), which allowed effect on the thorax to be limited, thus explaining the total absence of injury in this region of the body.

It can furthermore be noted that the identical collision conditions for the opposing vehicle did not lead to the same favourable results, for the occupants were not belted in.

Collision with Unfavourable Results

The vehicle we are interested in here is a vehicle weighing 950 kg, with a transversal,

<table>
<thead>
<tr>
<th>Test results</th>
<th>Vehicle A (mm)</th>
<th>Vehicle C (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic crushing in</td>
<td>600-650</td>
<td>600-650</td>
</tr>
<tr>
<td>Dynamic column recoil</td>
<td>90-100</td>
<td>70-80</td>
</tr>
<tr>
<td>Dynamic upward movement of column</td>
<td>150-200</td>
<td>45-55</td>
</tr>
</tbody>
</table>
front-wheel drive engine and one belted-in occupant, the driver. The vehicle was hit at the front on the left (fig. 4) by another vehicle weighing 1 050 kg, with a conventional front engine, rear-wheel drive (fig. 5), and one belted-in occupant, the driver.

This accident, analysed by our usual methods, has a slightly higher violence rating than the preceding one for the vehicle we are interested in, as its mass ratio was slightly unfavourable: 1:1. The vehicle in question was therefore rated as follows $\Delta V = 55-60$ km/h and $\gamma m = 12-14$ g. The driver of the vehicle in our analysis was killed outright, with a serious medical report: head contusions with bursting of the larynx and leg fractures.

If we examine the parameters of this collision, we can see that if we take into account the same three parameters as in the preceding accident, the comments we could make would not be different from all points of view.

Collision Conditions. The violence of the collision was similar to the preceding one, with very close vehicle interference and angle conditions (very slight angle between the lengthwise angles of vehicles, less than 10 degrees, and approximately half-car interference). It is not, therefore, the collision conditions that are responsible for the lack of protection.

Structural Behaviour. Although the total distance as the centres of gravity become closer is similar, and even slightly greater, than for the preceding case, the distribution over both vehicles was not equal. The vehicle we are interested in was much more deformed than the opposing vehicle, and, furthermore,
Figure 9. 90-degree barrier impact, passenger compartment deceleration.

Test
Computed

$V_o = 32 \text{ km/h}$

$V_o = 50 \text{ km/h}$

$V_o = 70 \text{ km/h}$

TIME (5/100 s)
distribution of deformation over the vehicle length was less favourable. The front block, which was quite stiff, made the door and the body side yield. The consequence was a considerable reduction in the space in front of the occupant.

Behaviour of the Restraining Devices. Reducing the occupant stopping space prevented the restraining device, that is, the belt, from functioning. This can be checked quite easily as, in this case as well, the vehicle was fitted with an energy absorber in the shoulder belt, and none of the five strands of material in the absorber was stressed (fig. 6).

The occupant was stopped by the units in front of him, under conditions similar to those he would have had, had he not been belted in. We can furthermore see that the injuries he suffered are quite similar to those that unbelted occupants have.

We would also point out that the opposing vehicle, which was much less deformed, proved to be “aggressive” as far as the vehicle we are interested in is concerned, and the vehicle occupant was rated ISL 4. This bad rating was due to visceral injuries brought about by submarining.

If we compare the behaviour of both vehicles involved in the standard orthogonal collision with a fixed barrier, the differences shown in table 2 can be seen.

It can be seen that vehicle A’s behaviour is apparently not so good as vehicle C’s. The greater column travel highlights greater deformation of the scuttle, the lower windscreen cross-member, and the floor.

We may wonder why a vehicle that was considered relatively better than another in the standard test is no longer the better in an actual accident. We have deliberately chosen two clear cases of accidents, but we must remain aware of the fact that they are not the only ones, and that it would have been easy to take many others, even if they were only those forming the subject of the detailed analyses and reconstructions published during the 19th STAPP Conference in November 1975 [3].

THEORETICAL ANALYSIS OF THE PROBLEM

To get a more thorough understanding of the differences in behaviour of a structure in a symmetrical frontal collision and the same structure in an asymmetrical collision, it would be interesting to carry out a brief theoretical analysis of the significant parameters in the asymmetrical collision.

The Structure

Chronology of the Collision. In a collision with a fixed, inclined barrier, it is possible for two phases to be outlined (fig. 7).

In the first phase, the vehicle colliding with the obstacle at velocity $V_o$ undergoes translation movement, that is, there is no rotation. This phase continues at least up to the
maximum deformation point of the vehicle; mean deceleration is in the order of 10 g. This value, which is lower than that for the orthogonal collision, can be explained easily by the fact that only a small part of the structure dissipates energy.

The second phase starts at the point of maximum vehicle deformation. It undergoes translation movement but rotation as well. The levels of deformation measured on the vehicle are generally lower, in the order of a few g. This phase, when the vehicle sometimes stays in contact with the inclined wall face, ends when the vehicle stops.

Using a Mathematical Structure Model to Simulate an Asymmetrical Collision. Using a model comprising three masses and seven different stiffnesses, it is possible to create frontal asymmetrical collisions in the same manner as for the orthogonal collisions. For example, we carried out one application on a Renault 5 (fig. 8).

1. Determining parameters. To determine the values of different stiffnesses, three orthogonal collisions were carried out at 30, 50,
and 70 km/h using a dynamometrical buffer [4].

The front axle wall and front axle passenger compartment stiffnesses were split into two to take account of the efforts transmitted through the side members whereas the K6 and K7 stiffnesses take account of the wheel compression efforts. Although this distinction is of no interest in the orthogonal collision, it is necessary when considering collisions at an angle for which the crosswise distance between the structural element under consideration and the median centre-line of the vehicle, determines the moment when this unit starts to come into play. The K6 and K7 stiffnesses were determined from wheel compression tests. It can be seen (figs. 9, 10, 11) that the results obtained using the mathematical model in an orthogonal collision with a fixed barrier are satisfactory when compared with results obtained in tests.

2. Applying this model to a collision with a barrier inclined at 30 degrees. The aforementioned model is a unidimensional one that does not allow the vehicle's sideways movements to be reproduced. As the program used does not allow anything but an orthogonal

<table>
<thead>
<tr>
<th>Item</th>
<th>Passenger compartment (mm)</th>
<th>Engine (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test (49.1 km/h)</td>
<td>623</td>
<td>580</td>
</tr>
<tr>
<td>Model (50 km/h)</td>
<td>680</td>
<td>600</td>
</tr>
</tbody>
</table>

Figure 16. Car displacement during an angled barrier test.
collision to be performed, the following device was used: if we suppose the sideways movement to be nil, the collision with an inclined obstacle will take place as follows (fig. 12): K1' stiffness will alone be crushed over a distance of 1\tan \alpha (\alpha \text{ barrier angle}). At the end of travel, K2' stiffness comes into contact with the obstacle. Further crushing equal to 1\tan \alpha is necessary before K4' stiffness in turn comes into contact with the wall. To change from the model simulating the orthogonal collision to the model simulating the collision with an obstacle inclined at an angle \alpha, one has only to shift K2' and K4' stiffnesses of 1\tan \alpha and 2 1\tan \alpha to the rear of the vehicle (fig. 13). Using the specified model (fig. 8), the one usable for a collision with an incident angle of 30 degrees can be determined (fig. 14). Figure 15 shows the rate of deformation acceleration and engine deceleration obtained during the test and with the mathematical model. It can be seen that the engine deceleration curve obtained by calculating is different from that obtained during the test. The reason for this is that the model allowed for breaking of the clutch bell housing, which is always effective in orthogonal collisions with a fixed barrier at 50 or 65 km/h, and breaking does not take place in the 30-degree collision at 50 km/h. There being no breaking explains why the level of actual deceleration curve is higher. The results obtained on deformation are shown in table 3.

Figure 17. Renault 5-30-degree barrier test car displacement and deformation.

Figure 18. Determining speed variation \Delta V.
Figure 19. 90-degree barrier crash, occupant and car movement.

Figure 20. 30-degree barrier crash, occupant and car movement.
SECTION 4: TECHNICAL SEMINARS

Seeing how simple the model is and how easy it is to use, the results can be taken into consideration if only to estimate the approximate amount of deformation.

Restraining Means

Determining Vehicle Deformation. In an orthogonal collision with a fixed and rigid obstacle, the vehicle stops over a distance that is equal to the dynamic deformation. In the case of collision with a fixed, inclined barrier, and to characterize the severity of the collision for the occupants, we can no longer speak of length of vehicle deformation, but rather of vehicle displacement. Vehicle displacement (D) has two sources (fig. 16): deformation d of vehicle and lengthwise displacement $d_1$ induced by sideways displacement $d_2$.

Using accelerometer measurements, it is possible to determine deformation $d_1$ of the vehicle. This is the apparent relative recoil of that vehicle point first coming into contact with the obstacle.

Let $\gamma_L$ and $\gamma_T$ be the values of lengthwise and sideways deceleration measured on the vehicle. Lengthwise displacement $d_1$ induced by sideways displacement $d_2$ is: $d_1 = d_2 \tan \alpha$ with $d_2 = \gamma_T$.

Vehicle deformation d can be written: $d = D - d_1$ therefore $d = D - d$. It is, therefore, possible for the vehicle crushing distance to be determined by double integration of $d = L - T\tan \alpha$.

Figure 17 shows the curve of lengthwise displacement and of crushing, as determined by this method, for a Renault 5 in collision at 49.1 km/h with a barrier inclined at 30 degrees.

To calculate mean deceleration $\gamma_m$, the displacement, that is, 740 mm, must be taken into account, and not the 623 mm, which represents only the dynamic deformation of the vehicle.

Determining Speed Variation $\Delta V$. If $V_o$ is the vehicle to obstacle impact velocity, and $V_L$ and $V_T$ the lengthwise and sideways velocities of the vehicle, at the moment the occupant stops with relation to the vehicle, a simple construction will enable us to determine the speed variation $\Delta V$ and thus its module $\Delta V$. If we suppose the trajectory of the occupant to be straight in relation to the ground (along $V_o$), the angle between $V_o$ and $\Delta V$ will be characteristic of the occupant trajectory within the compartment (fig. 18).

By definition $\Delta V = V_o - V_f$, $V_f$ being the vehicle speed whose components are $V_L$ and $V_T$.

Figure 21. Car deformation comparison for 50-km/h, 90-degree and 30-degree barrier tests.
In practice, for a collision at 50 km/h with a fixed barrier at 30 degrees, $V_L$ and $V_T$ are determined for the instant $t = 0.15$ s.

Determining Mean Deceleration. To take account of the levels of deceleration during the first phase of the collision, the mean deceleration is calculated between the moment the collision starts and the moment maximum deformation is reached.

If $V'_L$ and $V'_T$ are respectively the lengthwise and crossways speeds of the vehicle, and $d'_1$ and $d'_2$ the lengthwise and crossways displacement at the moment the vehicle undergoes maximum deformation, mean deceleration will be:

$$\gamma_m = \frac{1}{2} \sqrt{\frac{(V_o - V'_L)^2}{d'_1^2} + \frac{V'_T^4}{d'_2^2}}$$

Study of Occupant-Vehicle Ride-Down[7].

Definition. The energy $W$ generated when an occupant changes from an initial speed $V_o$ to a final speed $V_f$, that is, $\Delta V = V_o - V_f$, is dissipated in two different ways:

- Deformation of the restraining device (that may be a part of the vehicle being hit): $W_1$
- Further deformation of the front structure of the vehicle due to the occupant: $W_2$

By definition, the ride-down coefficient $C$ is the ratio between the extra energy $W_2$ absorbed by the structure due to the occupant, and the total energy lost by the occupant in speed variation $\Delta V$:

$$C = \frac{W_2}{W} \text{ or } 1 - \frac{W_1}{W}$$

Under these conditions, no ride-down ($C = 0$) will correspond to energy $W$ being totally dissipated by the restraining device, with no overload on the front vehicle structure.

In the case of integral ride-down ($C = 1$), the restraining device absorbs no energy at all; occupant movement is identical to the vehicle's. All $W$ energy is absorbed by further deformation of the front structure. This is the case for secured masses and is not met with in occupants.

Calculating ride-down coefficient. For unit mass, the overall energy is $W = \frac{1}{2} V^2$.

Energy absorbed by the restraining device is:

$$W_1 = \int_0^x \gamma_p \, dx_R$$

where $\gamma_p$ is occupant deceleration and $x_R$ is his movement in the vehicle passenger compartment. Maximum value of $x_R$ is obtained when the relative occupant-vehicle velocity is nil. The restraining device is not supposed to give back any

Figure 22. Car deformation comparison for 65 km/h 90-degree and 30-degree barrier tests.
energy; this hypothesis is valid in the case of a belt fitted with an energy-absorbing device. If \( x_p \) and \( x_v \) are the vehicle and occupant displacements with relation to a reference system depending on final vehicle speed: \( x_R = x_p - x_v \), that is,

\[
\int \gamma p \, dx_p = \int \gamma p \, dx_R + \int \gamma \, dx_v
\]

\[
\frac{1}{2} \Delta V^2 = W_1 + W_2
\]

Table 4. Backwards engine movement

<table>
<thead>
<tr>
<th>Type of car</th>
<th>90° test 50 km/h</th>
<th>65 km/h</th>
<th>30° test 50 km/h</th>
<th>65 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renault 5</td>
<td>165</td>
<td>380</td>
<td>80</td>
<td>210</td>
</tr>
<tr>
<td>Renault 30</td>
<td>165</td>
<td>325</td>
<td>70</td>
<td>195</td>
</tr>
</tbody>
</table>

\( W_2 = \int \gamma p \, dx_v \) is called the ride-down term. This term can be easily determined when analysing collision tests.

Application to asymmetrical collisions. In the frontal orthogonal collision at 50 km/h, for European vehicles the time the collision lasts is in the order of 0.06 second. If we suppose the occupant to consist of a single mass, it is possible to determine his movement within the passenger compartment: included area between the occupant and vehicle speed curves (fig. 19).

In a collision with an asymmetrical obstacle, and especially with a wall inclined at 30 degrees, the collision may last as long as 0.11 second. If the preceding hypotheses remain
unchanged, and with $\Delta V$ being equal, the occupant trajectory within the passenger compartment will therefore be smaller (fig. 20).

The energy absorbed by the restraining device is, in the second case, less than in the frontal orthogonal collision. Furthermore, the occupant-vehicle ride-down obtained with constant $\Delta V$ in this type of asymmetrical collision is greater than in the frontal orthogonal collision.

It is therefore possible, by taking these remarks into account, either to reduce the efforts delivered by the restraining device, and, therefore, increase occupant travel within the passenger compartment by reducing deceleration, or to aim at raising the impact velocity by maintaining the definition of the restraining device.

With constant $\Delta V$ and a restraining device for a given vehicle, the ride-down coefficient may be an interesting pointer to rating the severity of collisions. Thus, at 50 km/h for a Renault 30, the ride-down coefficient is 0.37 for an orthogonal collision, and 0.49 in the case of collisions with a barrier inclined at 30 degrees.

### Comparing Crushing In

Because the 30-degree asymmetrical collision involves mainly one side of the vehicle, it is a well-known fact that this type of collision leads to higher deformation than that obtained in a symmetrical collision with an orthogonal wall that spreads the efforts over the whole structure. The asymmetrical collision leads to deformation going further backward and nearer the passenger compartment (fig. 21, 22).

The 30-degree test enables us to better analyse the body-side strength, at the same time that the ride-down coefficient for the frontal orthogonal is raised (fig. 26).

### Analysing Vehicle Behaviour

Following the theoretical study, we are now going to undertake a practical and comparative analysis of vehicle passenger compartments in collision with the orthogonal wall and at 30 degrees.

**Figure 26.** Wheel static compression test force versus deflexion.
test speed, because of the greater lateral crushing in.

As a corollary of the increased crushing in, the measured mean deceleration is lower in the 30-degree collision than in the orthogonal collision (fig. 23). We have already shown [2] that the mean deceleration thus obtained is quite close to the upper bracket of what happens on the road.

Maximum deceleration is, generally speaking, lower in the 30-degree collision than in the orthogonal collision. This is, however, less evident than for mean deceleration, and depends on the type of vehicle.

Figure 27. Wheel static compression test, energy absorbed versus deflexion.

**Figure 28.** Body-side deformation at 65 km/h.

**90-degree barrier test**

**30 degree barrier test**

Spacing Effect of Engine Block

The spacing effect of the engine block comes about when dynamic crushing is greater than the following distance: overall distance from front to scuttle, minus the engine length.

It depends, therefore, on the quantity of energy to be dissipated, the configuration of the collision, and the architecture of the car (fig. 24).

In the case of lengthwise front-wheel drive engines, the spacing effect of the engine is distinctly more important in the orthogonal collision than in the collision at 30 degrees (table 4). This spacing effect exists for every vehicle for a given collision speed (it may not even happen), and then results in a sudden increase in passenger compartment deceleration, and considerable deformation in the middle part of the car due to the engine impacting the scuttle.

This deformation is extremely rare in actual accidents. It is to be found only in a high-speed collision with centrelines in line with a fixed obstacle, such as a wall or a post. These cases represent only a small percentage of frontal collisions. Furthermore, because
This phenomenon happens in real violent asymmetrical accidents, and leads not only to injuries to the lower limbs but also to the floor collapsing with much more serious consequences due to the scuttle and A pillar coming apart.

The Part Played by the Body Side

We have already pointed out that the body side is stressed much more in an asymmetrical collision such as the 30 degree one than in an orthogonal collision (fig. 28). It should evidently withstand the crushing pressure exerted by the front block components that are in front and deformed over a larger distance than in the collision at 90 degrees. Furthermore, it should withstand any wheel impact.

Any weakness in the body side is therefore better highlighted in a collision at 30 degrees. This can be seen by the crushing of the door sills, and the buckling of the front door thus making it difficult or even impossible to open.

In the analysis of actual accidents we have seen that collapsing of the body side has serious consequences for the occupant (fig. 4). The crushing, which is more often than not related to front door crushing, leads to the front pillar moving backwards, and consequently the dashboard and steering wheel. On top of this, once the phenomenon has started, it is practically impossible to control (fig. 29).

To obtain a satisfactory result, the following solutions may be used.

First, the quantity of energy the body side will have to absorb must be reduced. This can be done by having a front section with stiff sides, whereas in the orthogonal collision, it will suffice for the middle part to be stiff.

However, a compromise must be found between stiffness of the side part and limited aggressiveness. Body-side strength must also be ensured, mainly at front door level, by making it bear on the A and B pillars. Door strength must be ensured by fitting, if necessary, an antibuckling stiffener at the body waist-line level, and located on the caisson (interior) side. From the B pillar back, the stresses are sufficiently distributed in the structure and the inertia forces remaining to...
Figure 30. Renault 5 movement during a 30 degree barrier test.
be overcome are sufficiently low to make it unnecessary to reinforce the rear door.

**Compared Vehicle Movements**

In an orthogonal collision, bouncing back can be seen that varies depending on the cars and speed. Bouncing speed can reach 20 percent of the initial collision speed.

In the 30-degree collision, vehicle behaviour is more complex. A distinction can be made between vehicles rotating in a clockwise direction and those rotating in a counterclockwise direction. But the behaviour of the same vehicle may change depending on the collision speed and the coefficient of friction of the barrier.

However, one should not forget that for 0.15 second, that is, the active and violent phase of the collision for both the vehicle and the occupant, the movement is a pure one.

Observing the vehicle trajectories and analysing the acceleration measurements has shown that, generally speaking, vehicle movement during 0.15 second can be broken down as follows (fig. 30):

- Translation movement in the same direction as $V_o$ and representing the main vehicle movement with relation to the ground
- Translation movement with side movement
- Translation movement and rotation during the last part of crushing

**Compared Influence of Parameters Concerning Occupants**

We have seen that the collision at 30 degrees highlighted the structural weakness of the body side much better than the orthogonal collision. But penetration is not the only factor for accident seriousness.

- $\Delta V$. We note that for a given initial impact speed, the speed variation is generally higher in the orthogonal wall collision because of the bouncing back.
- $\gamma m$ and shape of the deceleration law. We note that the mean deceleration in the 30-degree collision is lower than in the orthogonal collision because the collision lasts longer.

- Occupant trajectory. In an orthogonal collision the occupant trajectory is parallel to the vehicle centreline except for the belt effect. In the 30-degree collision, the occupant trajectory in relation to the ground remains parallel with the initial speed direction whereas the vehicle is subject to the travel and rotation already mentioned. This results in the occupant trajectory within the vehicle deviating from the lengthwise plane passing through the seat centreline. The amplitude of deviation can be appreciated by observing, for example for the driver, the difference between the steering wheel centreline and the dummy’s head at the end of its trajectory in the restraining device. The trajectory can be put in the same category as a straight line forming an angle with the lengthwise centreline of the vehicle equal to the $(\Delta V, V_o)$ angle. This angle is characteristic of a vehicle at a given speed (fig. 31).

![Figure 31. Occupant trajectory inside the vehicle, $(\Delta V, V_o)$ angle.](image)

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CONCLUSIONS

Because our accident survey warned us of the abnormal behaviour in real accidents of certain vehicles, vehicles that were rated well in the orthogonal collision statutory test, and because statistics show that nearly two-thirds of frontal collisions are asymmetrical ones, we have been led to concern ourselves with asymmetrical frontal collision tests.

Among all the analysed types of tests [6], one-quarter wall, half wall, centered or offset post, tests with fixed barrier inclined at 30 degrees would seem to us to give the best structure/restraining device compromise for approaching what happens on the roads (fig. 32).

The 90-degree test with a fixed barrier is unduly severe and not selective: a vehicle considered acceptable is such a test may be incapable of ensuring occupant protection in a real asymmetrical accident.

Another test, which is similar to the 30-degree wall test, is a collision with a fixed, orthogonal barrier that is offset by half a car width. The radius chosen for the obstacle edge does not greatly change the result, but the validity of the test will depend mainly on the accuracy of the impact point. Depending on the type of vehicle, only 5 cm offset with relation to the ideal car or obstacle position can completely modify vehicle deformation and rate of deceleration.

On the other hand, the 30-degree barrier test is for all intents and purposes unaffected by differences in vehicle trajectory when they remain within the limits of what is generally achieved at the present time by all laboratory tests.

The half-wall test, in spite of vehicle kinematics being very close to those in vehicle/vehicle collisions, has the disadvantage of not representing reality because of a rate of deceleration very close to that of the 90 degree test. The relative movements of parts are not realistic: side movements of engines that are characteristic of vehicle/vehicle collisions and collisions with the fixed barrier inclined at 30 degrees, are practically never found in tests carried out on half walls.

Consequently, the collision test with a fixed barrier inclined at 30 degrees is a test capable of improving car safety because it allows the structural behaviour in asymmetri-

Figure 32. ΔV, γm comparison for different types of accidents.

- French real accidents
- American crash recorders
- 90° Barrier test (50 km/h)
- 30° Barrier test (50 km/h)
cal collisions, which group together two-thirds of real frontal accidents, to be better evaluated, and because it allows the protection afforded by the restraining device to be realistically appreciated.

BIBLIOGRAPHY


Nonsymmetrical Front Impact against Barrier—Analysis of the Behavior of the Different Car Models and Consequences to the Occupants

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INTRODUCTION

It is now well established that road accident investigations must be the premise and foundation for safety specifications or regulations. Such investigations prove that:

- The accidents concerning the front ends of cars (the “frontal impacts”) cause more than 55 percent of the occupants’ casualties and more than 60 percent of the connected costs. Therefore, occupant protection in frontal impacts has the highest priority.
- The absolute majority of car occupants’ casualties in frontal impacts are related to nonsymmetrical impacts (in respect to impact direction of deformation area) [1, 2].

Only a very low percentage of car occupants (fig. 1) experiences injuries due to dynamic accident conditions comparable to those met in the symmetrical impact against barrier (requested by the Federal Motor Vehicle Safety Standard (FMVSS) No. 208 and by the Experimental Safety Vehicle (ESV)/Research Safety Vehicle (RSV) Specifications); such test conditions have, therefore, very low statistical significance. This inconvenience cannot be underestimated because the earlier nonsymmetrical tests gave considerably different results from those of the traditional symmetrical tests [3]. Moreover, it ought to be kept in mind that the impact against an orthogonal barrier loads the car just
six comparative symmetrical and nonsymmetrical tests against barriers, carried out with two car models differing in weight, architecture, and crushability.

TEST CONDITIONS

The impact speed for all tests was 50 km/h.

In figure 2, the three different impact configurations are presented.

Table 1 shows the main characteristics and performances (dimensions, architecture, and impact resistance) of the two car models that were utilised.

In every test, two anthropomorphic dummies (Alderson VIP type 40 A male) were sitting in the front seats, restrained by traditional three-point belts and fully instrumented.

The compartment accelerations in three directions (longitudinal, lateral, and vertical) along a characteristic direction of structural symmetry; this is not the case in any nonsymmetrical barrier test, and it is not the case in most real accidents.

In the face of such disadvantages, the symmetrical test has the advantages of an easy and widely accepted definition and of being widely experienced.

At the Fifth ESV conference held in London, the European Experimental Vehicle Committee (EEVC) proposed, for future safety regulations, that a nonsymmetrical test of frontal impact against a barrier be chosen between an impact at a certain angle and an offset one [4].

The National Highway Traffic Safety Administration (NHTSA) opinion is still unknown.

We think it shall be necessary to make a choice between the symmetrical and the nonsymmetrical test; as a first step, however, we propose to extend as far as possible the knowledge about nonsymmetrical impacts.

As a contribution to this knowledge, Alfa Romeo presents, in this report, the results of...
Table 1. Basic characteristics of the tested cars

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>“A” model</th>
<th>“B” model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curb weight (kg)</td>
<td>1 060</td>
<td>860</td>
</tr>
<tr>
<td>Overall length (m)</td>
<td>4.28</td>
<td>3.89</td>
</tr>
<tr>
<td>Maximum width (m)</td>
<td>1.62</td>
<td>1.59</td>
</tr>
<tr>
<td>Maximum height (m)</td>
<td>1.43</td>
<td>1.37</td>
</tr>
<tr>
<td>Wheelbase (m)</td>
<td>2.51</td>
<td>2.45</td>
</tr>
<tr>
<td>Track: front (m)</td>
<td>1.36</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td>1.35</td>
<td>1.35</td>
</tr>
<tr>
<td>Engine location</td>
<td>Front</td>
<td>Front</td>
</tr>
<tr>
<td>Gearbox location</td>
<td>Rear</td>
<td>Rear</td>
</tr>
<tr>
<td>Drive</td>
<td>Rear</td>
<td>Front</td>
</tr>
<tr>
<td>Usable space (m³)</td>
<td>2.16</td>
<td>2.13</td>
</tr>
<tr>
<td>Road area (m²)</td>
<td>6.93</td>
<td>6.18</td>
</tr>
<tr>
<td>Usable space (m)</td>
<td>0.31</td>
<td>0.34</td>
</tr>
<tr>
<td>Mean front-end stiffness (kg/m)</td>
<td>70 400</td>
<td>52 600</td>
</tr>
</tbody>
</table>

near the outer anchorages of the lap straps (in proximity of the side sills) were recorded; some unidirectional accelerations were also recorded in other significant chassis areas.

Figure 3 shows the aspects of the six cars after the test: the different impact configurations can be easily identified by the different front-end deformations.

First Consideration

The car deformation mode is completely different for the various impacts, in relation to the angle and the shape of the barrier. If our purpose is to exactly reproduce the deformations of the real accidents, we must arrange a particular barrier for every accident.

Second Consideration

A question arises whether there is a correlation between the front-end deformation mode of the car and the compartment deceleration components and therefore between the deformation mode and the type of injury to the dummies.

For instance, does a nonsymmetrical deformation cause different accelerations between the driver and passenger? The answer to such questions is given by the analysis of the accelerometric records of the passenger compartment and of the dummies.

ANALYSIS OF THE COMPARTMENT ACCELERATIONS

Figures 4 and 5 show the trend of the instantaneous velocity of the belt anchorages along a longitudinal axis for car A and car B, respectively.

We have chosen the parameter “velocity,” as it is more easily interpreted than the “acceleration” signal and, moreover, because it reduces the relative importance of the very quick acceleration variations that have no effect on the dummy motion [5].

As it is clearly pointed out in figures 4 and 5, the instantaneous velocity differences between the right and the left side of the car compartment are in practice not relevant. That means that the compartment rotational velocity (yaw velocity) can be practically neglected, at least during the “hard” phase of impact. This does not mean, however, that the car will not have rotated at the end of the crash; it only means that the car inertia and the structure flexibility are such that the rotation happens in a time duration that is much longer than the “hard” impact duration (80-120 ms).

In the same interval, the lateral velocity components of the belt anchorages are not higher than 25 percent of the car’s speed at the beginning of the impact.

The largest error we made, when neglecting the lateral acceleration components in comparison with the longitudinal components, was not more than 5 percent.

In the nonsymmetrical tests, the compartment motion in the “hard” impact phase is straight and longitudinal on the whole. The consequences of this result are very important, particularly in the experimental area.

- The presumed complication due to the more numerous degrees of freedom of nonsymmetrical impacts is practically nonexistent; in fact, there is always only one main direction of motion for the compartment: the longitudinal one.
- It looks possible, using the usual frontal symmetrical sled tests, to simulate a wide
Figure 3. Postcrash views.
The accelerometric plots of the thorax (figs. 6 and 7) confirm the actual similarity between the driver's and passenger's motion: this is even more noticeable than the compartment's motion symmetry, and it means that the inner nonsymmetricals (such as the steering wheel) had a negligible effect.

Actually, in our tests, the driver's impact against the steering wheel was very soft; the thorax deceleration was, in every impact, caused above all by the belt load that attained, in the shoulder strap, even values very close to 700 kgf.

Figure 5. Longitudinal motion of the compartment's side sills, car B.

range of nonsymmetrical tests. Only the compartment longitudinal deceleration law is needed, obviously recorded on the real car in the various nonsymmetrical configurations.

- It is reasonable to foresee that the dummy motion (or, at least, its thorax's law of motion) is mainly longitudinal.

ANALYSIS OF THE DUMMIES' ACCELERATIONS

The results of the decelerometric records of the dummies' thoraxes and heads are shown in figures 6 through 13. We will only underline the main conclusions of the data.
Of course, such behaviour cannot be foreseen in all cases, in fact, we think that for higher impact speeds the decelerating effect of the steering wheel should be more important.

For both car models, a considerable parallelism has been found between the belt anchorage's motion and the thorax longitudinal motion (figs. 8 and 9).

Therefore, the thorax deceleration levels in the symmetrical test are much higher than in the nonsymmetrical ones, as it happens for the belt anchorage's deceleration levels.

There is a considerable time delay from the beginning of the impact and the actual start of the belt restraining effect (figs. 6 and 7). This delay tends to rise from 0-degree impact to offset impact to a maximum in the case of a 30-degree impact for both car models.

When we examine figures 8 and 9, we notice that practically, the softer the deceleration of the compartment occurring at the beginning of the impact, the higher the delay.

The higher intervention delay of the belts in the nonsymmetrical tests is caused by the higher car softness in these deformation directions; a longer crush is needed than in the symmetrical test to meet a comparable structural resistance.

Car A has a progressively harder deformation trend than does car B, and will result in more severe occupant protection requirements in every type of impact (figs. 10 and 11). The difference in severity between the two car models is more or less marked, depending on the impact configurations.

The resultant head accelerations (figs. 12 and 13) undoubtedly confirm a selection among the three types of impact, with respect to both acceleration levels and belts' intervention delay. The car severity classifications for the two tested car models are also confirmed.

OVERALL COMPARISON

In table 2, the characteristic parameters of the performed tests are synthetically tabu-
tion characteristics of the cars and because some discrepancies between the head and thorax are shown.

Moreover, in figure 14 we have plotted the values of \( \Delta V \) (speed change) and \( \bar{A} \) (mean deceleration) for the compartment, calculated in our tests according to an estimation procedure proposed by some manufacturers [3] for the real accidents classification.

It can be seen that at constant \( \Delta V \), our tests, too, show higher mean decelerations than in the actual road accidents in the case of the orthogonal (0 degrees) impact against a barrier. The results of the offset and 30-degree impacts seem to be more realistic.

**SUMMARY**

The two comparative sets of frontal symmetrical and nonsymmetrical impacts against barriers, carried out by Alfa Romeo

Figure 9. Comparison of compartment and dummy's thorax motion, car A.
Figure 10. Driver's thorax motion.

Figure 11. Passenger's thorax motion.
Figure 12. Head accelerations of the dummies, car A.

Figure 13. Head accelerations of the dummies, car B.

Table 2. Impact severity parameters

<table>
<thead>
<tr>
<th>Area</th>
<th>Parameter</th>
<th>&quot;A&quot; model</th>
<th>&quot;B&quot; model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0°</td>
<td>Offset</td>
</tr>
<tr>
<td>Car body</td>
<td>Max. static deformation (m)</td>
<td>0.48</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>Longit. velocity change (m/s)</td>
<td>13.8</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>Mean deceleration (g)</td>
<td>22.</td>
<td>14.3</td>
</tr>
<tr>
<td>Driver:</td>
<td>Max. resultant acceleration (g)</td>
<td>62</td>
<td>36</td>
</tr>
<tr>
<td>Thorax</td>
<td>SI</td>
<td>520</td>
<td>253</td>
</tr>
<tr>
<td></td>
<td>Head</td>
<td>108</td>
<td>106</td>
</tr>
<tr>
<td></td>
<td>HI</td>
<td>2 769</td>
<td>1 000</td>
</tr>
<tr>
<td>Passenger:</td>
<td>Max. resultant acceleration (g)</td>
<td>47</td>
<td>34</td>
</tr>
<tr>
<td>Thorax</td>
<td>SI</td>
<td>388</td>
<td>180</td>
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<tr>
<td></td>
<td>Head</td>
<td>103</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>HI</td>
<td>1 945</td>
<td>957</td>
</tr>
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</table>
with two car models, different in weight, architecture, and crushability, have allowed us to clarify some aspects of the nonsymmetrical impacts and therefore to attain a better understanding about real accident dynamics and about the difference between real crashes and standard impacts against barriers.

In detail, the following results are worth being mentioned:

- The compartment motion components that cause the occupants stress are, in practice, the same in the symmetrical and nonsymmetrical impacts against barriers: the basic deceleration direction of the compartment is straight and longitudinal. Therefore, the highest thorax and head stresses have not been systematically found in the dummy sitting in the more deformed side of the cars.

- Independent from the test type, the severity classifications between the car models remain unchanged. Due to their traditional structure, there is really some correlation between the crushability in the symmetrical impact and in the various types of nonsymmetrical tests. However, the behaviour of cars specifically designed for the frontal symmetrical test is not likely to be similar. It is necessary to specify that the efficacy in frontal energy absorption must be all-directional.

- The compartment deceleration levels in the nonsymmetrical tests are lower than in the symmetrical tests, at constant speed variation $\Delta V$. This is caused by the lower crush in the symmetrical tests. For this reason, the symmetrical test cannot actually reproduce the great majority of road crashes that involve two vehicles and hence cause large penetrations.

- The acceleration levels and injury indices of the restrained occupants in all our tests (symmetrical or not) are correlated to the compartment deceleration levels. Therefore, they reflect, in a selective way, both the characteristics of car severity and of test severity.

For all these reasons, we think that our tests confirm the feasibility and the advantage of a standard, nonsymmetrical impact test in place of the traditional symmetrical one.

REFERENCES


A Method of Estimating the Crashworthiness of Body Construction

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ABSTRACT

An index RD (Residual Deformation) has been introduced as a measure of estimating to what extent the car body affects occupant protection in a vehicle collision. This RD can be easily determined from the crash stroke-time curve of vehicle body. Calculations using a simple simulation model were made on this RD index. Further, the experimental results of modified bodies during the Experimental Safety Vehicle (ESV) development were rearranged by RD. As a result, the RD index was confirmed to be effective in the evaluation of body characteristics.

INTRODUCTION

At the Fourth International Technical Conference on Experimental Safety Vehicle in 1973, we reported the developmental results of the four-door, four-passenger ESV family sedans, E1 and E2. In developing these ESV's, a number of variously modified bodies were subjected to a battery of tests. To design a vehicle body that will provide maximal safety in front-end collisions, it is of critical importance that the relationship between the front-end crashworthiness of vehicle bodies and occupant injury values be understood. Regarding precisely what kind of front-end crashworthiness a body construction should have in order to effectively reduce occupant injuries in front-end barrier collisions, there are different ways of thinking, to wit:

1. To reduce the maximum $g$ of body construction
2. To increase the maximum crash stroke of the body
3. To lengthen the duration of $g$ of the body

However, these methods are of no use in evaluating the quality of body crashworthiness of various modified bodies. In this paper, the experimental results obtained since the commencement of ESV development are analyzed to introduce a new index for evaluating vehicle crashworthiness.

RELATIONSHIP BETWEEN BODY CHARACTERISTICS AND OCCUPANT INJURY VALUES

Simulation Model

In order to macroscopically grasp phenomena in collisions, calculations were made

Figure 1. Simulation model.

Figure 2. Occupant restraint device characteristics used for calculation.
SECTION 4: TECHNICAL SEMINARS

restraint device; here the triangular wave shown in figure 2 was used. The characteristics shown in figure 2 are considered to be applicable both to an actual case of restraint with seatbelts and to that with air cushions in nearly the same manner. Further, in this model the chest-g is the object taken as the value of occupant injury.

Figure 3 shows, by way of verifying this model, a comparison of the calculated values and experimental values for occupant restraint by means of air cushions. Although the model is a very simple one, it may be said to express the actual phenomena relatively well as a primary approximation.

Body Characteristics and Occupant Deceleration

The above mathematical model was used to examine the relationship between the body characteristics and the deceleration of the occupant. It was noted that, even though the g waveforms are similar, the values of occupant injury vary despite similar body characteristics (calculated value).

Figure 4. Example showing small occupant injury value variation with different body characteristics (calculated value).

Figure 5. Example showing large occupant injury value variation despite similar body characteristics (calculated value).
terms of the amount of crash stroke including this structural part. As shown in figures 4 and 5, a seemingly small difference in the body characteristics could cause a great difference in the value of occupant deceleration.

Figure 6 illustrates various front-end characteristics. These characteristics were introduced into the mathematical model $K_1$ in figure 1 to investigate variations in the value of occupant deceleration.

Figure 7 indicates the relationship between the body crash stroke and the maximum occupant $g$'s.

Figure 8 shows the relationship between the maximum vehicle $g$'s and the maximum occupant $g$'s.

Figure 9 illustrates the relationship between the duration of vehicle $g$'s and the maximum occupant $g$'s. Regarding these figures, though a rough tendency is seen on each index (horizontal axis), they cannot be said to

Figure 6. Vehicle front-end characteristics used for calculation.

Figure 7. Maximum body stroke and maximum occupant $g$ (calculated value).

Figure 8. Maximum body $g$ and maximum occupant $g$ (calculated value).
be well arranged; and owing to modifications to the body construction made in the developmental process, they are of no use in determining whether the characteristics of the body have been improved or not.

Ride-Down Efficiency

Besides the indexes (1), (2), and (3), there is another index called the "Ride-Down Efficiency" that indicates the quality of various vehicle characteristics. This index is the rate at which the body construction absorbs energy from the total occupant's energy. A vehicle with a higher ride-down efficiency is more beneficial to the occupant.

$$\text{Ride-down efficiency} = \frac{\int_0^t m \cdot a(t) \cdot \dot{X}_b \cdot dt}{1/2 \cdot (mV^2)}$$

$m = \text{Occupant's mass}$
$V = \text{Velocity at collision}$
$a(t) = \text{Occupant deceleration}$
$\dot{X}_b = \text{Body deformation speed}$

Complicated calculations are required to obtain the above ride-down efficiency quantitatively, and its practical application is very difficult. $a(t)$ of the above equation is a value that varies with the quality of the occupant restraint device even if the body has the same crashworthiness. It is, therefore, practically impossible to compare the quality of body crashworthiness between two vehicles from the results of collision tests in which the bodies differ in crashworthiness and the occupant restraint devices used differ in restraint characteristics. Therefore, we have introduced a new index, described below, into the evaluation of vehicle crashworthiness.

INTRODUCTION OF RD (RESIDUAL DEFORMATION)

Residual Deformation

We have taken notice of the stroke-time curve (S-T curve) of the vehicle and have defined the length shown in figure 10 as RD (unit: mm). This is an index that indicates the amount of separation of the S-T curve from point Q in the direction of P. Point Q is the point of maximum stroke to which displacement is assumed to have progressed at an initial velocity. RD, which should originally be expressed by $QR$, is experientially selected after 5 ms from point Q with a practical view to reading the value of RD accurately. So this is in no way physically significant.

Moreover, though the amount of maximum displacement actually varies according to vehicle, a vehicle whose displacement amount is small is considered to be equipped with a
When RD is small
When F~D is large

Figure 11. RD and maximum occupant g (calculated value).

Figure 12. Changes of RD and occupant deceleration waveform (calculated value).

structural part with no reaction force at its front end; thus each vehicle is considered to have a certain constant amount of maximum displacement. In this method, point Q becomes identical if the initial velocity is the same, permitting a comparison which is always under the same condition.

As it may be noted, since RD can be easily obtained if only the S-T curve of the vehicle is known, it has the advantage of being easy to use compared with the ride-down efficiency.

The S-T curve of a vehicle is easily obtained by making a high speed film analysis after experiment. At the design stage RD can be calculated comparatively easily through an estimation of the front-end characteristics of the vehicle by the use of data on the crushing load characteristics of the body member so far obtained in the ESV development. If only this S-T curve can be obtained, it will be possible for us to obtain the RD of the vehicle at the design stage.

Physical Meaning of RD

As stated previously about figure 10, RD is an index that indicates the measure to which the vehicle S-T curve comes off from point Q in the direction of P. Therefore, regarding the following facts it is significant that RD is a large value,

(1) The body crash stroke is small in the initial stage of collision.

Figure 13. Ride-down efficiency and RD (calculated value).

Relationship Between RD and Occupant Injury Value

Figure 11 shows the value of occupant injury in the case of the vehicle front-end characteristics shown in figure 6; this was computed using the model in figure 1 and arranged by RD. As is obvious from the figure, the maximum occupant g decreases as RD increases and both are found to be nearly in linear relation.
SECTION 4: TECHNICAL SEMINARS

Relationship Between RD and Ride-Down Efficiency

When the restraint capability of the occupant restraint device is taken as figure 2, computation of the ride-down efficiency, using the model shown in figure 1, is related to RD as shown in figure 13. The figure indicates that when the crash velocities are the same, both are nearly proportional to each other, and RD can take the place of the ride-down efficiency as a new index of vehicle crashworthiness.

(2) The body crash stroke is great in the latter half of collision.

Consequently, the occupant begins to be restrained early due to (1) at this time, and then the reaction force of the occupant restraint device will not rise too high and the occupant will be decelerated over a long period of time. This can be depicted as shown in figure 12, and it can be said that the larger RD is, the lower the maximum occupant g.

Incidentally, the index RD derives from the amount of deformation that still remains in the latter half of collision in (2) above.

CHARACTERISTICS OF RD

Figure 14 shows the calculated results of 30, 40, and 50 mi/h collisions using the simulation model in figure 1. The figure shows that RD is almost linearly related to the maximum occupant g at each of the collision speeds. Furthermore, in the same vehicle body, RD tends to increase as the crash speed is increased.

The above calculations are based on the assumption that the occupant restraint device has a sufficient stroke and that bottoming does not occur.
EXPERIMENTAL SAFETY VEHICLES

When Bottoming Occurs in Occupant Restraint Device

When bottoming occurs in the occupant restraint device as in figure 15, the vehicle characteristics influence the level of occupant injury very significantly, as shown in figure 16.

In comparatively high-speed collision tests, bottoming of the occupant restraint device was frequently observed. This leads us to believe that increasing the vehicle RD is very important in reducing the occupant injury value.

COMPARISON OF THEORETICAL AND MEASURED RESULTS

Figure 17 shows the experimental results of seven kinds of vehicle characteristics plotted in one figure; the relationship between RD and the occupant chest g is nearly the same as the straight line in figure 11 obtained by calculation. For the occupant restraint devices, an air cushion plus a 2-point seatbelt was used for the front seat and a 3-point energy absorbing seatbelt for the rear seat.

The rear-seat occupant g is generally low compared to the front-seat occupant g. This is considered to result from the fact that the effective vehicle RD to the rear-seat occupant is generally greater than that to the front-seat occupant due to the presence of the slight deformation of the compartment and from the different restraint capabilities of the restraint devices. (In figure 17, occupant g's are plotted in the assumption that rear seat RD is the same as front seat RD in the same vehicle.)

As stated above, the values of the front-seat occupant chest g differ from those of the rear. However, the occupant g decreases as RD increases in both of the seats, and this experimentally supports our thinking regarding RD.

Figure 18 shows the test results of the ESV's (E1 and E2) and actual small-sized cars arranged by RD. It can be seen that these results tend to coincide with the calculated results in figure 14.

CONCLUSION

(1) In vehicle front-end to barrier collisions, the relationship between the vehicle front-end characteristics and the maximum occupant g cannot be well arranged by indexes such as the maximum body crash stroke, maximum g, or duration of g.

(2) Although besides the above indexes there is an index called “Ride-Down Efficiency,” this index is difficult to put to practical use.

(3) The use of the RD index introduced in this paper permits the relationship between the vehicle front-end characteristics and the
maximum occupant g to be definitely ar-
ranged, to wit: as the vehicle RD increases,
the maximum occupant g decreases.
(4) This RD can be obtained from the
vehicle stroke-time curve by a very simple
procedure and is quite easy to use. In addi-
tion, the use of the S-T curve effectively
reduces the amount of scatter in measured
values.
(5) If it is possible to estimate the vehicle
front-end load stroke characteristics from the
design drawings, and so forth, the vehicle S-T
curve can be derived from these character-
istics comparatively easily, and hence the
quality of the vehicle characteristics can be to
some degree presumed at the initial design
stage.
(6) As a result of collating the collision
test results on several vehicles with different
front-end characteristics by using RD, we
were able to ascertain the foregoing items in
our tests using actual vehicles.

Experimental Program on Frontal Impact Test Procedures—Preliminary
Report

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ABSTRACT

Part of the United Kingdom’s contribution
to the development of European car safety
standards consists of a series of full-scale
impact tests using three models of cars of
similar mass but distinctive layout (conven-
tional, front drive, and rear engined). The aim
is to compare different impact test procedures
in relation to occupant protection in frontal
impacts. The relative merits of the test meth-
ods for ensuring equal severity for different
models of cars and encouraging good design
for safety are discussed.

The test programme includes car-to-car
head-on impacts with 40 per cent overlap and
a series of tests of cars impacting into
different types of partial and angled barriers.
All cars were moving at about 50 km/h. The
paper briefly describes the test facilities and
gives some preliminary results from the par-
tially completed programme.

INTRODUCTION

Three years ago the European Experimen-
tal Vehicles Committee (EEVC) recognised
the need for concerted work in Europe to
prepare for possible international require-
ments to improve protection for car occu-
pants in accidents. A working group was set
up under the chairmanship of Dr. Pocci and
the group quickly agreed on several guidelines
[1]. It was recommended that compliance
with future standards should be checked by
measuring decelerations and loadings on
dummies under conditions representative of
road accident impacts. It was assumed that
car occupants would mostly be wearing seat-
belts, and the test dummies would be appro-
priately restrained during the tests. Full-scale
impact test would necessarily be restricted to
an absolute minimum and most attention
should be given to frontal impact, some to
side impact into cars, and possibly some to
simple requirements for the less frequently
injurious rear impacts and overturning sit-
uations. The need for compatibility between
large and small cars to ameliorate impacts into
small cars was recognised as was the need to
modify car designs for the protection of
pedestrians.

Several of the experimental safety cars
presented at the Fifth Experimental Safety
Vehicle (ESV) Conference demonstrated that
protection greater than that needed in all but
very few accidents can be produced in practi-
cal engineering forms. Since 1974 much work

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nic Majesty’s Stationery Office.
has been carried out. Many of the new designs of production cars provide better impact protection than did their predecessors. The current work is a contribution to finding out how test requirements might be set up. It has been planned on the basis of accident studies [2] and the working group 2 recommendations [1] from EEVC and forms part of the United Kingdom's contribution to working group 5 of EEVC, which is continuing the work started by group 2.

**DESIRABLE IMPACT PROTECTION FEATURES FOR FRONTAL IMPACT TESTS**

The companion accident study [2] and the results of some of the tests being reported in this paper suggest that there are five considerations when proposing a package of requirements for frontal impact:

1. The need to check on the restraint system to show that the restraint itself and the car interior are suitably matched in design assuming that the interior is not damaged.
2. The need to check that the frontal structure resists intrusion into the passenger compartment.
3. Encouraging designs for cars that will not interlock in highly offset impacts.
4. Ensuring that there is an acceptable degree of compatibility in impacts between large and small cars.
5. Setting impact requirements at levels which correspond to fatal and disabling injury severities.

It does not seem possible to select one test to check that all these requirements have been met. The main objective of the tests described in this paper is to find what tests might check the second of these requirements (freedom from intrusion), although there are implications for some of the others. The tests are either car-to-car frontal impacts between three models of cars of different layout or corresponding car-into-barrier test impacts. The present paper is a progress report and not a final one. It is hoped that the completed programme will give some indication of several important features of impact tests:

- Realism of representation of accident circumstances
- Accuracy needed for main test conditions
- Repeatability of results
- Indication that tests are likely to ensure safe designs in the longer term
- Verification that tests are of similar severity for cars of different layout
- Durability of test devices such as dummies

Tests should be reasonably representative of the accident circumstances most commonly causing serious injury to vehicle occupants. Although stylized tests can be developed for assessing existing designs of components or occupant protection devices, if these designs change such tests may prove unsuitable. An example of this is the Blak Tufy test that was developed for assessing low angle steering wheel and column assemblies in impact from the driver's chest. As higher angle columns have increased in popularity, its suitability has been brought into question.

Following the requirement that tests must be representative of accident circumstances is the need to verify that any tests proposed are equally representative in severity for cars of different layouts. If a particular layout or construction of a car gives an enhanced performance in an accident, then the test should reflect such a performance. For other layouts it should not unduly penalise any of those that behave adequately in accidents.

The tests described in this paper form part of the United Kingdom's programme to assess various proposed methods for carrying out impact tests. This programme is made up of the following stages:

1. To identify the most frequently occurring injury-producing accidents by analysis of accident data.
2. To carry out tests reconstructing the accidents identified in phase 1 to determine the important parameters in these accidents in terms of vehicle deformation and deceleration characteristics using a representative range of vehicles. The car-to-car impacts described in this paper represent this phase of the programme.
3. To assess various test methods proposed in the light of the above tests to
SECTION 4: TECHNICAL SEMINARS

Figure 1. The different types of impact tests carried out.

Test A: Full head-on impact into 30° angled barrier

Test B: Partial head-on impact into barrier face normal to car direction of travel

Test C: Partial head-on car-to-car impact, both cars moving at same speed on parallel axes
see how closely they represent the parameters in the accidents and how suitable they are for use as routine test procedures for occupant protection assessment including their repeatability.

4. To consider the effect of the most suitable test methods chosen in phase 3 by using them on current production vehicles and determining the economic cost of complying with the test at various levels of protection. This phase will provide further feedback of data for the next phase.

5. To set realistic test speeds and tolerance levels in terms of dummy measurements that will result in worthwhile reductions in injuries at an economically viable cost. Again these will be based on analysis of accident data.

6. To determine the probable effect of the proposed test methods in order to ensure, as far as possible, that their introduction will have the desired result of encouraging the production of vehicles giving a reduction in injuries in accidents rather than merely causing design modifications that produce little safety improvement in the longer term.

**CARS USED IN THE TESTS**

Three basically different models were selected. These were:

- **Leyland Marina** A steel unitary construction two-door coupe with front engine and rear-wheel drive
- **Leyland Allegro** A steel unitary construction two-door coupe with front engine and front-wheel drive
- **Volkswagen Beetle** A steel platform construction two-door coupe with rear engine and rear-wheel drive

One car of each model was subjected to each barrier test of type A (angled) and B (offset) (fig. 1). Type C tests were also made with one of each model impacting another of the same model and one of each of the other two. Additionally, a front-engined, rear-wheel drive, Ford Cortina Mark III two-door saloon (P2) was impacted into a Marina and a front-engined, front-wheel drive Fiat 128 (P5) into an Allegro. All the cars used were of nominal 1 300 cc engine size, of 1 000 kg ± 100 kg weight in the test conditions with dummies, structurally sound and free of rust and previous accident damage. They were of 1970 or later manufacture. All the cars were fitted for the tests with the same design of lap and shoulder inertia reel belts for both driver and passenger.

To indicate differences in impacts occurring on a major longitudinal structural member and impacts outside of such a member, different degrees of overlap were used ranging from 20 per cent of car width to 30 per cent of car width in the type B tests and from 30 per cent to 45 per cent in the type C tests.

**TEST METHOD**

The three types of impact tests are illustrated in figure 1. The same methods of propulsion, control, instrumentation, and recording are used in all three.

**Propulsion and Control**

The impact car(s) are attached to a cable and pulley system and towed to impact by a tow car driving away with one end of the cable attached. The speed at impact is controlled by the speed of the tow car. Guidance of the impact car(s) is achieved by running the nearside pair of wheels of each in a channel fixed to the test track to give the desired relation of car-to-car or block on impact. This channel ends about 0.5 m before the point that the nearside rear wheel reaches impact. The car is also automatically released from the tow cable as it leaves the guidance channel so that at impact it is free from restraint. In the event of a test having to be stopped during the run up, a single control releases all cars from the cable, cuts their
Table 1. Available results of impact test programme

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<th>Car serial number</th>
<th>Make</th>
<th>Model</th>
<th>Weight as tested (kg)</th>
<th>Per cent of car width</th>
<th>Velocity at impact (km/h)</th>
<th>Rotation at .003s (degrees)</th>
<th>Off-side A.B. post at waist level (mm)</th>
<th>Off-side A.B. post at sill level (mm)</th>
<th>Passenger compartment deceleration* (g)</th>
<th>Driver (Fore and aft deceleration) (g)**</th>
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* Maximum for more than .003 of continuous duration.

b British Leyland.

c = anti-clockwise.

d = clockwise.
ignition, and applies their brakes to decelerate them at about 0.6 g. Car engines are run at normal r/min for the speed of impact and lights are switched on.

Instrumentation and Recording

Impact cars are equipped with event markers and passenger compartment accelerometers; safety belts are marked to enable the amount of extension to be obtained from high speed cine film and are fitted with load gauges to lap, shoulder straps, and the buckle.

Two Occupant Protection Assessment Test (OPAT) dummies are used in each test of type A and B as driver and front seat passenger of the car, but in type C tests as drivers of both cars. Front seat passengers in the car-to-car tests are RAE Mk VB dummies, which are not instrumented. Head and chest and fore and aft accelerations, chest deflection, and femur loads are measured for each OPAT dummy. Impact speed is obtained from recorded signals of light-sensitive transistors as the car travels the last 3 m to impact. Signals from all the instruments are fed by trailing cable to multi-channel recorders in stationary vehicles located midway between the tow start and impact points.

High Speed Cine Film

High speed cine cameras operating at about 400 frames per second are located to give whole car and front half closeup films from both sides of the car(s) and from overhead. The films are analysed to obtain car and dummy movement and velocities, as well as seatbelt extension using a Vanguard automatic printout analyser.

RESULTS

The results so far available from this program of work are given in table 1, but a more detailed study of the features, such as passenger compartment intrusion, is needed before making full comparisons.

Although the driver's chest and head struck the steering wheel assembly in many of the cars, the human tolerance levels suggested in references 3 and 4 were not exceeded in any of the tests. The seatbelt buckle loads were greater in the angled barrier tests than in the other tests; however, only the total belt load of 18.3 kN for the driver of car N3 exceeded the 17 kN tolerance load suggested in reference 4. The seatbelt failure that occurred on vehicle N1 was due to a defect in the belt mechanism that permitted the belt to unlock after the initial lock up. The major injury risk appeared from the femur loads to be due to knees impacting facias. In cars N2, N8, and P5, femur loads exceeding the suggested 4 kN injury tolerance level were recorded and in cars N4, N11, and P4 the loads equalled this value.

The most noticeable differences between the types of test were in the trajectories of the car after impact and the pattern and degree of structural deformation.

In the angled barrier tests the cars were pushed around in the direction of the barrier slope (counter-clockwise); they changed their direction of motion and slid off the face of the block. In the car-to-car and partial barrier tests, all the cars closely retained their original directions of motion. Those constructed in the more usual European pattern (Leyland, Ford, and Fiat) with two main longitudinal structural members to the front compartment, tended to engage the impacted object, rotate in a clockwise direction, and recoil.

The possible effect of width of engagement was illustrated by the trajectories of the Volkswagen cars. Tests N2 and P7 (type C), which had the greater width of overlap, behaved much as the other cars. Car N6 in the partial block (type B) test, car N11 (to Marina), and cars P3 and P4 (into one another, type C tests) were pushed to one side at impact with only slight counter-clockwise impact rotation and then continued in a straight line in the pre-impact direction of travel for at least 0.1 second, finally turning to the right under the influence of the steered wheels that had been impacted into a right hand lock. Examination of cars and film showed that in these cars with a lesser width of overlap, the impacts had either been outside the stiff point formed by the bumper mounting (N6 and N11) or had coincided on the offside mounting point (P3 and P4). The
bumpers of the Volkswagens tested were much stiffer than those of the other cars tested and were also considerably curved in the horizontal plane of the car. It is considered that this had prevented entanglement of the cars, in particular of the offside front wheels, and guided them off to the side of the block or car impacted.

In the angled barrier tests, crushing of the front compartment was spread across the width of the car. In the car-to-car tests and car-to-partial barrier tests, crushing was generally confined to the offside of the compartment and in some cases the nearside was extended as the front compartment was pulled around to the offside in the impact. Passenger compartment intrusion was, therefore, greater in the car-to-car and car-to-partial barrier tests as is indicated by the measurements given in Table 1 both for forward movement of the centre of gravity point after 0.1 second (when the cars had rotated less than 5 degrees), and the final reduction in A post-B post measurements at sill and waist levels.

The driver's door of P8 opened during the impact with P7 as distortion of the door panels operated the link rod between the interior handle and the lock mechanism. In all other impacts the door locks held.

The effect of barrier edge radius in the type B tests and of a plywood face on the angled barrier (type A) test in preventing the impacting car from sliding off will not be available until the completion of the programme. This entails analyses of the results of four more car-to-barrier tests already made and five tests now being carried out.

DISCUSSION OF RESULTS AND CONCLUSIONS

Whilst detailed assessments of the results of the various car-to-barrier tests await the completion of the programme, the results of testing to date have shown the following points of interest.

- Both the tests of car-to-angled barriers (steel-faced and 30 degrees to head-on) and car-to-offset barriers with radiused edges, reproduce reasonably well the damage to cars seen in the car-to-car impacts with 40 per cent overlap. There is a tendency for car front structures to be forced away from the site of impact in car-to-angled barrier tests but to be pulled around towards each other because of interlocking of the two vehicles in the car-to-car impacts and interlocking of the car into the barrier in the car-to-barrier tests. This difference affects only the later stages of the trajectories of the occupants.

- Corresponding to the differences in damage between car-to-car and car-to-offset barrier tests on the one hand and angled barrier tests on the other, it has been shown that the cars rotate in opposite directions. When striking an angled barrier there is also some tendency for the car front face to slide along the barrier face and not to be brought to rest at the point of impact. The car thus experiences a reduced change in velocity compared with car-to-car impacts and this in consequence reduces impact loadings measured on the test dummies. These reductions are probably greater for a narrow steel faced angled barrier because cars can slide around the side of the barrier past the rear edge of the front face.

- These conclusions are based on steel-faced angled barriers with relatively low friction between car and barrier. Studies in the United States, France, and elsewhere, have been carried out with plywood-faced barriers that have greater effective frictions because of damage to the wood face. Presumably any face that prevents the car front sliding along it does not so easily give an opposite rotation and reduced change in velocity compared with typical car-to-car impacts. The current part of the United Kingdom's programme is investigating this point.

- In all cases the tests of cars into offset barriers with suitably rounded edges gave good representations of car-to-car impacts although the results at low overlaps appear to be sensitive to the match between the particular percentage overlap, the edge radius, and the detailed front structural design of the car. It appears from further results not yet fully analysed that satisfactory barrier performance can be achieved.
with overlaps of about 30 per cent and a suitable edge radius as a means of representing car-to-car impacts with 40 per cent overlap.

- In the car-to-barrier and to a lesser extent in the car-to-car impacts, the VW Beetle showed a marked tendency to glance off the vehicle it impacted at the degrees of overlap tested. This resulted in lower velocity changes for the occupants and less severe injuries might have been expected if full occupant protection had been afforded by the interior of the vehicle. This tendency to glance off was much stronger than in any of the other models tested, probably due to several design features. First, with the rear-engined layout the mass of the vehicle is concentrated more to the rear, making it easier for the front of the vehicle to move sideways in an impact. Second, the bumper is comparatively rigid and tends to resist penetration by the opposing vehicle structure. This reduces the chances of interlocking. The bumper is mounted at two points fairly close to the centreline of the vehicle and so can pivot about these points reasonably, readily deflecting the vehicle off whatever it strikes. Third, this pivoting of the bumper appears to deflect the front wheels away from the point of impact encouraging the vehicle to glance off.

- The standard inertia reel seatbelts used for the front seat dummies were of one design that generally performed correctly with belt loadings for 50 km/h impacts and were generally acceptable in relation to estimated tolerance levels [4].

- OPAT dummies have been used throughout this series of tests. To date two dummies have been used and each dummy has experienced 16 50 km/h impacts. One femur load cell has been the only component requiring a repair.

It would appear from the results available so far from this test programme that it will be possible to propose a frontal impact test of a car into a barrier that will verify that a car's structural design sufficiently resists intrusion into the passenger compartment. Bearing in mind that about half of the most serious frontal car impacts are across much of the car front, it may be appropriate to check the restraint system performance at greater decelerations and changes in velocity than produced by intrusion check tests. Such a test may not need to be a full test, but rather a test of dummies in a body shell placed on an impact test rig and subjected to a representative deceleration. This pair of tests could be developed to ensure that many fatal and severe injuries to car occupants would be avoided by improved car design. Consideration is now being given to assessing compatibility between cars of different size and design, perhaps by using an impact test similar to those being reported. The barrier might have either a deformable face or one that measures impact forces and might possibly be mobile rather than rigid.

ACKNOWLEDGEMENTS

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REFERENCES

The Accles Britax Automatic Cushion Restraint—Its Use in Delivery Vehicles

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ABSTRACT

The Automatic Cushion Restraint (A.C.R.), a passive system, consists of a cushion or pad, 70 square inches in area, held in light contact with the chest, and a knee restraint. In normal travel the occupant of a vehicle is free to lean forward, but in an emergency the arm carrying the cushion is locked to the floor, and in a frontal impact exerts a predetermined force to bring the occupant safely to rest.

The A.C.R. system can be applied to private cars and is particularly suited to delivery vehicles and the like, where drivers have to enter and leave frequently. For this reason, the United Kingdom Transport and Road Research Laboratory is to organise and supervise trials, which will include 30 mi/h impact tests and user studies under service conditions, on A.C.R. units fitted to Post Office vans. This study is to be carried out in cooperation with the Post Office, the Post Office Management Staff Association, the Union of Postal Workers, and the Post Office Engineering Union.

This paper describes the latest A.C.R. designs, the work already done to assess its performance in accidents and its convenience in use, and the evaluation to be carried out by the Transport and Road Research Laboratory.

WHAT IS AN AUTOMATIC CUSHION RESTRAINT?

It will be recalled that the Accles-Britax Automatic Cushion Restraint (A.C.R.) system was described in a paper presented by one of the authors [1] to the Second Interna-

Figure 1. Two 50th-percentile males, Simca 1100 interior.
Figure 2. A 50th-percentile female and a 90th-percentile male, Simca 1100 interior.

Figure 3. Schematic layout of the mechanical system of Mark 1 units.
approximately constant force of 1500 lbf at the hinge point of the pad. This load is distributed over the area of the cushion so that the average pressure exerted on the chest is less than 25 lb/in². The lower part of the body is decelerated and prevented from “submarining” by a knee pad or cushion placed in front of the knees.

CAN A.C.R. UNITS BE FITTED TO DIFFERENT TYPES OF VEHICLES?

The first A.C.R. units produced were of the Mark 1 type shown in figure 3. These units were designed to be fitted to each side of a transmission tunnel adjacent to the front seats, or if the car floor is flat, to a centrally placed bracket.

A Mark 2 mechanism has since been developed that has been packed in a case almost half the size of the Mark 1 unit. The compactness of the Mark 2 mechanism allows units to be placed on top of a transmission tunnel between the seats as illustrated in figure 5. Standard units are bolted to a saddle that is specially designed to fit the transmission tunnel and, if necessary, the underside of the tunnel is strengthened. Existing designs allow A.C.R. units to be fitted to most cars and commercial vehicles without major modifications to their interior. The system can be installed when the vehicle is manufactured or later as an accessory.

The restraint has been found to be particularly suitable for small commercial vehicles of the types used for collecting mail, delivering goods from door to door, servicing apparatus, and the like. The drivers of such vehicles, and sometimes their assistants, have to get in and out of their seats many times a day, and in most cases will not take the trouble to use ordinary lap and diagonal seatbelts. In Great Britain, where the compulsory wearing of seatbelts is likely to become law in the near future, the occupants of vehicles of this type may have to be given exemption from wearing belts, unless some acceptable alternative, such as the A.C.R., which requires less effort by the wearer, is adopted. The commercial class of road user is, generally, exposed to the dangers of traffic more frequently and for
Figure 5. General arrangement of a Mark 2 installation.
longer periods than the private motorist. Exemption from wearing belts would mean that the commercial road user is at greater risk than others when performing his job.

DOES A CUSHION RESTRAINT SYSTEM PROVIDE ADEQUATE PROTECTION?

Let Us First Consider Some of the Studies Carried Out on the Performance of the System in Frontal Impacts

In the paper presented by Grime in 1972, calculations of the performance of the restraint were made for a barrier impact at 30 mi/h—calculations that were possible because of the predictable behaviour of the mechanical components of the system. It was assumed that the effective mass of the chest of a 50th-percentile man was 60 pounds and that the chest pad moved forward when a load of 1500 lbf was exceeded. The movement of the pad required to restrain this 60-pound chest was then calculated to be between 7.5 and 9.4 inches. At the knees, the movement was calculated to be between 5.8 and 7.8 inches for a decelerating force of 2000 lbf. A test with two 50th-percentile dummies at the Motor Industry Research Association was found to be in general agreement with the calculations for the chest, but neither knee restraint allowed enough forward movement. Since the paper was written further experimental work has been done, in the first place to check the basic theory of the device, and secondly, to assess its performance under standard test conditions similar to those used in approval procedures for seatbelts. Frontal impacts were simulated at the Byfleet plant of Britax (London) Limited with an impact machine that produces a good approximation to a half sine wave deceleration/time curve. The sled carrying the dummy was arrested by seatbelt webbing, and the duration of the impact was adjusted to be 0.09 seconds, corresponding with that commonly experienced in barrier impacts with European cars. The velocity changes ranged from 25 to 32 mi/h. Fiftieth-percentile dummies for three different types were mounted on the sled, two being of simple construction, the first of a Royal Aircraft Establishment dummy, and the second a dummy of the type used in the British Standard dynamic test for seatbelts; the third, an Ogle dummy, was of the most modern type. The tests were of two kinds, first with the dummy restrained by an instrumented mock-up of the system, which enabled forces and movements at chest and knees to be measured; three different chest loads were used and the slack at both the knee and the chest was varied. In tests of the second kind, Mark 1 restraints were tested for operating characteristics and strength.

The results of the laboratory tests confirmed the basis of the original calculations as far as the chest was concerned. However, the force required to restrain the knees was found to be considerably less than had been assumed (about 1000 instead of 2000 lbf). The properties of the knee restraint are, therefore, less critical than was originally thought, and are probably satisfied if the knee impact area is of good modern design.

It was also important to demonstrate that the A.C.R. is capable of meeting the test requirements applied to seatbelts. British seatbelts, most of which are of the 3-point lap and diagonal type, must be tested and approved by the British Standards Institution Test House. These tests have now controlled the design of seatbelts in Great Britain for over a decade, and have produced belts of a high standard, which the most authoritative research has shown to reduce the incidence of serious and fatal injury by about 50 per cent, when worn by the occupants of front seats of cars, under the traffic conditions prevailing in Great Britain. The most important part of the approval procedure consists of a dynamic test in which the sled carrying a simple 50th-percentile belted dummy is arrested in a distance of 24 inches from 30 mi/h. The main requirements of this test are that the belt shall be substantially undamaged and that the forward movement of the dummy relative to the sled shall not be more than 12 inches at the shoulder and 8 inches at the hip.

An equivalent test of the A.C.R. was carried out at the British Standards Test Centre with the same conditions for speed and stopping distance. The tests were made
with two different energy absorbers, one giving a force at the chest pad hinge of 1 400 and one of 1 800 lbf. The knee restraint was placed at approximately 6.5 inches from the dummy's knees. Locking of the arm was by means of the inertia locking mechanism only. The resulting forward movements of the chest pad were respectively 4.8 inches and 2.4 inches, and the corresponding movements at the shoulder of the dummy were 4.8 inches and 3.8 inches. At the hip, the forward movements were 10 and 9.5 inches. Thus, even with the weaker energy absorber, the movement at the shoulder was less than one-half of that allowed by the British Standard. The movement at the hip was of necessity greater than the 8 inches allowed by the Standard, because there were 6.5 inches of free movement before the knees made contact with the knee restraint. However, the resulting attitude of the dummy, inclined backwards at an angle of about 12 degrees, was better than if the greater movement had been at the shoulder, because there would be less likelihood of the head striking the interior of the car (the British Standard allows a forward inclination of the dummy of more than 10 degrees).

Finally, the results of a real accident may be of interest. A Rover car, fitted with early prototype A.C.R. units was involved in a head-on collision with another car. This resulted in an estimated velocity change for the Rover of 25 to 30 mi/h. The driver, a man, 6 feet 1 inch tall and weighing 190 pounds, and the front seat passenger, a girl 11 years old, were protected only by the A.C.R. and were unhurt. These early prototype restraints were not fitted with energy absorbers and, on impact, were locked to the floor. The girl was restrained without any permanent movement of the chest pad, but on the driver's side, the floor was distorted by the force decelerating the driver, although it was certainly great enough to restrain a heavy man without serious contact with the inside of the car.

What Protection Will It Provide in Roll-Over Accidents and Side Impact?

The A.C.R. may be expected to have beneficial effects in roll-over accidents. Mackay and Tampen [2] found that the steering assembly greatly reduced the risk of ejection for drivers in comparison with front seat passengers in roll-over accidents. One would, therefore, expect the A.C.R., which lies much closer to the occupant's body than a steering wheel, to be even more effective in preventing ejection for both driver and passenger; and the arm itself is likely to prevent movement across the car.

Mackay and Tampen also found that 95 per cent of the occupants in their sample received a head or face injury caused by impact with the inside of the car. The A.C.R. should prevent most impacts with components in front of the occupants, and these were shown to account for nearly 50 per cent of those suffered by drivers, and over 25 per cent of those suffered by front seat occupants.

Ejection is also of some importance in side impacts, and the A.C.R. may be expected to have the same beneficial effect as in roll-overs; and in side impacts there is often a frontal component and as a result the occupant will tend to be prevented from moving sideways by friction with the chest pad.

IS THE A.C.R. SYSTEM ACCEPTABLE TO THE USER?

When designing the A.C.R., considerable attention was given to the shape and structure of the chest pad as well as its position to ensure maximum comfort and convenience for all types of users. It was found that a pad of the shape shown in figure 5 having a height of 7 inches and an area of 70 square inches can be placed so that it provides good protection without adjustment, for anyone between the size of a small (2.5 percentile) woman and a large (97.5 percentile) man. In cars, a simple adjustment has been provided for child passengers, but this is not needed when the system is used in commercial vehicles. A hinge has also been introduced to allow the cushion to rock slightly in the vertical plane so that it adjusts to chest and stomach profiles.

Provision has been made for the cushion to be locked away from the occupant when the ignition is switched off to give extra freedom.
when the vehicle is parked. When locked in this way, the cushion and arm give support to anyone getting in or out of the car. When the ignition is switched on the arm is released and the cushion moves gently into position against the occupant's chest.

Another improvement has been to arrange that the arm is locked in position whenever the footbrake is operated. This mainly benefits passengers, preventing them from moving forward in heavy braking; it also protects sleeping or inattentive passengers. Perhaps more important still, it eliminates any delay, small though it may be, in the inertia lock.

Several thousands of miles of driving experience have been gained with prototype installations in cars, and the opinions of a large number of people of both sexes as to comfort and convenience, both as drivers and passengers have been obtained in separate investigations carried out by Accles Britax Limited and an independent consumer research organisation in the United Kingdom. The reactions of drivers, both men and women, are generally favourable, and many claim to prefer the A.C.R. to a 3-point safety belt, even to one of the emergency (inertia reel) type. The reason for the preference is probably the greater freedom of shoulder movement which the newer system allows.

Most women who have tried the system favour it. They find the cushion comfortable and several have said that it gives them a sense of assurance. Many who find seat buckle and strap adjustment arrangements confusing welcome the simplicity of the new system.

WHAT OTHER TRIALS ARE PLANNED?

Contracts have been placed by the Transport and Road Research Laboratory for the construction of two types of passive restraint systems for Post Office vans, an automatically placed seatbelt and the cushion restraint. Trials have been planned to assess the convenience and acceptability of the two systems to the users under working conditions. Before the vans are put into service, however, 30 mph barrier impact tests will be carried out to ensure that the systems are correctly matched to the model of van.

The Post Office employs large numbers of vans for collecting and delivering mail, and for various servicing purposes. Both the Post Office management and the unions represent-
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ing the operators are anxious that, when compulsory wearing of belts is introduced in the United Kingdom for the general public, an alternative restraint system is available that is more convenient and acceptable than ordinary seatbelts and gives comparable protection.

Before the Post Office agreed to take part in the Transport and Road Research Laboratory study, demonstrations of the restraint systems were given to representatives of both management and staff unions. Cars fitted with the restraint systems were driven around a network of roads specially designed to simulate typical motoring hazards such as islands, hump-back bridges, bends, and junctions. Those taking part included representatives of the Postal Headquarters Motor Transport Division, the Safety Services Branch and Telecommunication Headquarters, the Post Office Management Staff Association, the Union of Postal Workers, and the Post Office Engineering Union. All were satisfied that the proposed "user" study should take place.

Post Office workers make use of small delivery vans for two main purposes: first, for the collection and delivery of mail, and secondly, by Telecommunication engineers for installation and maintenance work. Working conditions differ in the two branches of the service; in Telecommunications, journeys are generally longer than in the Postal vans making collections, and entries and exits less frequent. In spite of this difference, it was agreed by representatives of unions and management that in both types of work there is a need for a restraint system that requires less effort on the part of the driver and his companion than ordinary seatbelts, if these workers are to have protection comparable with that enjoyed by the general public when the wearing of seatbelts becomes compulsory.

A.C.R. units will be fitted in each of six Bedford H.A. Post Office vans of the type illustrated in figure 6. Three of the vans will be used by postal services, and three by Telecommunications. One month was agreed to be a suitable period of assessment by each driver or passenger. In each year, therefore, 72 driver assessments will be made, and since Telecommunication vans carry two men, 36 passenger assessments will also emerge. An attempt will be made to conduct the "user" studies at a number of places chosen to represent town and country use; the exact details have not yet been worked out.

This government-controlled experiment is planned to last for 2 years, but useful indications may be expected to emerge after the first year. The whole study represents a notable example of cooperation in the cause of safety between a government research establishment, management, and workers in a large organisation, and industrial firms in the safety field.

REFERENCES

The Development of a Passive Seatbelt Restraint System

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ABSTRACT

Several passive seatbelt systems have been developed for preliminary evaluation by Kangol Magnet, Ltd. working with Smith's Industries, and one has been selected for trials in service with the United Kingdom's Post Office. It consists of a single diagonal seatbelt attached to the door and a knee restraint provided ahead of the occupant. This layout is thought to be particularly suitable for delivery van drivers.

INTRODUCTION

A contract was placed by the Transport and Road Research Laboratory (TRRL) in
SECTION 4: TECHNICAL SEMINARS

Figure 1. Lifting arm system.

Figure 2. Cord actuated system.
June 1971 with Auto Restraints, Ltd. (a company that had been jointly formed between Kangol Magnet, Ltd. and Smith’s Industries, Ltd.) for the development of passive seatbelt systems.

This was the result of work carried out at TRRL on passive seatbelt systems that deploy themselves automatically around the driver and passengers. Their engineers became convinced that such systems could represent a better cost/effectiveness than the crash deployed inflatable restraint systems then being developed in the United States in response to proposed legislation calling for passive restraint systems in all vehicles made after 1973.

This project was part of a programme sponsored by the Department of the Environment of the United Kingdom’s Government as a contribution to the NATO and the United States’ Government’s collaboration in an experimental safety vehicle (ESV) programme.

EVALUATION OF ALTERNATIVE SYSTEMS

Seven different schemes of passive seatbelt installation were evolved and the majority fitted in vehicles in mock-up form to enable a selection panel to evaluate them.

Four of the systems had upper and lower anchorages on the door and various electrically operated devices, mounted between the front seats, that would pull the belt away from the occupant. Two further designs used somewhat more complex arrangements of tracks along which the webbing could be withdrawn electrically and the final system was based on a safety seat.

The panel evaluated these designs for twelve aspects ranging from “General appearance in driving position” through “Ability to cater for seat position adjustment” to “Economical in manufacturing cost.”

DESIGN AND DEVELOPMENT OF SELECTED SYSTEMS

As a result of this exercise and following on from further work that had, meanwhile, been carried out at TRRL, three systems were selected for further development.

Tests on these systems have included impact tests installed on seating bucks, body shells on sleds (frontal, side, and 30-degree
angle), and complete vehicle (frontal impact and rollover) as well as endurance tests on the automatic withdrawal devices.

**Lifting Arm Scheme**

The basic system was fitted to an Austin 1800 in which the outboard shoulder and lap anchorages were mounted on the rear edge of the suitably strengthened door. A special heavy-duty reel was mounted on the transmission tunnel behind an electrically operated pivoted arm which lifted the webbing upward and forward from the occupant when the door was opened (fig. 1).

Further experience was obtained with an improved installation fitted to another Austin 1800 and the lifting arm scheme was exhibited at the 1973 ESV Conference fitted to a Triumph 2.5 P.I. and in 1974 fitted to a British Leyland Safety Car and the Austin 1800.

**Cord-Actuated Scheme**

This scheme was installed in a Hillman Avenger. It was similar to the system described above but the webbing was moved forward by means of a cord wound on an electrically driven drum mounted behind the fascia (fig. 2).

An improved version, also fitted to an Avenger, had the webbing from the outboard lap location passing through a guide loop which was pulled along a track built into the door when it was opened. This vehicle was shown at the 1974 ESV Exhibition.

**Single Diagonal and Knee Restraint**

This was a development based on proposals and experimental work carried out by TRRL; and it was a simple and inexpensive design when compared to the foregoing, but it retained most of the advantages (fig. 3).

The webbing passed from a reel mounted in the lower rear corner of the door through an adjustable shoulder anchorage at the upper rear corner (which was also fitted to some of the other systems) and across to an inboard anchorage between the seats. No mechanism was required to pull the webbing away from the occupant as this occurred automatically when the door opened, but a parking hook could be provided for user convenience. The knee restraint took the form of a padded steel semicylinder, designed to collapse at a given load to avoid knee damage, fitted in the lower fascia area.

This system has been fitted to an Austin 1800, Austin Allegro, and MGB-GT. The Allegro was also shown at the 1974 ESV Exhibition.

**Conclusion**

The original programme of work was completed in September 1974 but, since then, further development work has been carried out on the single diagonal and knee restraint system by Kangol Magnet, Ltd.

**SINGLE DIAGONAL AND KNEE RESTRAINT SYSTEM IN DETAIL**

The system has been improved in certain particulars and has been fitted to the Alfa Romeo Alfusud and Ford Escort Mark 11 vehicles.

**The Components Described**

**The Inertia Reel.** The reel is mounted in the lower rear corner of the door which is suitably strengthened for the purpose.

Initially, a vehicle-sensitive reel was used. This incorporated a plunger that, held out of engagement when the door closed, will drop to prevent the lockbar engaging when the door is open, thus preventing the reel locking if the door moves briskly.

However, this means that the reel would become unlocked if the door comes open in an accident. Consequently, improved systems are currently being worked on and one will be incorporated in the Post Office vehicles. One such system is a dual-sensitive reel using an electrically operated inertia-sensing mechanism which ensures a locked reel condition in the event of current failure.

**Reel Control Circuit.** In an emergency situation the circuit is broken (and the reel
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locked) either by a remote inertia switch mounted inside the vehicle or by a foot-brake operated switch, the two being connected in series.

It was thought undesirable to wire the circuit through the ignition, as it would then be necessary to switch on the engine before the belt could be put on. This can be avoided by providing for the reel to be unlocked when either the door is open or the seat occupied. To achieve this a pair of switches, connected in parallel, are wired in series with those mentioned above. The first of these is a door switch that will allow the current to pass as soon as the door is opened, unlocking the reel and enabling webbing to unwind as the door is moved. The second is a seat switch that will let current flow only when the seat is occupied.

Adjustable Shoulder Anchorage. The shoulder running loop is mounted at the upper trailing edge of the door. A latch plate on the door engages with a similar plate on the B/C post to transfer the load to the usual belt mounting position (fig. 4).

The loop is adjustable in height and may be set in any one of a number of positions. This is achieved by spring loading the reel mounting bracket against the rear edge of the latch plate. A pin on the former will engage in any one of a number of slots in the latter, thus holding the loop in position. It can be adjusted by moving the loop bracket rearward against the spring so that it comes out of the slot. It can then be moved to another position.

Inboard Mounting. The inboard end of the webbing is attached via a conventional buckle that is, in this instance, only intended for use in an emergency. It can be fitted with a switch operating an ignition inhibit system if required.

Parking Hook. A ring attached to the webbing can be slipped over a hook that protrudes from the fascia. Thus, the belt can be held away from the occupant, if necessary, to make it even easier to get in and out. A bowden cable running between the hook and the handbrake lever will cause the former to retract into the fascia when the handbrake is released, thus ensuring that the belt is freed to deploy itself correctly before the vehicle moves off.

Knee Restraint. A padded sheet steel semi-cylinder is rigidly mounted to the vehicle structure and stretches across the passenger compartment below the fascia. It is in such a position as to be contacted by the knees in an accident and is designed to collapse at a load lower than one that would cause damage to the femur.

Figure 4. Adjustable height, diagonal anchorage.

TRIAL INSTALLATION IN POST OFFICE VEHICLES

Programme Objectives

The system is considered to be particularly suited to situations involving frequent occupant ingress and egress where the use of a conventional belt would be irksome and time consuming.

Consequently, TRRL has recently placed a contract with Kangol Magnet, Ltd., for a long term evaluation of the system.

After being fully evaluated and tested to the requirements of the BSI, it will be fitted to six Post Office Bedford light vans and run with the fleet for a period of three years.

Three of these vehicles will be Post Office collection/delivery vans and will be fitted up
for the driver only and three will belong to
the Telecommunications branch and will be
fitted for both driver and passenger.

Description of Proposed Scheme

The installation is similar to that described
above except that the shoulder anchorage will
not be adjustable and a parking hook will not
be fitted. These are not considered essential
to the efficient operation of the passive
system and it is desired to make it as
inexpensive as possible in order that it will be
a practical economic proposition for com-
mercial vehicles.

Crash Test Performance of British Leyland Marina Safety Research Vehicles

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ABSTRACT

Two recent car-to-car crash tests of Phase I
Marina Safety Research Vehicles (SRV) de-
veloped by British Leyland Motor Corporation
are described. The tests included a central
head-on collision of a Marina SRV with an
American Machine and Foundry Corporation
(AMF) experimental safety vehicle at a clos-
sing speed of 60 mi/h and a 90-degree side
impact of the Marina SRV by a modified
production Marina automobile at a speed of
30 mi/h. The objective of the test program,
which was performed by Calspan under a
contract with the National Highway Traffic
Safety Administration, was to evaluate the
safety performance of the Marina SRVs from
the vehicle and occupant responses measured
in the crashes. Based on current injury cri-
teria, the test results indicate that human
occupants probably would have sustained
only minor, if any, injuries in either of the
collisions.

INTRODUCTION

Since 1971, when the International Experi-
mental Safety Vehicle (ESV) Program was
initiated, the National Highway Traffic Safety
Administration (NHTSA) of the U.S. Depart-
ment of Transportation has participated in a
cooperative effort to develop, test, evaluate,
and exchange information on the perform-
ance of prototype ESVs. Results of earlier
safety evaluation tests of foreign ESVs (Fiat,
Nissan, and Toyota) that were performed
under the sponsorship of the NHTSA are
summarized in reference 1. In a continuation
of such testing activities as part of the
international cooperative effort program, the
NHTSA recently contracted for the crash test
evaluation of two additional foreign ESVs by
Calspan Corporation. These automobiles were
the Phase I Marina Safety Research Vehicle
(SRV) developed by British Leyland and the
French Renault Basic Research Vehicle
(BRV). The design features, physical charac-
teristics, and results of developmental tests of
both of these vehicles were reported at the
preceding ESV Technical Conference by the
manufacturers [2, 3].

Results from two crash tests to evaluate the
structural integrity and degree of occupant
protection afforded by the Marina SRV in
impacts with other vehicles are presented in
this paper. These tests were: (1) a central
head-on collision between a four-door Marina
SRV and the AMF ESV at a nominal closing
speed of 60 mi/h, and (2) a 90-degree side
impact of a two-door Marina SRV by a
modified standard Marina automobile travel-
ing at 30 mi/h.

CONCLUSION

At the present time, the single diagonal and
knee restraint system is considered to be the
optimum in cost/effectiveness for a passive
restraint system and, with the imminent
introduction of compulsory belt wearing in
the United Kingdom, is particularly applicable
to the delivery vehicle.

The forthcoming field trials with the Post
Office represent a valuable step forward in the
development of the system into a practical,
reliable, and economic passive restraint
system.
FRONTAL IMPACT TEST

Test Description

The frontal centerline crash of the Marina SRV with the AMF ESV was conducted with each car traveling 30.28 mi/h or a closing speed of 60.56 mi/h. The AMF vehicle, consisting only of the body shell and the chassis with the front bumper hydraulic energy absorber system, weighed 4,040 pounds. The test weight of the Marina SRV was 2,870 pounds, so the AMF/Marina weight ratio was about 1:41. A pretest photograph showing the relative positions of the vehicles at impact is given in figure 1. Considerable care was taken to insure an acceptable engagement of the bumpers by adjustment of the suspensions of each car, which resulted in a slight initial pitch-down attitude of the AMF ESV. Figure 2 shows the interface of the front bumpers prior to the test.

Two 50th-percentile male anthropomorphic dummies occupied the front seats of the Marina SRV. Each dummy was tested for conformance to FMVSS Part 572 require-
ments prior to the crash test. Both a primary and a redundant set of triaxial accelerometers were installed in the head and chest of each dummy to assure that measurements of these important responses would be obtained. To further guard against the loss of data, 100 percent redundancy of transmission lines for all of the dummy and vehicle-mounted electronic transducers and at least 70 percent recording redundancy on FM magnetic tape recorders were provided.

The dummies were restrained with lap and shoulder belts that were not equipped with emergency locking retractors and were adjusted to be snug. The belt restraints were experimental systems having a load limiting energy absorber connected to the upper torso strap and anchored to the “C” pillar as shown in figure 3. The lap belts incorporated nearly 2 inches of tear webbing having a yield load of about 1 5000 pounds.

As may be noted from the photographs of figure 3, the head of each dummy was covered with chamois for the purpose of detecting lacerating head contact with the vehicle interior.

Test Results

The high speed films of the crash show that both vehicles initially pitched downward with the Marina SRV subsequently pitching upward approximately 10 degrees and finally coming to rest with its bumper on top of the bumper of the AMF ESV as shown in figure 4. Pretest and posttest photographs of the underside of the Marina SRV illustrating the deformation of the forward structure are presented in figures 5 and 6, respectively. All of the doors were easily opened after the crash and all glass remained intact. Posttest measurements at selected points of the vehicle interior indicated less than 1 inch of compartment intrusion, which was of little significance with regard to detracting from the safety of the occupants.

The dynamic crush of each vehicle and the maximum mutual crush were determined from film analysis of the displacements of photographic targets on the side of the Marina SRV and on the side and bumper of the AMF ESV. The measured maximum combined
EXPERIMENTAL SAFETY VEHICLES

dynamic crush from both the film analysis and integration of the vehicle-mounted accelerometers was about 42.5 inches that occurred at 0.082 second. The maximum dynamic crush of the Marina SRV was approximately 26.5 inches, whereas grease marks on the cylinders of the AMF bumper hydraulic energy absorber indicated a stroke of 17 inches. However, the test data indicate that the maximum crush of each of the vehicles did not occur at the same time.

The integrated accelerometer data show the common velocity of the vehicles at the time of maximum mutual crush was 5 mi/h in the direction of motion of the heavier AMF ESV, which is close to the theoretical value of 5.13 mi/h based on the conservation of momentum. This result adds confidence to the validity of the vehicle acceleration measurements.

A comparison of the acceleration-crush characteristics of the two vehicles derived from the vehicle test data is shown in figure 7. It may be noted that the longitudinal acceleration fluctuated greatly, with a peak value of 36 g measured by an accelerometer installed near the base of the “B” pillar of the Marina SRV when the forward structure had crushed about 18 inches.

By assuming that the entire mass of each car experienced the accelerations measured in the respective passenger compartments, an approximation of the energy dissipated during the crush of each car was determined from the curves of figure 7. As shown in the summary of vehicle data presented in table 1, approximately 57 percent of the total energy dissipated was accomplished through deformation of the Marina SRV structure and 43 percent by stroking of the AMF ESV bumper energy-absorber units. Viewed in terms of the distribution of the total initial kinetic energy of the cars, with the energy of the AMF ESV being more than 40 percent greater than that

Figure 7. Acceleration-crush characteristics Marina-AMF frontal impact test.
Table 1. Summary of vehicle data—Marina versus AMF frontal impact test

<table>
<thead>
<tr>
<th>Measurement differences</th>
<th>AMF</th>
<th>Marina</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test weight (lb)</td>
<td>4 040</td>
<td>2 870</td>
</tr>
<tr>
<td>Impact velocity (mi/h)</td>
<td>30.28</td>
<td>-30.28</td>
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<td>Common final velocity (mi/h)</td>
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<td>5</td>
</tr>
<tr>
<td>Speed change (mi/h)</td>
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<td>35.28</td>
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<tr>
<td>Maximum combined dynamic crush (in)</td>
<td>42.5 @ .082 s</td>
<td>42.5 @ .082 s</td>
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<tr>
<td>Maximum dynamic crush (in)</td>
<td>16.75/17.25 left/rear</td>
<td>26.5</td>
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<tr>
<td>Post-test static crush (in)</td>
<td>15.75</td>
<td>14.3</td>
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<tr>
<td>Compartment intrusion (in)</td>
<td>0</td>
<td>0.75</td>
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<tr>
<td>Maximum compartment acceleration (g)</td>
<td>27</td>
<td>34</td>
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<tr>
<td>Initial kinetic energy (ft-lb)</td>
<td>123 729</td>
<td>87 893</td>
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<td>Total dissipated energy (ft-lb)</td>
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<td>205 857</td>
</tr>
<tr>
<td>Approximate percent of total</td>
<td>43</td>
<td>57</td>
</tr>
</tbody>
</table>

*a5.13 mi/h from conservation of momentum.
*Film analysis.
*Determined from post-test cylinder grease marks.

of the Marina SRV, a disproportionately large amount of the energy was dissipated through crushing of the smaller, lighter weight Marina SRV.

British Leyland had previously indicated that the energy-absorber units for the driver and passenger upper torso restraint belts were designed to produce different force-deflection characteristics. The passenger system was designed to yield at a nearly constant load whereas, for the driver, it was desired that the device allow the load to initially increase to a peak value, with subsequent yielding at a substantially lower and nearly constant load level. The measured loads in the driver and passenger upper torso belts are shown in figure 8 for comparison. Although the loads are plotted as a function of time, the different characteristic shape of the curves is clearly evident and it is believed that the energy absorbers functioned essentially as designed. The measured posttest stroke of the devices was 5.5 inches and 2.91 inches for the driver and passenger systems, respectively.

The head and chest resultant acceleration responses of the two dummies in the Marina SRV are shown in figure 9. The rapid rise of the driver head acceleration at 0.082 second to a peak value of 75 g resulted from the head impacting the padded hub of the steering wheel at that time. A strip switch mounted on
the face of the dummy signaled the instant of contact. The chest acceleration responses of the dummies were very similar, with peak values of 42 and 43.8 g for the driver and passenger, respectively.

The values of various injury criteria parameters and other occupant and restraint system response data measured in the frontal impact test are summarized in table 2.

Comparison of these data with injury criteria values indicates that all of the response measures for both dummy occupants are well below the current specifications for human injury tolerance levels. Therefore, in this test the Marina SRV successfully met the occupant crash protection requirements employed as the performance standard for automobiles in the United States.

SIDE-IMPACT TEST

Test Description

This test was a 90-degree side impact of a Phase I design Marina two-door SRV by a modified standard Marina automobile whose front structure had been reinforced and included the SRV energy-absorbing bumper system. The stationary Marina SRV was struck on the left (that is, passenger) side, with the centerline of the bullet car aligned with the front seat reference point. Great care was also taken to assure proper vertical alignment by adjusting the vehicle suspensions. The preimpact relative position of the cars is shown in figure 10 where it may be seen that the bumper of the striking vehicle engaged both the sill and the lower portion of the door. The speed of the bullet car at impact was 30.16 mi/h. The test weights of the Marina SRV and the striking vehicle were 2 720 pounds and 2 630 pounds, respectively, so the weight ratio of the cars was very nearly the same.

The test was performed with two fully instrumented 50th-percentile male dummies in each automobile. A dummy developed and used by the British Transport and Road Research Laboratory (TRRL) specifically for side impact testing and a Part 572 certified dummy, each provided with redundant triaxial head and chest accelerometers, were positioned in the left front and left rear seats, respectively, of the Marina SRV. Certified Part 572 dummies with a normal complement of instruments occupied the front seats of the striking vehicle. The dummy occupants of both cars were restrained with lap and upper torso belt systems that included tear webbing for energy absorption but no emergency locking automatic retractors. The restraint belts of all of the dummies were adjusted to the desired level of initial tension by British
Leyland and TRRL engineers who participated in the Calspan tests. The belts were unrealistically tight, particularly those restraining the TRRL dummy. However, this was done to closely duplicate the condition of similar side impact tests previously performed by the vehicle manufacturer. The British personnel also requested that belt loads of the Marina SRV not be measured, it being feared that if any of the load sensors should happen to fall between the dummy and the side interior, the dummy response would be adversely affected.

Test Results

The high speed films of the test show that the Marina SRV rolled to the left and the striking vehicle pitched downward during the impact. The roll motion of Marina SRV resulted in the tendency for the upper portion of the vehicle interior to move away from the

<table>
<thead>
<tr>
<th>Measurement differences</th>
<th>Modified Marina</th>
<th>Marina SRV</th>
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<tbody>
<tr>
<td>Test weight (lb)</td>
<td>2 630</td>
<td>2 720</td>
</tr>
<tr>
<td>Impact velocity (mi/h)</td>
<td>30.16</td>
<td>0</td>
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<tr>
<td>Common final velocity (mi/h)</td>
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<td>15.2</td>
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<tr>
<td>Maximum combined dynamic crush (in)</td>
<td>18.1 @ 0.066 s</td>
<td>18.1 @ 0.066 s</td>
</tr>
<tr>
<td>Post-test static crush (in)</td>
<td>2.75/1.75—left/rear</td>
<td>7.2</td>
</tr>
<tr>
<td>Compartment intrusion (in)</td>
<td>0</td>
<td>3.75</td>
</tr>
<tr>
<td>Maximum compartment acceleration (g)</td>
<td>22.5</td>
<td>25</td>
</tr>
<tr>
<td>Initial kinetic energy (ft-lb)</td>
<td>79 900</td>
<td>0</td>
</tr>
<tr>
<td>Total dissipated energy (ft-lb)</td>
<td>40 600</td>
<td>40 600</td>
</tr>
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</table>

*a14.83 mi/h from conservation of momentum.
*b17.8-inch dynamic crush from film analysis.
dummies, thereby reducing the severity of the subsequent occupant contact with the padded interior side panels.

Posttest photographs of the damaged vehicles are shown in figure 11. The deformation of the exterior of the Marina SRV was irregular with a maximum value of slightly more than 7 inches about midway between the "B" pillar and the rear wheel fender opening. All of the windows remained intact but the left door could not be opened after the test. The maximum measured static intrusion of the passenger compartment was 3.75 inches. The principal damage to the bullet car consisted of crumpling of the fenders, slight collapse of the forward longitudinal frame members and other surrounding structures, and the radiator area, which was displaced rearward into contact with the engine. The glazing was undamaged but the left side door of the car was jammed and could not be readily opened. The measured posttest static longitudinal crush was 2.75 inches and 1.75 inches on the left side and right sides, respectively, and there was no interior intrusion.

The lateral acceleration measured near the base of the right "B" pillar opposite the struck side of the Marina SRV is depicted in figure 12. The peak acceleration of 25 g occurred at 0.032 second when the cars had not yet achieved the common final velocity at which the mutual crush is a maximum and they begin to separate through the release of a small amount of energy absorbed by elastic deformation of the structures. The common final velocity derived from acceleration data recorded for both cars was 15.2 mi/h at 0.066 second compared to a theoretical value of 14.8 mi/h based on conservation of momentum. The measured maximum mutual dynamic crush of the vehicles was 18.1 inches, which was in close agreement with the value of 17.8 inches determined from analysis of high speed films of the crash.

Vehicle data for the side impact test are summarized in table 3. Because the cars were nearly of equal weight, the speed change of each car was also almost the same and about half of the initial system kinetic energy was dissipated in the crash. The manner in which the dissipated energy was distributed between the Marina SRV and the modified Marina striking vehicle cannot be ascertained, however, because only data on the mutual crush and not the instantaneous crush of the individual car structures are available.

A summary of the measured responses of the dummies in each car is presented in table 4. It is evident from the low values of

<table>
<thead>
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<th>Parameter differences</th>
<th>Marina SRV (target)</th>
<th>Modified Marina (bullet)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Left front</td>
<td>Left rear</td>
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<tr>
<td>Maximum head resultant acceleration (g)</td>
<td>70</td>
<td>31</td>
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<tr>
<td>Head injury criterion</td>
<td>162</td>
<td>66</td>
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<tr>
<td>Maximum chest resultant acceleration (g)</td>
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<td>23</td>
</tr>
<tr>
<td>Chest severity index</td>
<td>210</td>
<td>55</td>
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<tr>
<td>Maximum pelvis resultant acceleration (g)</td>
<td>37</td>
<td>53</td>
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<tr>
<td>Left femur load (lb)</td>
<td>-</td>
<td>200</td>
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<tr>
<td>Right femur load (lb)</td>
<td>-</td>
<td>150</td>
</tr>
<tr>
<td>Shoulder load (lb)</td>
<td>265 (1 350)</td>
<td></td>
</tr>
<tr>
<td>Rib No. 1 load (lb)</td>
<td>260 (225)</td>
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<tr>
<td>Rib No. 2 load (lb)</td>
<td>135 (225)</td>
<td></td>
</tr>
<tr>
<td>Rib No. 3 load (lb)</td>
<td>142 (225)</td>
<td></td>
</tr>
<tr>
<td>Rib No. 4 load (lb)</td>
<td>205 (225)</td>
<td></td>
</tr>
<tr>
<td>Iliac crest load (lb)</td>
<td>664 (1 125)</td>
<td></td>
</tr>
<tr>
<td>Hip load (lb)</td>
<td>360</td>
<td></td>
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</table>

*aAll numbers in parentheses indicate TRRL injury criteria.*
acceleration and other injury criteria recorded for the dummies in the bullet car that the frontal impact was, in fact, of low severity and one that did not present a large demand on the performance of the structure or the restraint system to provide safety for the occupants. The responses of the TRRL dummy in the left front seat of the Marina SRV are somewhat higher than those reported in reference 2 for nearly identical crash test conditions. The increased loading of the dummy resulted from the greater compartment intrusion that occurred in the Calspan test. The larger intrusion is attributed to a small difference in the region of impact on the vehicle; this test did not include contact of the strong “A” pillar by the bumper of the bullet car, as is believed to have been the case in previous tests performed by the vehicle manufacturer.

The responses of both dummies are within defined injury criteria values except for the load on the first rib of the TRRL dummy, which slightly exceeded the TRRL recommended maximum load. However, these results indicate that a human occupant probably would not have sustained injuries much more severe than a fracture of some of the ribs. The shoulder load was much lower than had been expected on the basis of previous tests. It is possible that, in the present test, the shoulder load cell “button” of the armless TRRL dummy may have entered the small space between the door padding and the “B” pillar, thereby decreasing the load on the shoulder and resulting in increased loads applied to the ribs.

Films from the onboard cameras viewing the dummy occupants show that the dummy in the rear seat lightly struck the padding of the “C” pillar with the side of the head but the head of the front dummy did not contact the vehicle interior. However, a comparison of the data for the two occupants of the Marina SRV shows the front seat dummy experienced higher accelerations; it was more vulnerable because that seat location was more central to the region of impact on the side of the car. It is also quite likely that some of the response differences of the two dummies are attributable to their different physical characteristics. These include the stiffness of the neck that reportedly is greater for the TRRL dummy compared to the neck flexion stiffness of the Part 572 dummies currently used as the standard for evaluating vehicle occupant crash protection in the United States.

CONCLUDING REMARKS

The results from the two tests of the Marina SRV described herein indicate that the crashworthiness performance of the structural and occupant protection systems incorporated in the vehicle design was adequate for the impact conditions selected for the safety evaluation. The tests confirm the achievement of safety performance objectives specified for the SRV development program that already had been demonstrated in previous tests of equal or, in the case of frontal impacts, greater severity by the manufacturer. However, the impact with the AMF ESV was useful in further proving and demonstrating car-to-car frontal crash performance of the SRV equipped with a new, experimental belt restraint system and with different dummies than had been used before in developmental tests of the vehicle.

Finally, an important aspect of the test methodology employed in the current series of crash tests deserves comment. One of the problems often encountered in experimental crash work, especially in tests involving a large number of data channels, as was the case for these tests with as many as 110 signal sources, is the loss of data due to equipment failures. The redundancy provided in the data gathering system, particularly the dual recording of data, proved to be an effective and valuable safeguard with the result that no data of major significance were lost in any of the tests.

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Fifth International Technical Conference
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1974.

Crash Test Performance of Renault Basic Research Vehicle

RUDY H. ARENDT
Calspan Corporation

ABSTRACT

Two crash tests of the Basic Research Vehicle (BRV) developed by the Renault Motor Company are described. The test program, which was performed by Calspan Corporation under contract to the National Highway Traffic Safety Administration, included a 30-degree frontal, oblique rigid-barrier crash at a speed of 42.5 mi/h and a second 75-degree side impact of the same BRV by a standard production Renault R-12 vehicle at a speed of 31.3 mi/h. The test results obtained from the measured occupant responses show that only minor injuries would have been inflicted on human occupants in either of these tests.

INTRODUCTION

To increase the protection afforded occupants involved in automobile accidents, a number of vehicle safety development programs have been initiated in many countries throughout the world. In 1971 the International Experimental Safety Vehicle (ESV) Program was initiated and vehicles were developed in support of this program both in the United States and other countries. Evaluations of some of these foreign-developed safety vehicles have been conducted by the National Highway Traffic Safety Administration (NHTSA), and the results of these evaluations have been published and made available to all interested parties. As a continuation of this effort, NHTSA contracted for the crash test evaluation of two additional foreign safety vehicles by Calspan Corporation. These vehicles were the Phase I Marina Safety Research Vehicle (SRV) developed by British Leyland, and the French Basic Research Vehicle (BRV) developed by Renault. The development work for both of these vehicles was reported at the Fifth Safety Vehicle Conference by the respective manufacturers [1, 2].

This paper presents test results of two crash tests performed to evaluate the structural integrity and degree of protection afforded by the BRV. The results of tests performed on the Phase I Marina SRV are contained in a separate paper presented at this conference.

The BRV tests were:

1. Left front oblique impact with a rigid 30-degree barrier at a speed of 42.5 mi/h
2. 75-degree right side impact of the stationary BRV by the front of a production Renault R-12 automobile at a speed of 31.3 mi/h

The test description and the results obtained for both of these tests are presented in this paper.

BRV FRONTAL 30-DEGREE ANGLED BARRIER IMPACT TEST

Test Description

The frontal angled barrier crash of the Renault BRV was performed at a nominal impact speed of 42.5 mi/h. The test weight of the BRV with two Part 572 test dummies in the front seat was 3,320 pounds. A pretest photograph of the BRV positioned in front of the angled barrier is shown in figure 1 and a three-quarter front view of the BRV taken just prior to the crash test is presented in figure 2 that shows the attachment of the tow cable to the front of the vehicle and the outrigger attached to the rear of the car to tow the instrumentation umbilical cables.
straint belt loads could not be measured because the retraction of the belts upon initiation of the preloaders prevented suitable installation of belt load transducers.

A photograph of the driver dummy positioned in the test vehicle is presented in figure 3. The head of each dummy was covered with chamois to detect lacerating head contact with the vehicle interior. Event contact switches were also attached on the front centerline of the heads of both dummies to identify the instant of contact with the vehicle interior.

Vehicle crash sensors included accelerometers located at strategic points throughout the vehicle and event switches to measure the time of occurrence of crash-related events such as: front wheel/wheel well, engine/radiator, engine/transverse support, and dummy head/interior contact. The initiation of the seatbelt preloaders was also measured.

A typical vehicle-mounted accelerometer package, illustrated in figure 4(a), consists of an assembly of one or more accelerometers, a base plate, a protective cover, and a vehicle attachment plate. A photograph of a uniaxial sensor package is shown in figure 4(b). Lightening holes are incorporated into the vehicle attachment plate to minimize weight. The
Figure 4. Accelerometer package and method of attachment to vehicle.
basic method of installation consists of welding the attachment plate to the vehicle structure. The accelerometers are separately mounted on the base plate that is bolted to the vehicle attachment plate. The protective cover is used in those installations where the accelerometers might be damaged during the crash. Accelerometer packages were placed in the vehicle locations identified in table 1.

The event switches consist of long, narrow conductive plates separated by an insulating material. The complete assembly is covered with a rubber coating. Because these event sensors would be positioned in hazardous locations, the likelihood of them being cut and shorted to the vehicle chassis was high. To eliminate the possibility of data contamination due to electrical ground loops caused by event switches being shorted to the vehicle chassis, the event switches were isolated from the instrumentation ground by means of solid-state optical isolators. Each isolator consisted of a solid-state light-emitting diode and a photo detector. The event switches were connected in a circuit so that when a switch was activated, a voltage from a separate small battery was applied to the input terminals of the light-emitting diode, causing it to generate light. The light was sensed by the photo detector that converted the change in light intensity to a change in voltage. The photodetector output voltage was then recorded as the sensed event.

Sixteen cameras, including documentary film and a video camera, were employed in the test. Two high-speed cameras were mounted onboard the test car and the remainder were positioned at various locations to provide several different views of the impact. In addition to the timing marks recorded on each film, the flash from an electronic strobe was recorded by all cameras to identify the instant of first contact (time = 0). The same contact event signal was also recorded on magnetic tape recorders.

Several umbilical cables were used to provide 100 percent redundancy of transmission of signals from the on-board sensors to the ground station recording equipment. The test data were recorded on magnetic tape using FM tape recorders that provide 14 record channels on 1-inch wide magnetic tape. Ten tape recorders were used on this test to provide 100 percent recording redundancy for the 64 data signals (exclusive of impact "time zero") in the test. A precision 100 Hz timing reference signal was also recorded on one channel of each tape recorder to establish a common time base for all recorded data.

30-DEGREE ANGLED BARRIER TEST RESULTS

The BRV impacted the 30-degree angled barrier at 42.45 mi/h. Both front doors of the vehicle were jammed tightly and could not be opened following the test. All of the restraint belt preloaders functioned as designed. Both dummy occupants moved forward and to the left during the crash and chalk marks on the chamois covering the heads indicated contacts with interior surfaces. Head contact is also evident from the films but only the event switch mounted on the face of the passenger dummy was activated. The films show that the head of the passenger dummy struck the instrument panel to the left of the vehicle centerline and then contacted the “A” pillar during rebound.

Photographs showing the final rest position and damages to the vehicle after the impact are presented in figures 5 and 6.

A summary of the dummy responses obtained in this test is given in table 2.

The head and chest resultant responses of the driver and passenger dummy in the BRV angled-barrier test are presented in figure 7.

Upon impacting the 30-degree angled barrier, the BRV crushed about 30 inches on the left side, as determined from integrated accel-

<table>
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<th>Location</th>
<th>Sensing axis</th>
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<td>1</td>
<td>Base “A” post (left)</td>
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<tr>
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<td>3</td>
<td>Base “C” post (left)</td>
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<td>4</td>
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<td>5</td>
<td>Base “B” post (right)</td>
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<td>6</td>
<td>Base “C” post (right)</td>
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<td>7</td>
<td>Engine intake manifold</td>
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<td>8</td>
<td>Front crossmember (left)</td>
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<td>3</td>
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<tr>
<td>9</td>
<td>Front crossmember (right)</td>
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<tr>
<td>10</td>
<td>Tunnel</td>
<td>X, Y, Z</td>
<td>3</td>
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</table>

Table 1. BRV vehicle-mounted accelerometers
wheel well. All significant vehicle deceleration occurred during the first 100 milliseconds of the test, and the vehicle crushed about 41 inches on the left-hand side during this time. The vehicle longitudinal deceleration pulse measured on the center tunnel at a point nearly in line with the “B” posts is presented in figure 8 along with the displacement obtained from double integration of this pulse. It can be seen that the maximum acceleration is about 35 g’s and the average value over the 100 millisecond interval is about 20 g’s. The time of occurrence of other test events is also identified in figure 8.

The X and Y components of the accelerations measured at the base of the “A,” “B,” and “C” posts were all mutually similar. Cross plots of the lateral and fore-aft displacements computed from the accelerations measured at the base of the “A” and “C” posts are presented in figure 9. These cross-plots show that the vehicle began to rotate clockwise 50 milliseconds after impact, at which time the crush was about 30 inches. Also, the front of the vehicle compartment moved about 12 inches laterally during the approximately 100 millisecond time interval of the impact.

Table 2. Dummy responses—BRV angled barrier test

<table>
<thead>
<tr>
<th>Criteria</th>
<th>BRV occupant</th>
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<tbody>
<tr>
<td></td>
<td>Left front</td>
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<td>Head Severity Index</td>
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<td>Head Injury Criteria</td>
<td>277</td>
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<tr>
<td>Maximum head resultant g</td>
<td>45</td>
</tr>
<tr>
<td>Chest Severity index</td>
<td>190</td>
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<tr>
<td>Maximum chest resultant g</td>
<td>30.5</td>
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<tr>
<td>Maximum pelvis resultant g</td>
<td>56</td>
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<tr>
<td>Left femur load—lb</td>
<td>288</td>
</tr>
<tr>
<td>Right femur load—lb</td>
<td>208</td>
</tr>
</tbody>
</table>

*a*352 tension.

erometer data, and then began to rotate clockwise and slide along the face of the barrier. The yaw rotation of the vehicle began at about 50 milliseconds after impact, which is the time that the left wheel contacted the
struck on the right side by a Renault R-12 automobile at a nominal speed of 31.5 mi/h. An overall view of the side impact test vehicles positioned in the initial impact configuration is presented in figure 10 and a close-up of the first point of vehicle-to-vehicle contact is shown in figure 11. The impact point was determined by positioning the BRV so that the front dummy “H” point, projected and marked on the outer door panel, was aligned with the centerline of the R-12 car. The BRV was also positioned so that its longitudinal centerline formed an angle of 75 degrees to the test track centerline. Because of the damage from the barrier test, it was necessary to support the left front corner of the BRV on timbers to achieve a nearly normal pitch and roll attitude of the car. An attempt was also made to allow the front doors to be opened and closed by jacking between the lower “A” and “B” pillars to remove some of the buckling that had occurred in the door sills and other distortions of the body. However, this was only partially successful since the doors, once closed, could not be readily opened.

The weights of the vehicles were 3,070 pounds and 2,720 pounds for the BRV and the R-12 striking vehicle, respectively. Each car contained two certified Part 572 dummies, in the right (struck) side front and rear seats of the BRV and in the left and right front seats of the R-12.

The test dummies for both vehicles were certified to FMVSS requirements before the test. All dummies were instrumented with primary head, chest and pelvic triaxial accelerometers, and femur load cells. Redundant triaxial sensors were also installed in the head and chest of the dummies used in the BRV. It should be pointed out that the rear seat of the BRV did not include the safety design features provided for the front seat occupants. Therefore, higher levels of injury exposure in this location were anticipated.

Each of the dummies in both vehicles was restrained with a standard Renault lap and shoulder belt restraint system. Each of the restraint systems was instrumented with load cells to measure the tension in the upper torso portion and in the lap belt on the side opposite the buckle. Due to mechanical in-

From integration of the lateral acceleration measured at the base of the “A” post, on both the left and the right-hand side of the vehicle, it was determined that the maximum lateral velocity at that compartment station was about 15 mi/h and occurred at about 80 to 85 milliseconds after impact.

Based on current injury criteria, it appears that a human occupant in the driver’s position would have suffered very little injury during this test. The severity of the impact for the passenger occupant was somewhat greater but he also would likely have sustained non-fatal injuries in the collision.

Since all the dummy response data presented previously in table 2 are below the tolerance levels established for humans, it can be concluded that the BRV satisfied the occupant protection requirements established for automobiles in the United States.

BRV 75-DEGREE SIDE IMPACT

Test Description

In the 75-degree side impact test, the same BRV used for the angled barrier test was
compatibility between the belt load cells and the restraint system, the belt loads could not be measured at the inboard anchorage point. Photographs of the dummies as they were positioned in the BRV and R-12 vehicles are shown in figures 12 and 13, respectively. The heads of all dummies were covered with chamois just before the test to detect lacerating head contact with the vehicle interior.

Event contact switches were attached to the right side of the head of both dummies in the BRV and on the shoulder and hip of the right front occupant to sense the time of vehicle contact of the respective dummy areas. Contact switches were also attached to the face, on the vertical centerline, of the dummies in the R-12 vehicle. Two additional
A total of 106 data signals (exclusive of impact "time zero") were recorded on 181 channels of 15 tape recorders and no data were lost. A precision 100 Hz timing reference signal was again recorded on one channel of all tape recorders to establish a common time base for all recorded data. Extensive photographic coverage was provided for the side impact test, including a video camera for immediate posttest viewing, and two cameras installed on each test vehicle to record the occupant kinematic responses.

75-DEGREE SIDE IMPACT TEST RESULTS

The R-12 impacted the BRV at 31.3 mi/h. Posttest inspection of the vehicles revealed that neither the front nor rear doors on the struck side of the BRV could be opened. The doors on the opposite side opened easily but after the left front door was opened, it could not be closed again because of the deformation that had occurred in the barrier test.

A posttest photograph of the BRV that shows the overall vehicle damage is presented in figure 14 and a posttest close-up of the
front portion of the R-12 car is shown in figure 15.

All of the doors of the R-12 bullet car were easily opened after the crash and none of the windows nor the windshield was broken or cracked. Most of the front end damage area was to the right of the vehicle centerline as a result of the initial 75-degree angle between the longitudinal axis of the cars at impact.

Marks were observed on the head chamois of both dummies in the BRV which indicated contact with the roof of the car above the top of the windows. In addition, the outer chamois over the head of the rear dummy was cut slightly in three places.

Chalk marks found on the chamois covering the dummy heads in the R-12 car indicated that the left front (driver) dummy struck the steering wheel and/or hub and that the passenger dummy head had contacted the dash and the sun visor. However, there were no cuts in any of the chamois on the R-12 dummies.

A summary of the dummy responses obtained in the BRV side impact test for both the BRV and the R-12 vehicles is given in table 4.

The head and chest resultant responses of the right front and rear dummies in the BRV during the side impact test are presented in figure 16. The large spike on the right rear resultant head acceleration occurs at the time that the head struck the vehicle, as indicated by the event switch mounted on the head of the dummy. As previously noted, the rear seat area of the BRV was not safety equipped for side impacts and, therefore, the occupant protection provided in the right rear seat was

<table>
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<tr>
<th>Sensor</th>
<th>Location</th>
<th>Sensing axis</th>
<th>Data channels</th>
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</thead>
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<td>Base “A” post (left)</td>
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<tr>
<td>2</td>
<td>Base “A” post (right)</td>
<td>X</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Base “B” post (left)</td>
<td>X, Y</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Base “B” post (right)</td>
<td>X, Y</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Engine</td>
<td>X, Y</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Floor—front seat</td>
<td>X, Y, Z</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Floor—rear seat</td>
<td>X, Y, Z</td>
<td>3</td>
</tr>
</tbody>
</table>

not expected to be comparable to that provided in the front seat.

The three cuts in the outer chamois on the rear dummy had a combined cut length of about 34 millimeters. In accordance with the lacerative rating scale, the laceration index of 4 for this combined length of cuts represents moderate human injury.

As was previously mentioned, standard Renault seatbelts with emergency locking retractors were installed in both the BRV and the R-12 vehicles prior to the side impact test. The upper torso belt loads for both occupants of the BRV are presented in figure 17. These belt load time histories show that the loads were very low with peak values of only 230 pounds and 150 pounds for the front and rear occupants, respectively.
Table 4. Dummy responses, BRV side impact test

<table>
<thead>
<tr>
<th>Criteria</th>
<th>BRV vehicle</th>
<th>R-12 vehicle</th>
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<td></td>
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<td></td>
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<tr>
<td>Head Severity Index</td>
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<td>Maximum head resultant g</td>
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<td>Maximum pelvis resultant g</td>
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<td>23</td>
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<tr>
<td>Left femur load—lb</td>
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<td>120</td>
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<tr>
<td></td>
<td>(0 tension)</td>
<td>(57 tension)</td>
</tr>
<tr>
<td>Right femur load —lb</td>
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<td>74</td>
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<td>(75 tension)</td>
<td>(52 tension)</td>
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<tr>
<td>Maximum torso belt load—lb</td>
<td>230</td>
<td>150</td>
</tr>
<tr>
<td>Maximum outboard lap belt load—lb</td>
<td>376</td>
<td>64</td>
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</tbody>
</table>

Since the rear seat compartment did not include the safety design features provided for the front seat occupants, the higher levels of injury exposure in this location were anticipated.

A summary of the side impact vehicle-related performance data is tabulated in table 5 for both the BRV and the R-12 vehicles. A graph of the compartment acceleration in the BRV and the R-12 is presented in figure 18. The left "B" post location was selected in the BRV vehicle for the compartment acceleration plot because this location was on the nonimpact side of the vehicle and it was nearly in line with the X-axis accelerometer located on the right "A" post of the R-12 vehicle. The difference between the displacements obtained from the integrals of the two acceleration pulses given in figure 18 was calculated and is also plotted in the figure.

From a comparison of the test data summarized in table 4 with current injury criteria, it can be concluded that a human occupant in the right front seat probably would not have sustained any significant injuries in an equivalent crash. The right rear occupant would have sustained moderate head lacerations but he also would likely have survived the impact.
Table 5. Summary of vehicle data BRV and R-12 side impact test

<table>
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<tr>
<th>Parameter</th>
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<th>R-12</th>
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<td>Test weight—lb</td>
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<td>2 720</td>
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<tr>
<td>Impact velocity—mi/h</td>
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<tr>
<td>Final velocity—mi/h(a)</td>
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<td>14.7</td>
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<tr>
<td>Velocity change—mi/h</td>
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<td>Combined dynamic crush—in(b)</td>
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<tr>
<td>Post-test static crush—in(c)</td>
<td>0/2.9/0/'A'/'B'/'C'</td>
<td>3.75/13 L/R</td>
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<tr>
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<td>2.5/2/0.25/'A'/'B'/'C'</td>
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</tr>
<tr>
<td>Max. compartment accel.—g's</td>
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<td>25</td>
</tr>
<tr>
<td>Initial kinetic energy—ft-lb</td>
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<td></td>
</tr>
<tr>
<td>Energy dissipated—ft-lb</td>
<td>47,175</td>
<td>89 009</td>
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</tbody>
</table>

*From conservation of momentum.
*From accelerometer data.
*CBase of ‘‘A’’, ‘‘B’’, and ‘‘C’’ posts.

versus time. This variable represents the total combined dynamic crush that occurred between the two vehicles during the impact. From the graph, it can be seen that the maximum combined dynamic crush was nearly 22 inches which occurred about 100 milliseconds after impact.

The relatively small amount of occupant compartment intrusion indicates that the BRV side structure performed satisfactorily in this side impact test.

CONCLUSIONS

The results of the two crash tests performed on the Renault BRV show that it provides levels of protection sufficient to prevent serious injury to human occupants in similar accidents. Of the two tests, the angled barrier was the most severe and imposed the greatest degree of damage to the vehicle, both in terms of the exterior crush and also deformation to the occupant compartment.

Although the responses of the test dummies were below accepted tolerance levels, sufficient structural deformation occurred in the barrier impact to cause both doors to be jammed shut. This could create a problem in extracting incapacitated victims of a crash from the vehicle. There was some intrusion into the occupant compartment in the barrier test and the seats moved forward a small amount; however, these are both minor effects considering the severity of the impact and are not believed to have significantly increased the hazard to the occupants.
In summary, the BRV vehicle appears to provide a level of occupant protection adequate to satisfy safety criteria and standards currently in use in the United States for the given test conditions.

REFERENCES

Effectiveness of ATD’s and Cadavers in Evaluation of Restraint System

EDWIN A. KIDD and MICHAEL J. WALSH
Calspan Corporation

ABSTRACT

The results of cadaver and Anthromorphic Test Dummy (ATD) tests with a variety of restraint systems, but primarily with 3-point belts, are examined. Response measures and restraint loads are correlated with injuries determined in autopsies. ATD’s and cadavers are compared to these same measures for similar test exposures. It is concluded that cadavers and ATD’s, used in conjunction for the evaluation of restraint systems, will provide good predictions of human performance in accidents.

INTRODUCTION

The ultimate value of any human surrogate is its utility in the prediction of the performance of a restraint system in actual accidents. Thus, the primary question in examining the effectiveness of ATD’s and cadavers in evaluating restraint systems is whether either, or some combination of both, correlates with the injuries incurred in highway accidents.

This cannot be answered in a direct way. There is no adequate set of well-defined accidents, particularly in the severe-serious exposure range, for which injuries of occupants can be described, labeled, and measured on a precise, linear scale. Similarly, no set of sled or crash test results with ATD’s and cadavers is available to provide an adequate comparison of the responses of the two types of surrogates with various restraint configurations over the range of exposures of interest.

The data that are available on ATD’s and cadavers are from a variety of test facilities on tests run with a variety of objectives. Some of these data are presented in tables 1 through 4. These tables were constructed with emphasis on cadaver tests and ATD tests conducted specifically for comparison with cadavers. The preponderance of the data is reported in the 18th and 19th Stapp Conference Proceedings and is for 3-point belt restraints, as this is the system on which most of the cadaver testing has been concentrated. Cadavers and ATD’s are now being tested simultaneously in car-to-car crash tests with air-cushion and 3-point belt restraints [1]. Available results from this program are included in table 4. ATD’s and human volunteers are compared in sled tests with air-cushions in [2] and will be referred to later in this analysis.

CADAVER INJURY RATINGS AND INJURY CRITERIA

Torso and head acceleration responses are available for a number of the cadaver tests. Resultant accelerations, Chest Severity Indices (CSI), and Head Injury Criteria (HIC) are presented in figure 1 versus the overall Abbreviated Injury Scale (AIS) rating.

Five of the AIS ratings (four at AIS 1 and one at AIS 2) were estimated from physical examination and/or X-rays without an autopsy. The remainder were determined from autopsy results. The data of figure 1 were obtained in sled and car-to-car crash
Figure 1. Measured cadaver responses versus overall AIS rating.
Table 1. Cadavers with 3-point belt restraints

<table>
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<th>Source</th>
<th>Subject No.</th>
<th>Sex</th>
<th>Age (meters)</th>
<th>Height (kg)</th>
<th>Weight (kg)</th>
<th>Torso belt load (kg)</th>
<th>Number of rib fractures</th>
<th>AIS rating</th>
<th>ΔV (km/h)</th>
<th>Torso acceleration (g/CSI)</th>
<th>Head acceleration (g/CSI)</th>
<th>Test type</th>
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<td>490</td>
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<tr>
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<td>28/188</td>
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Drivers:

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aNo autopsy.
bACIR injury ratings revised to AIS.
Table 2. ATD’s with 3-point belt restraints

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<th>External</th>
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Table 3a. Human passengers with 2-point torso belt restraints

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<th>Torso belt load (kg)</th>
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\(^a\) ACIR injury ratings revised to AIS.

Table 3b. ATD passengers with 2-point torso belt restraints

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tests, with cadavers in driver and right-front-passenger positions, with velocity changes from 19 to 47 mi/h (31-75 km/h), and with a variety of restraint systems—3-point belts, air belts, air cushions, and bag bolsters. Data points from the latter three types of restraints with their increased occupant loading areas, as compared with that of belts, are separately identified.

Considerable scatter is evident in each of the data plots even with separation of the distributed loading restraints. One difficulty is the use of an overall AIS rating when the
Table 4a. Air belt, bag bolster, and air cushion restraints on human subjects

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<td>73.9</td>
<td>57/835</td>
<td>104/728</td>
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<td>[6]</td>
<td>Bag bolster</td>
<td>RFP</td>
<td>10</td>
<td>M</td>
<td>67</td>
<td>1.65</td>
<td>58</td>
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<td>64.9</td>
<td>10</td>
<td>3</td>
<td>39/237</td>
<td>275/814</td>
<td>Car-Car</td>
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Table 4b. Air belt, bag bolster, and air cushion restraints on ATD’s

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<th>Occupant position</th>
<th>Run No.</th>
<th>ADT make-percentile</th>
<th>Weight (kg)</th>
<th>Torso belt load (kg)</th>
<th>AV (km/h)</th>
<th>Test type</th>
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<td>RFP</td>
<td>16-R</td>
<td>Humanoid (572)—50th</td>
<td>73.9</td>
<td>75.6</td>
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<td>RFP</td>
<td>273</td>
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<td>-</td>
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<td>Driver</td>
<td>261</td>
<td>Humanoid (572)—50th</td>
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<td>49.0</td>
<td>33/168</td>
<td>38/261</td>
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<td>Driver</td>
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<td>-</td>
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<td>Bag bolster</td>
<td>RFP</td>
<td>1430</td>
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<td>76.3</td>
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<td>73.9</td>
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<td>57/835</td>
<td>104/728</td>
</tr>
</tbody>
</table>

Particular criteria are concerned with the torso and head separately. Although most of the papers from which the sample of cadaver data in Tables 1, 3, and 4 were obtained reported only overall AIS ratings, some did include injury descriptions. From these descriptions and from some test reports, AIS ratings were obtained for the chest-abdomen and head-neck areas separately as presented in Table 5. Head-neck AIS ratings were predominantly cervical injuries.

Figure 2 presents these body area ratings as functions of the appropriate measured cadaver responses. The data for air belt, air cushion, and bag bolster restraints continue to demonstrate a somewhat lower AIS rating than the 3-point belts for a given chest resultant acceleration and chest severity index as would be expected for a more distributed loading of the torso. Head-neck AIS ratings also tend to be somewhat lower for a given head resultant acceleration. Air bag and air belt restraints generally provide considerable restraint to forward head motion that would reduce neck injuries as compared with belts in the more severe exposures and could account for the apparent higher survivable head accelerations. Similar interpretation can be given to the head-neck AIS ratings versus head injury criterion.

The data presented in figures 1 and 2 should not be viewed as a definitive evalu-
Figure 2. Measured cadaver responses versus body area AIS ratings.
SECTION 4: TECHNICAL SEMINARS

The application of belts versus the more distributed loading restraints. The sample size is small and much unexplained scatter remains. These test results are presented to indicate the application of cadaver AIS ratings in conjunction with the measured responses now in use in the evaluation of restraint systems. Improvement in instrumentation techniques should greatly increase their utility in this regard. Nevertheless, there is an indication that the present criteria may need modification to better define survivable exposures, particularly with more advanced restraints.

**TORSO BELT LOADS AND CADAVER INJURIES**

The passenger cadaver tests summarized in table 1 comprise a set of data where injuries have been produced only by the belt restraints. There are no reported head-impact injuries, but there are cervical spine injuries. Torso belt loads are those measured at the upper anchorage. Figure 3 presents these belt loads versus overall AIS rating.

There is appreciable variability as indicated by the correlation coefficient of 0.68. However, these data demonstrate considerably less scatter than any of the cadaver response measures of figure 1.

In order to separate the more direct injuries from belts, the body area AIS ratings of table 5 were used in figure 4. Tests of five cadavers [13] were lost for this analysis, as no details of injury were available for the categorization of injury ratings.

Torso belt load is highly correlated \((r = 0.81)\) with chest-abdomen AIS. The belt load at which the linear equation crosses the serious injury category, AIS 4, is approximately 1,500 pounds (680 kg); however, an injury rating of AIS 5 was achieved in one test at a belt loading of approximately 1,100 pounds (500 kg).

No attempt has been made to correct the cadaver AIS ratings for age. For blunt impacts on cadavers, an age correction was obtained in reference 14. If this correction were applied to the ratings in figure 4 for the mean subject age of 53 years, three AIS ratings would be increased by one rating. The effect on the least squares fit or on the correlation coefficient would be minimal.

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</tr>
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<td>12</td>
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<td>54</td>
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These test results are presented to indicate the application of cadaver AIS ratings by body area.
Figure 3. Torso belt load versus overall AIS rating—cadaver passengers with 3-point belts.

The belt restraint systems included in this analysis vary as to belt characteristics, use of limiters and retractors, and the overall restraint configuration. The effects of none of these factors can be specifically identified in this analysis, although they may well be apparent, particularly in the head-neck injuries of figures 2 and 4. More of the total cadaver data sample is included in figure 4 than in figure 2, as more belt loads were reported than head acceleration responses. This may account for the increased scatter in the head-neck injuries.

The etiology of head-neck injuries of cadavers is difficult. Injuries as severe as cervical fractures can readily be identified. Brain injuries, unless relatively gross, cannot be identified unless special techniques are employed, such as, pressurization of the head-arterial system with a detectable fluid. Also, it is not known that the autopsies conducted by the various organizations that conducted the tests included pathological examinations of the head and brain.

Therefore, any conclusions regarding the head-neck injuries in terms of either belt load or head response measures must be tentative. From the test data used, both for figures 2 and 4, the conclusion that can be made with most confidence is that cervical spine injuries did occur at the levels of head responses and belt loads as measured.

RIB FRACTURES AS INJURY INDICATORS

The number of rib fractures as a measure of injury is an intriguing concept that has been used in reference 3 to integrate cadaver test results. Rib fractures are countable after an autopsy, and constitute a relatively continuous measure that is also not as subjective as injury ratings. Ribs (plus sternum and clavicle) are the body structural elements directly loaded by torso restraints.

Figure 5 presents the number of rib fractures with 3-point belt restraints versus torso belt load. The correlation is less than that obtained with torso belt load versus chest-abdomen AIS (fig. 4); however, rib fractures and chest-abdomen AIS are not linearly correlated as shown in figure 6. Up to approximately 12 to 16 fractures, there appears to be a relatively linear relationship. For greater numbers of fractures, the AIS ratings tend to be relatively constant. This should be expected, as the rating scale has an upper limit. There are only so many fatal chest injuries that can occur in a given exposure, however severe.
ATD AND CADAVER INJURY CRITERIA MEASURES

Internal and external instrumentation for ATD response measurements were used for a few of the tests conducted for comparison with cadavers (table 2). The internal and external measures on the ATD's are compared in figure 7. Although somewhat different chest and head installations (and number of accelerometers) were used, the difference between internal and external measures are similar for the tests of references 4 and 11.

Chest resultant accelerations and CSI tend to vary about the line for agreement. Head resultant accelerations and HIC tend to be proportionately higher for external as com-
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Figure 5. Torso belt load and cadaver rib fractures—3-point belt passengers.

Figure 6. Rib fractures and AIS rating.

pared with internal measurements on ATD’s.

With the construction of the ATD heads and their “skin” characteristics, head mounts are less rigidly attached than those for cadavers. However, with additional accelerometers to provide center-of-gravity cadaver head accelerations, there will be increased weight. Exactly how this somewhat increased mounting stiffness and increased weight, as compared with ATD’s, will affect the dynamic response of cadaver head measurements can only be speculated until instrumentation packages are standardized.

For the ATD tests conducted for comparison with cadaver tests, the internal ATD measures are compared with the external cadaver measures in figure 8, as are torso belt loads. Chest responses and belt loads compare reasonably well as do the head responses if the tests in which the cadaver head instrumentation struck the car interior are discounted. However, the available data comprise a small sample from which to draw conclusions. For the individual comparisons, there are differences in impact conditions (such as velocity change) and differences in
cadaver and ATD weights in addition to the instrumentation differences. Also, the data plotted in figure 8 are both single test comparisons and multiple test comparisons as shown in table 6.

**CADAVER INJURIES AND INJURIES IN ACCIDENTS**

When cadaver injuries have been compared with injuries received in accidents, the comparison is made most generally on the basis of the number of rib fractures. It has been concluded that cadaver tests result in more injuries than are received in comparable accidents as in references 12 and 15. There are many rib fractures in the sample of tests collected for this analysis; in fact, there are only six cadavers for which there were no fractures of a total of 51 cadavers on which autopsies were performed.

A disproportionate (compared with accident frequencies) number of cadaver tests have been run at relatively severe exposures. Approximately 30 percent of the cadaver tests reported in tables 1 and 3, for which both rib fractures and torso belt loads were available, were conducted at exposures that resulted in torso belt loads of 1,500 pounds (680 kg) or greater. Equivalent belt loads were obtained with 50th-percentile ATD’s in barrier crashes of full-size 1974 automobiles at speed changes of approximately 30 to 40 mi/h (48-64 km/h) [16]. For some recent model subcompact automobiles, such belt loads were not realized until speed changes of approximately 50 mi/h (80 km/h) were reached [17,18].

In actual accident exposures, it is suspected that a great number of rib fractures go undetected. Complaints of chest pain are numerous and are generally assigned AIS 1 ratings. Even with radiological examinations, the majority of such fractures are undetected. In posttest radiological examinations for programs conducted by Calspan, 22 (including one possible) fractured ribs were detected as compared with a total of 79 at autopsy. This detection rate of 27.8 percent is further reduced if the total number of fractures is used. Only 23 fractures of a total of 112 were detected for a rate of 21 percent.

Cadaver subjects tend to over-represent the older segment of the population in accidents. This should be accounted for if it affects the injuries resulting in their use in
Figure 8. ATD internal versus cadaver external response measures.
Table 6. ATD and cadaver response measures

<table>
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<th>Number of ATD's</th>
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<th>Head acceleration</th>
<th>Torso belt load (kg)</th>
<th>Number of cadavers</th>
<th>Torso acceleration</th>
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<td>168</td>
<td>37</td>
<td>344</td>
<td>-</td>
<td>-</td>
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</tr>
</tbody>
</table>

*aNo autopsies.

Restraint system evaluations. As indicated earlier, an adjustment on AIS ratings of .03 per year of age has been determined for blunt impacts [14].

In reference 3, a correction of the number of rib fractures of three per 10 years of age was used based on the data of reference 20. This rib fracture age effect resulted from a univariate analysis and appears to be too large from a general examination of the data presented herein. Whether an age effect is apparent in these data can be determined only through a comprehensive multivariate analysis.

One study [7] compares CSI and HIC responses of ATD’s and human volunteers in sled tests with an air cushion restraint. It was concluded that, for this exposure, ATD responses were somewhat greater (CSI and HIC) when compared with human volunteers. The two cadaver tests with an air cushion restraint [19] were in close agreement with the human volunteers on CSI and on HIC for the driver. The passenger cadaver had a value of HIC closer to the ATD’s reported.

Two rib fractures resulted from this double exposure of the cadaver to car-to-car crash tests with air cushion restraint. On this basis for this one cadaver, it must be concluded that the AIS rating of two was slightly conservative when compared with the minor injuries experienced by the human volunteers.

CONCLUSIONS

Cadaver and ATD response measures appear to be generally equivalent in similar exposures. However, the chest and head injury criteria, as measured on either surrogate, have a relatively high variability. This becomes most apparent in the correlation of cadaver response measures with AIS ratings determined in autopsies.

Torso belt load appears to be a considerably better indicator of cadaver injuries to the chest-abdomen area when 3-point belts are worn. However, chest and head resultant accelerations versus AIS ratings are sufficiently sensitive that the performance of distributed load restraints (such as air belts, air cushions, and bag bolsters) can be distinguished from that of 3-point belt restraints. This distinction is improved when body area AIS ratings are used rather than overall ratings.

The use of cadavers as surrogates must include autopsies in order to adequately assess injury; therefore, there should be no multiple use. Their most appropriate use, in restraint system evaluation, is to establish limits of protection. Such employment, in
conjunction with ATD's, should provide
good predictions of human performance.

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Crash Victim Simulation—A Tool to Aid Vehicle Restraint System
Design and Development

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GREGORY W. KOSTYNIUK,
and SAVERIO M. PUGLIESE
Calspan Corporation

ABSTRACT

The three-dimensional computer simulation of crash victim dynamics developed by Calspan is briefly described. Applications of the model that demonstrated its usefulness in providing guidance for the design and development of an advanced air bag restraint system for subcompact car passengers and for defining the most suitable restraint system configuration for the Research Safety Vehicle are discussed. Some comparisons of predicted responses with those measured in subsequent tests performed in developing the restraint systems are presented.

INTRODUCTION

Over the past decade, the development of mathematical models of crash victims and their environments has resulted in a dramatic advance in the capability to predict occupant response to vehicle crash stimuli. From early planar models of the occupant and vehicle interior in frontal impact developed by McHenry and Segal [1, 2, 3] the state of the art has been advanced to today's sophisticated three-dimensional models with the advent of large-scale, high-speed digital computing equipment. One such model is the Crash Victim Simulation (CVS) devel-
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DESCRIPTION OF THE CVS III SIMULATION

Mathematical Model

The CVS III is a mathematical model written in Fortran IV language that describes the kinematical responses of a simulated human to prescribed impact stimuli. The crash victim is simulated by \((n)\) rigid ellipsoidal segments connected by \(n-1\) joints. Vehicle geometry contacted by the occupant is simulated by a maximum of 20 planes each having specific force-deflection properties, coefficients of friction, and restitution. The occupant is also reacted by simulated restraints such as an inflating air bag, which is modeled as an ellipsoidal body, belt system, or by a fixed ellipsoid with specified force-deflection properties.

The size of the computer program that describes the mathematical model is substantial; it has eighty subroutines requiring 500K bits of core storage on an IBM 360 or 370 computer system.

Program Input and Output

Inputs to the program version employed in the design studies include dimensional, mass, and force-motion properties of the crash victim; the geometric and compliance properties of the vehicle interior surfaces; the vehicle deceleration time history; the restraint system geometry; and the parameters that describe the air bag inflation system or the belt force-deflection characteristics.

Input data for the occupant include the inertial parameters (weight, center of gravity location, and moments of inertia), link lengths, and the center and semi-axes of ellipsoids used to approximate the exterior contact surfaces of each segment; and parameters that define the joint torque characteristics as a function of the angular deflection and velocity of each joint.

Output from the computer program consists of printed tabular time histories of the occupant's kinematical responses and restraint system reaction variables.

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2\((n)\) Limited by capacity of computer storage.
occupant segment linear and angular accelerations, velocities, and displacements, joint torques, and forces and associated deflections resulting from contact between specified occupant segments and vehicle interior surfaces. In addition, similar tabulations of loads developed between the air bag or belt restraints and specified occupant segments and ellipsoidal air bag reaction surfaces are included as output. The program also generates a digital tape for use as input to a post-processing program which computes head and chest severity indices and the head injury criterion (HIC) number. A simplified representation of occupant and air bag kinematics is provided as a printer-plot showing the location in the X-Z and Y-Z planes of body segment joints and centers of gravity and the air bag center and surface points.

APPLICATION OF THE CVS TO THE DESIGN OF RESTRAINT SYSTEMS

Approach and Methodology

Three applications of the CVS simulation to the design of restraint systems are described in this section. Two were performed in the RSV Phase II program, which included an air bag and an advanced belt system, and the third was performed in the Aspirated Inflator Air Bag development effort. All three studies shared certain aspects of methodology and input parameters for the CVS program. These included methods for developing geometric descriptions of vehicle interiors, dimensional scaling, input parameters for the 50th-percentile male occupant, interior surface force-deflection properties, and techniques for developing inflator input parameters for simulations involving air bag inflation. The common aspects of the simulation efforts are described in detail in this section, while specific methodology unique to each program is addressed in those sections dealing with the respective projects.

The model of the crash victim employed in these studies consists of 15 segments and 14 joints to represent the human body as illustrated in figure 1. Each segment is a rigid ellipsoidal body having semi-axis dimensions approximating the external components of the human anatomy. For the 50th-percentile male occupant, the geometric, joint torque, and inertial parameters were based on available data published for the Part 572 (Hybrid II) and Sierra 1050 anthropomorphic dummies. Geometric data were obtained from NHTSA SA150M series drawings referenced in 49CFR-Part 572. The assembly drawings of the dummy were used to determine the equivalent ellipsoidal representation of each body segment. Input values for the moments of inertia of the segments and for the joint torque properties were based on measurements reported by Bartz and Butler [6]. Static torque-angular deflection data for the neck and lumbar spine components of the Hybrid II dummy reported by Miller [7] and by Naab [8] were used to estimate the location of the head and neck pivots and the waist and pelvis joints.

Only limited data were available for determining the joint viscous torque and stop location parameters of current dummies. Hence, generalized joint stop data for the 50th-percentile male [9] were employed as input for the simulation. Coulomb friction parameters for the joints connecting the distal segments were calculated on the basis of equivalent joint torque to sustain the weight of the segment in a horizontal position.

Measurements of vehicle interior geometry [10] provided the necessary data for simulation input. The vehicle interior layout shown in figure 2 is an example of the planar and ellipsoidal representation of the vehicle interior developed from the aforementioned data. The figure also illustrates the ellipsoidal representation of the occupant and its equilibrium position prior to a simulated impact.

The program requires input mutual force-deflection characteristics for each specified occupant contact plane. The data must represent contact force as a function of the combined deflection of a given body segment and the surface in contact with it. Data of this nature are particularly important for program input descriptions of seat cushion and seat back characteristics. Hence,
measurements of these properties were obtained for the RSV base vehicle (Simca 1307) and the vehicle selected for installation of the aspirated air bag system (Volvo 244 DL) [11].

The CVS III air bag subroutine models have a stored cold gas inflation system. However, the gas dynamic data available for these studies represented an inflation system containing a pyrotechnic hot gas generator.

Figure 1. Body dynamics model.
Therefore, sets of equivalent cold gas input parameters were developed. To do this, static inflation end point pressure, volume, temperature, and mass data were used in calculations to determine the peak pressure differential in the design bag volume employed in the simulations [12].

In the simulation, the air bag geometric shape is an ellipsoid of revolution defined by semi-axis dimensions X, Y, and Z. For simulating air bags of cylindrical shape, the cross section semi-axes X and Z were made equal and the width of the ellipsoidal bag (Y axes) adjusted to provide the same volume.

Air Bag Restraint System Simulations

Research Safety Vehicle (RSV) Program. As part of the Calspan RSV effort, a preliminary passenger air bag restraint design concept was developed. The development of this concept was executed in three distinct tasks—review of available data on small car inflatable restraints, CVS modeling, and validation sled testing.

The air bag restraint data generated by the literature review (bag size, shape, pressure, sensing time, inflation time, and so forth) were used as initial input for the simulation study.

Vehicle input parameters were, for the most part, obtained directly from the RSV baseline vehicle, the Simca 1307. Measurements taken in a Simca [10] were used to define the vehicle interior geometry. Force-deflection data for the Simca seat back and seat cushion were acquired from static tests performed by applying loads to the respective cushions with a Part 572 dummy [11]. Similarly, knee bar properties were obtained.
from sled test data of dummy femur responses to impact with aluminum honeycomb bolsters.

For other occupant contact panels, force/deflection properties were chosen primarily on the basis of availability since no applicable data were established for the RSV baseline vehicle. Thus, “typical” properties for the windshield, toeboard, floorboard, and roof-header were simulated.

The vehicle deceleration pulses used during the course of the simulation effort were generated from a vehicle impact structural response model (BASHSIM Program) using the static crush properties of the RSV.

On the basis of twenty-three simulation runs, parameter sensitivity ranges for the restraint system variables were established and a preliminary design concept developed.

The results of three sled runs were used to validate the conclusions of the modeling effort. Actual sled deceleration pulses measured in each test were used as input to the comparable simulation. A tabulation comparing predicted and observed results for each sled test is presented in table 1. A comparison of selected time histories of these data is displayed in figure 3. The results of the validation effort suggest the following observations:

- The air bag model loads the occupant earlier than the sled tests indicate ($\approx 12.5$ millisecond shift in the pulse)
- When this shift is taken into account, there is an excellent correlation with the gross occupant acceleration response, which is typified by the chest (see fig. 3)
- The simulation overpredicts the air bag pressure

![Figure 3. Selected examples of CVS-III validation results.](image)

<table>
<thead>
<tr>
<th>Table 1. Comparison of sled tests and simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation</td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Peak chest resultant $g$</td>
</tr>
<tr>
<td>Peak head resultant $g$</td>
</tr>
<tr>
<td>Peak bag pressure</td>
</tr>
</tbody>
</table>

NOTE. T = test; S = simulation.

- Femur load responses compare well with the tests
- The head responses are similar in wave shape but overpredict the test results

Based upon the results of this study, the simulation is capable of predicting occupant response changes that result from changes of restraint system parameters. However, care must be exercised in cases in which occupant displacement within the vehicle interior may be critical because air bag simulation results in this regard tend to be conservative.

Aspirated Air Bag Inflator Program. The primary objective of this effort was to pro-
vide guidance in selecting a suitable inflatable restraint configuration for testing and optimization in development experiments. A further objective was to predict changes in occupant kinematics that could result from changes in the system design considered during the development test phase.

To accomplish these objectives, simulation of the normally seated 50th-percentile male occupant and the out-of-position 6-year-old child were performed using the CVS III computer program.

Available data describing the age 6 child segment geometry, weight, moment of inertia, and center of gravity [9] were given in a format consistent with input to the requirements of an earlier version of the CVS. Hence, reformatting of this data was done for the Version III program used in this study. Furthermore, joint principal axis orientation and coulomb and viscous friction data for the 50th-percentile male were used as age 6 child input because of the lack of equivalent child parameters. The geometric configuration of the out-of-position child simulation is shown in figure 4 in conjunction with the vehicle interior and air bag deployment arrangement illustrated previously in figure 2.

To identify an optimum restraint configuration with which to begin experimental development, iterations of selected inflation and air bag venting parameters were investigated in conjunction with bench mark vehicle interior and crash pulse parameters. A total of seven CVS III simulations were performed for the normally seated 50th-percentile male and the out-of-position 6-year-old child occupant cases.

Four system design revisions were simulated with the CVS using the bench mark vehicle and 50th-percentile male occupant parameters.

Descriptions of the CVS simulations performed during this effort are summarized in the run matrix presented below.

<table>
<thead>
<tr>
<th>System Definition Runs</th>
<th>Restraint Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run</td>
<td>Occupant</td>
</tr>
<tr>
<td>AAB4</td>
<td>50th-percentile male</td>
</tr>
<tr>
<td>AAB5</td>
<td>50th-percentile male</td>
</tr>
<tr>
<td>AAB6</td>
<td>50th-percentile male</td>
</tr>
<tr>
<td>AAB7</td>
<td>6-year-old child</td>
</tr>
<tr>
<td>AAB8</td>
<td>6-year-old child</td>
</tr>
<tr>
<td>AAB10</td>
<td>50th-percentile male</td>
</tr>
<tr>
<td>AAB11</td>
<td>50th-percentile male</td>
</tr>
</tbody>
</table>

System Optimization Runs (Run AAB11 is bench mark)³

<table>
<thead>
<tr>
<th>Run</th>
<th>Occupant</th>
<th>System change</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAB12</td>
<td>50th-percentile male</td>
<td>6-inch knee bar spacing</td>
</tr>
<tr>
<td>AAB14</td>
<td>50th-percentile male</td>
<td>50-ms bag deployment time</td>
</tr>
<tr>
<td>AAB15</td>
<td>50th-percentile male</td>
<td>28-inch diameter bag</td>
</tr>
<tr>
<td>AAB16</td>
<td>50th-percentile male</td>
<td>bag deployment point 4 inches rearward</td>
</tr>
</tbody>
</table>

³AAB11 = 2-inch knee bar spacing; 30-ms bag deployment time; 24-inch diameter bag.
A tabulation of selected peak occupant responses computed in each simulation run is presented in Table 2. Included in the summary are occupant head and chest acceleration and rebound velocity, femur loads, and air bag and knee bar penetration data. In addition, corresponding head and chest severity indices and HIC numbers are provided. The tabulated values of longitudinal (X) and vertical (Z) head and chest displacements correspond to peak values attained during ride-down for the 50th-percentile male simulations, and during rebound from the air bag for the 6-year-old child runs.

Table 2. CVS simulation results for 48 mi/h normally seated adult and forward position child—static condition

<table>
<thead>
<tr>
<th>Run</th>
<th>Occu-</th>
<th>Head</th>
<th>Chest</th>
<th>Knee</th>
<th>Maximum pressure bag</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pant</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HIC</td>
<td>HSI</td>
<td>V</td>
<td>X</td>
<td>Z</td>
</tr>
<tr>
<td>AAB4</td>
<td>50th</td>
<td>131</td>
<td>922</td>
<td>1,315</td>
<td>5</td>
</tr>
<tr>
<td>AAB5</td>
<td>50th</td>
<td>106</td>
<td>1,006</td>
<td>2,166</td>
<td>35</td>
</tr>
<tr>
<td>AAB6</td>
<td>50th</td>
<td>90</td>
<td>1,081</td>
<td>1,246</td>
<td>18</td>
</tr>
<tr>
<td>AAB7</td>
<td>50th</td>
<td>57</td>
<td>335</td>
<td>496</td>
<td>35</td>
</tr>
<tr>
<td>AAB8</td>
<td>6-yr-old</td>
<td>49</td>
<td>111</td>
<td>142</td>
<td>17</td>
</tr>
<tr>
<td>AAB9</td>
<td>6-yr-old</td>
<td>98</td>
<td>1,705</td>
<td>2,007</td>
<td>31</td>
</tr>
<tr>
<td>AAB10</td>
<td>50th</td>
<td>98</td>
<td>1,705</td>
<td>2,007</td>
<td>31</td>
</tr>
<tr>
<td>AAB11</td>
<td>50th</td>
<td>84</td>
<td>1,179</td>
<td>1,382</td>
<td>14</td>
</tr>
<tr>
<td>AAB12</td>
<td>50th</td>
<td>92</td>
<td>1,250</td>
<td>1,454</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AAB14</td>
<td>50th</td>
<td>91</td>
<td>1,382</td>
<td>1,593</td>
<td>17</td>
</tr>
<tr>
<td>AAB15</td>
<td>50th</td>
<td>67</td>
<td>899</td>
<td>1,057</td>
<td>22</td>
</tr>
<tr>
<td>AAB16</td>
<td>50th</td>
<td>58</td>
<td>705</td>
<td>814</td>
<td>16</td>
</tr>
</tbody>
</table>

NOTE—
HIC, HSI, CSI = Head injury criteria, head severity index, chest severity index
X = Maximum longitudinal motion with respect to vehicle interior, in
Z = Maximum vertical motion with respect to vehicle interior, in
F = Target penetration normal to target surface, in
V = Peak X component rebound velocity, ft/s
P = Maximum femur force, lb
(1) X and Z exclude rebound in 50th runs
(2) Design version simulations AAB12, 14, 15, and 16 are relative to run AAB11 benchmark.

Target penetration (P) is the peak penetration into the air bag by the head or chest and peak deformation of the knee restraint by the knees. Air bag penetration is defined as the distance measured between the most forward point on the head or upper torso ellipsoid and the midpoint of the air bag arc segment formed by the intersection of the ellipsoid. Knee bar penetration is defined as the X axis component of knee displacement with respect to the vehicle reference.

Although no formal validation tests were required as part of this effort, data were available from one development sled test in which the test configuration closely matched the input of a simulation run. Hence, it is possible to evaluate the accuracy of CVS III predictions on the basis of these data.

To provide an overall indication of the correlation between predicted and measured responses, time histories of head and chest resultant acceleration, and bag pressure comparing simulation run AAB12 and sled test 1510 are presented in figure 5.

A comparison of the amplitude-time characteristics of these plots indicates reasonably good correlation of wave shapes and peak amplitudes between the predicted and observed results. It is also noted, however, that the predictions lead the experimental results by a consistent time interval for all variables except for decreasing values of bag pressure. Further, it is observed that the simulation overpredicts the peak bag pressure.
importance in this study, the investigation did not extend to displacement criteria. Furthermore, the basic qualification that no hard contact between occupant segments and interior surfaces should occur was reflected in the majority of the simulation results. Hence, the problem of occupant free space in this context did not appear to be critical insofar as the predicted results were concerned, and the need, therefore, to evaluate computed and experimental results in terms of segment displacement time histories appeared to be unwarranted.

Belt Restraint System Simulations

RSV Program. As part of the effort to select a restraint system for the RSV, a computer simulation study was conducted using the CVS program to develop basic information on advanced belt restraint systems.

The purpose of the study at this point was not to analytically refine one particular design but rather to quantitatively define system performance potential, determine total system performance characteristics and sensitivity, investigate component requirements and their performance contribution, and isolate potential design and material performance problem areas.

To validate the computer program, a limited series of runs simulating the 35-mi/h barrier crash of the C-6 base vehicle was performed. The test selected for comparison was conducted with a 1975 Plymouth lap/shoulder belt system. The simulation was concerned with the front seat passenger part 572 dummy with the Plymouth belt restraint.

Measured interior dimensions of the C-6 vehicle [10] were input to the program as a series of appropriately sized and placed flat planes. Restraint system anchor point locations, obtained by measurement, were also specified in the above geometry input. Except for the shoulder/lap belt and the seat, representative values for force-deflection characteristics of all planes were used. Seat force-deflection data were obtained experimentally from the C-6 vehicle seat.
Data describing the stress-strain characteristics of the restraint webbing and the dummy upper torso compliance caused by belt loading were used to develop the necessary restraint system input parameters. However, since the CVS program does not compute chest deflection under belt load, the effect is simulated as virtual lengthening of the belt. This "lengthening" can be superimposed on the basic stress-strain curve of the belt to provide a modified characteristic that represents the total phenomenon. The modified stress-strain curve for the torso belt as used in the validation runs is shown in figure 6. Since the characteristic is dependent on belt length, a different curve is required for the lap belt. Simulated values of initial slack of 3.0" and 1.5" for the torso and lap belt, respectively, were obtained by measurement. A simulation run using the above data yielded more restricted dummy motion than was observed in the test data with accompanying higher than recorded peak acceleration and belt loads. However, it was noted in the test data that the torso belt load (stress) output had the characteristics of a load limited belt after 60 ms at a 1 300-pound level. This phenomenon had been observed on previous occasions and was believed to be caused by additional belt tightening inside the reel housing or slippage of the reel itself.

Hence, this characteristic was simulated by limiting the belt load level on the stress-strain curve, figure 6, to a constant level after the 1 300-pound point. In addition, the lap belt was limited to a 1 600-pound peak level.

The resulting simulation yielded head and chest acceleration results, which are shown in figure 7 superimposed on actual test data. Also shown are the predicted and observed torso belt loads.

The acceleration results in figure 7 are considered adequately matched both in level and pulse form for the purposes of this validation.

A closer match would probably be attained if the belt load level decrease (after 60 ms) was simulated. This would reduce the chest X-direction acceleration level and would possibly allow the head to contact the dash, as indicated by the spike in the test data at the 110-ms point. In the simulation, the head came close to the dash but did not contact it.

The results of the validation runs viewed from the extent of correlation between predicted and observed dummy accelerations provided confidence in the predictive capability of the CVS in a planned series of parameter variation runs.

Advanced Belt System Development. Most of the input data used in the validation phase remained intact throughout the study. Changes that were made were those mandated by geometrical design changes or by the addition of new restraint system components. In addition, vehicle deceleration pulses were changed as dictated by RSV structural changes and their response to various barrier impact speeds based on results computed by the BASHSIM simulation.

In addition to simulations involving geometric and vehicle parameter variations, several runs with various positions of the dashboard were also performed to investigate the effects of intrusion.

Variations of the belt system included simulation of load limiters and application of belt preloaders. The lower dashboard panel, repositioned and modeled with appropriate force-deflection characteristics, served as a knee bolster.

Impact Sled Validation. A small number of sled runs were performed employing dummies in a restraint system resembling the
simulated belt systems. Their purpose, in part, was to provide validation data for the CVS program configuration used in the course of this study.

Two runs were simulated, Run 1487, using a three-point standard belt system with torso belt load limiters and an energy absorbing knee bolster. Run 1489, using a two-point inflatabelt manually inflated prior to the start of the run. The system included torso belt load limiters and an energy absorbing knee bolster.

Figure 8 shows the two sled acceleration

![Graphs showing sled acceleration data with X, Y, and Z components]
Figure 7. Validation run and test C data comparison.—Con.
pulses, with the BASHIM predicted pulse included for reference. The sled pulses provide the same onset rate and final velocities as the BASHSIM model prediction but are of a different shape on the trailing part of the pulse. The actual sled pulses were used in the validation simulations.

For sled test 1487, figure 9 shows a comparison of predicted and observed head and chest resultant accelerations, as well as belt and knee bolster loadings. In this test, the lap belt broke at about 60 ms inducing dummy head oscillations. Because this phenomenon was not simulated, head acceleration agreement is poor in the interval between 70-100 ms.

Reaction forces of restraint system components (fig. 9) are not as closely matched on an individual basis; that is, lap belt and lower torso belt loads are underpredicted, while upper torso belt and bolster loads are overpredicted.

Figure 10 shows a comparison of predicted and observed head and chest acceleration for sled test 1489 with the preinflated inflatabelt restraint. The dummy’s chest contacted the instrument panel during the sled run; the simulation does not indicate contact but the chest does come to within an inch of the panel. The inflatabelt deflated prematurely in the test and this is believed to have increased the chest displacement reflected in the sled test.

The head acceleration test data reflect head-panel contact. This is also predicted by the simulation results, but the resulting spike is of lower magnitude (see head X-acceleration).

The simulation indicates the start of the head “whipping” (Z-acceleration increase) at about 50 ms, while actual data do not. This is the result of chin support provided by the air belt during the initial stage of dummy motion, an effect which was not simulated.

CONCLUSIONS

Air Bag Restraint System Simulations

The RSV validation tests and subsequent simulations reveal that the results of the simulation predict better performance than that which was achieved. The problem of phase shift error between predicted and observed results is common to both the RSV and the Aspirated Inflator simulation studies. Hence, in both simulation efforts, predicted occupant displacements, particularly the head, were considerably less than
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Figure 9. Three-point belt restraint performance—comparison of sled test and simulation results.

those measured in sled tests of equivalent configurations. For example, in (RSV air bag) test 1489, the dummy “lightly” impacted the air bag panel—yet the simulation indicated that the occupant had an additional 5 inches of stroke available. Thus, considerable care must be used in exercising the CVS model in situations in which the occupant stroke distance is extremely critical. However, since the main thrust of these studies concentrated on acceleration responses and related injury criteria, which were successfully simulated by the model, the predictive capability of the CVS was deemed adequate for the purpose of characterizing the restraint system requirements of the respective development programs.

Belt Restraint System Simulations

The results of the C-6 baseline crash test validation effort indicate good correlation between the measured responses and the predictions of these responses by the CVS model. However, the experimental data reflect head contact with the vehicle interior, a phenomenon that was not predicted by the simulation. If post-yield, stress-strain characteristics of the torso belt were included in the simulation input, more head travel would have resulted in head contact with the interior. Since this was not done, the simulation did not predict the measured head contact acceleration spike. Nevertheless, the CVS was judged to be adequate for the purposes of this study based on the observed degree of correlation within the context of the limitations cited above.

In the simulations of the advanced belt system sled test measurements, correlation between certain predicted and observed results is not as good as in the baseline validation runs. This is primarily the result of an inability to simulate the actual restraint properties with input describing the inflated belt characteristics in terms of equivalent webbing elongation. Recalling that the simulated belt force-deflection characteristics involve both belt and dummy compliance properties, it would be necessary to include these effects in the inflatabelt
input based on measurements of belt elongation and belt load distribution effects on dummy chest deflection. Measurements such as these involve elaborate experimental efforts which were beyond the scope of this validation effort.

Despite some lack of correlation in restraint force results, head and chest responses are in good phase agreement. In view of the experience with restraint characterization gained in the baseline test validation, it should be possible to achieve better occupant acceleration and restraint load amplitude agreement through the use of refined restraint system input characteristics.

**ONGOING EFFORTS TO IMPROVE THE CVS MODEL**

Recent Validation Efforts

In an attempt to explain and, more importantly, to eliminate the phase disagreement observed in the CVS air bag simulation results, a simulation of an aspirated inflator system sled test (1547) was run in which improved parameter input was used. Since the cause of phase shift was thought to be related to the parameter choices for the CVS bag inflation and venting algorithms and bag deployment geometry, particular attention was paid to the development of improved descriptions of these parameters. Because static deployment test data were available, the CVS bag inflation and venting equations were programmed in a separate routine to provide an inexpensive program that could be used to vary the CVS bag inflation parameters for a best fit to that data. The program, BAGFIL, was run to match the results of static test S-2 to predicted bag pressure measurements based on optimum CVS parameter choices. Figure 11 illustrates

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4Bag pressure versus time without occupant contact or vehicle acceleration.
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reflects a "slumped" orientation of the spine which causes the hip and thus the knee to be located forward of the measured joint positions. Arm trajectory is not in agreement because contact force reaction between the arm segments and the air bag was not specified in the simulation. However, in general, the measured head and upper torso displacements are in much closer agreement with predicted values than were previous simulation results.

the degree of correlation between predicted and measured bag pressure achieved with the BAGFIL routine. The inflation parameters thus derived, as well as more detailed measurements of vehicle interior geometry, were combined with a more elaborate method for simulating the actual bag deployment geometry in simulation run AAB-19. Predictions of head and chest resultant acceleration and bag pressure time histories and injury criteria are compared to measured counterparts in figure 12. Both the amplitude and the phase agreement of each variable show considerable improvement over the comparisons presented in previous discussions of air bag simulation results. Since the head and chest acceleration predictions more closely approximate actual measurements, it is meaningful to compare the predicted occupant kinematics to measurements taken from high-speed motion pictures. Such a comparison is given in figure 13 using a printer plot format, which depicts the occupant as a series of straight lines connecting segment joints. The predicted and observed head and upper torso positions show good agreement but the knee and arm trajectories do not. The cause of the overpredicted knee displacement is believed to be related to the choice of knee bar force-deflection characteristics and the simulated articulation of the lower torso joint of the dummy. It is noted in the simulated kinematics that the angle between the center and lower torso centerlines

NHTSA Program—"Validation of the Crash Victim Simulator"

At the present time, this research effort (Contract DOT-HS-6-01300) is being performed by Calspan to provide a detailed validation of the CVS model. To accomplish this, a series of comprehensive parameter measurements of a Part 572 dummy and of the restraint systems selected as part of the validation test configurations will be performed. Much of the parameter data for the Part 572 dummy will serve to fill the gap where no published data exist. Validation studies will consist of component response tests (head-neck, upper and lower torso-spine, and so forth) and complete system tests involving air bag and belt restraint systems. The tests for validity of predicted results will encompass variables not included thus far in any of the efforts described in this paper. For example, contact forces between occupant segments and vehicle interior surfaces or restraint systems will be measured for comparison with predictions.

A substantial portion of this effort will be devoted to model improvement and functional checking of the CVS-III subroutines. New routines are planned such as one that will automatically compute the pre-impact equilibrium position of the crash victim.

The results of this program will greatly enhance the current CVS capability by providing users with a detailed parameter description of the Part 572 dummy, additional model flexibility, and greater assurance of the validity of predicted results.
Figure 12. Comparison of predicted and measured responses.

Head resultant acceleration
- Sled test 1547
- Simulation AAB-19

HSI
730 Test
658 Simulation

Chest resultant acceleration
CSI
680 Test
576 Simulation

Air bag pressure
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PATRICK M. MILLER and
FRANK A. DUWALDT
Calspan Corporation

ABSTRACT

The Research Safety Vehicle (RSV) program encompasses safety, economy, resource conservation, and emissions relative to automobiles appropriate for the U.S. economy in the latter 1980's. The Calspan/Chrysler approach is based upon derivation of the RSV from a current advanced state-of-the-art production automobile. Adoption of a base vehicle approach provides a framework for introducing incremental changes in vehicle design consistent with program goals and typical automotive production constraints.

Characteristics of candidate materials, from the standpoints of availability, vehicle weight, and potential recovery, have played an important role in shaping the RSV designed. Resources entered into design considerations at several levels:

- Minimization of vehicle bulk via efficient packaging
- Weight reduction through materials substitution
- Materials selection and usage to permit efficient materials recovery

Base vehicle characteristics with respect to general layout—engine/driveline, occupant packaging, and cargo capacity—are reviewed briefly. Base vehicle packaging efficiency is demonstrated; run-flat tires, proposed for the RSV, would further increase this efficiency.

Two general alternative paths with respect to materials conservation are inspected—design for long life versus design for recovery and reuse of primary materials. Anticipated continuous changes in vehicle design (in response to requirements for increased fuel economy) and introduction of nonpetroleum propelled vehicles in the latter part of the century appear to favor a recycling strategy. Problems attendant to recycling are considered after the magnitude of automotive materials demands is reviewed.

The magnitude of passenger car demand for major materials is generated from estimates of car production and composition. These are compared to projected overall demands and reserves to establish the necessity for conservation. Estimates of the resource content of obsolete vehicles indicate the potential for recycling. Some of the problems associated with efficient recycling are pointed out and the results of a shredding experiment are described.

Finally, the design related material changes that convert the base vehicle to the RSV are identified and related to recycling efficiency.
INTRODUCTION

The objective of the Research Safety Vehicle (RSV) program as defined by the National Highway Traffic Safety Administration (NHTSA) is to provide research and test data applicable to automobile safety requirements for the mid-1980’s and to evaluate the compatibility of these requirements with environmental policies, efficient energy utilization, and consumer economic considerations. This paper attempts to present some of the constraints that resulted from material supply/demand forecasts and were then imposed upon the Calspan/Chrysler RSV design approach. Attention is focused, for the most part, on U.S. domestic considerations; however, it is recognized that the U.S. must necessarily continue a strong dependence on world reserves for vital mineral resources.

Results of our Phase I RSV study [1] strongly suggested that the availability of natural resources (both domestic and worldwide) would play the most important role in shaping future U.S. car design practice. The situation with respect to petroleum is well documented and, currently, fuel economy constitutes the most important concern in motor vehicle development. The pressure on manufacturers results from two sources. First, higher fuel prices have caused consumers to demand better fuel economy. Second, Federal legislation, beginning with 1978 models, requires manufacturers marketing cars in the U.S. to increasingly improve fuel economy performance. The legislation essentially strives to insure fleet average fuel economy (using Environmental Protection Agency (EPA) test methodology) of 27.5 mi/gal beginning with 1985 models.

We are not aware of similar efforts on the part of either automobile manufacturers or government institutions to develop long-range automobile technology consistent with constituent material conservation. One notable and important exception is the research activities of the Porsche organization directed towards the development of a long-life automobile [2]. In this instance, material conservation strategies are evident because of planned longer vehicle life and improved potential for eventual automotive constituent material recycling.

The intent of this paper is to highlight the expected shortages of a number of resources that are used in the production of automobiles. This problem will gain more attention in the latter part of this century as mineral shortages become apparent to the general public. It is important that the time frame of the RSV be placed in perspective. The RSV is an exercise that implies the development of an “idea” car suitable for mid-1980 requirements. This vehicle must be shaped by best “estimates” of technology, economics, and so forth, that will operate at least a decade and beyond in the future.

In this time frame, a strategy of severe conservation is called for relative to both petroleum and mineral resources. In many respects, conservation of petroleum and metals tends to be complementary. For example, automobile fuel efficiency is demanding a downsizing in automobiles. Thus, a reduction in mineral consumption as a result of improved fuel economy will take place. On the other hand, efforts to improve fuel economy could result in detrimental effects on vital mineral consumption. Two principal possibilities are noted: (1) material substitution in support of weight reduction might create supply problems—that is, materials in short supply might be substituted for ones having more generous supplies; and (2) weight reduction schemes might employ material application and design techniques which could adversely affect future potential for material recovery.

All of these factors influenced our suggested “family car,” believed to be suitable for the mid-1980’s. When contrasted with current U.S. family cars, this automobile may appear to represent a drastic change; but we believe that the movement to such vehicles will be gradual and consumers will indeed come to accept considerable downsizing in motor vehicles within the next few years. Thus, utility, cargo capacity, and so forth, were felt to be more important to the study than current consumer attitudes. Accordingly, efforts were made to substantially reduce vehicle bulk and weight.
while keeping packaging parameters relatively consistent with current practices.

In the following discussion it is noted that within the RSV program material conservation played the most dominant role in limiting vehicle size. A more modest consideration was given to possibilities of extending vehicle life (over present practice) and recycling potential. Our judgment tended to suggest that recycling has far more potential than longer-life cars. Indeed, at least in the United States, longer-life cars might lead to an adverse situation with respect to petroleum conservation since more fuel efficient cars would then not be introduced (and thereby replacing older, less efficient cars) as rapidly to the highway system.

As a result, material selection and joining techniques were geared to the expected material availability and the potential for recovery. To a certain extent, some progress in recovery technology is anticipated in the next several years; but, as a minimum, recovery of RSV constituent materials should not be degraded from that of current production automobiles.

**VEHICLE PACKAGING**

Reduction of vehicle weight is an obvious and strong material conservation strategy which carries with it a highly desirable energy conservation effect. The typical relationship between fuel consumption and vehicle weight (size) is presented in figure 1 (taken from ref. 1). Marketplace forces, however, place limits on such a strategy—that is, the consumers perceive transportation functions that cars must provide and choose passenger/cargo configurations that satisfy these perceptions. Although consumer perception may change with time, current perceived needs strongly influence RSV packaging requirements. Review of ownership and usage data led to the estimate that “family” use might well be the governing factor in consumer selection in spite of evidence that such usage does not dominate trip mileage patterns. Hence, a family sedan was selected as the recommended initial RSV configuration.

Extrapolation of family size led to the following car accommodation specifications appropriate to the mid-1980’s:

- 4-5 occupants (2 adults in front, 2 adults or 3 children in the rear)
- 14-19 ft² cargo volume
- 4 doors plus liftgate

These specifications then became the constraints on RSV sizing.

Car manufacturers have devoted attention to the creature comforts of seated, confined humans and achieved consumer acceptance in this area. The RSV passenger compartment layout, then, should fall in the range of automotive practice. Recommended ranges for RSV interior dimensions, luggage capacity, and curb weight are presented in table 1 for a number of production cars that span a curb weight range from near 2300 pounds to about 5300 pounds. It can be seen from these data that the RSV recommendation is slightly generous with dimensions normally associated with occupants. It is noted that the recommended RSV headroom has a lower limit that is

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1 The continuing growth of the second car market could have justified selection of a smaller vehicle, having a reduced capacity, that could accommodate a very large proportion of personal transportation use.
EXPERIMENTAL SAFETY VEHICLES

representative of current practice because our studies suggested that a more upright occupant seating configuration would permit a decrement of required compartment length that would be reflected in weight savings (and, hence, energy and material savings).

Next to be considered is the engine/drivetrain. Here, again, the use of components that would fit within the lateral dimensions of the car and minimize the length is indicated. At the same time, the engine layout should not compromise the controlled collapse of the structure on impact (crashworthiness). These items are, in fact, characteristic of the transverse front engine/front drive configuration. Furthermore, the absence of the drive shaft tunnel allows great freedom in the treatment of the structure in the firewall area and contributes to ease of packaging of occupants and the fuel tank.

For a number of reasons, principally related to limited program resources and the need for a demonstration of producibility within the program, we elected to derive the RSV from a current production automobile. This base car approach, therefore, placed additional constraints on the program. The selection of the base car accordingly empha-

sized excellent capacity to weight characteristics. Review of many candidate cars suggested the use of an automobile such as the recently introduced (in the European market) Chrysler Simca 1308.

Table 1 illustrates that the Simca 1308 has interior dimensions nearly within the range of those recommended for the RSV. Furthermore, its curb weight, near 2,300 pounds, would permit some growth (and still remain within the recommended RSV weight range) to provide for small improvements in capacity and major improvements in crash safety.

Although automobiles such as the Simca 1308 are not now manufactured within the United States, concepts embodied in this vehicle such as its front engine/front drive layout and corresponding occupant package will likely gain greater favor with future U.S. vehicles. Thus, in this sense, we are suggesting that future U.S. cars will begin to take on characteristics of a number of European automobiles. Accordingly, the RSV is to be efficiently packaged. Family accommodations are to be provided in a crashworthy structure at a curb weight less than 2,700 pounds. In effect, the role of the compact/intermediate vehicle is being played at a

Table 1. Typical car characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Body type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front compartment (in):</td>
<td></td>
</tr>
<tr>
<td>Effective head room</td>
<td>37.3-39</td>
</tr>
<tr>
<td>Maximum effective leg room--</td>
<td>40.4-2</td>
</tr>
<tr>
<td>accelerator</td>
<td></td>
</tr>
<tr>
<td>Shoulder room</td>
<td>54.6-60</td>
</tr>
<tr>
<td>Hip room</td>
<td>54.6-60</td>
</tr>
<tr>
<td>Rear compartment (in):</td>
<td></td>
</tr>
<tr>
<td>Effective head room</td>
<td>37.3-9</td>
</tr>
<tr>
<td>Minimum effective leg room</td>
<td>35.3-8</td>
</tr>
<tr>
<td>Shoulder room</td>
<td>54.6-60</td>
</tr>
<tr>
<td>Hip room</td>
<td>54.6-60</td>
</tr>
<tr>
<td>Usable luggage capacity (ft³)</td>
<td>14-19</td>
</tr>
<tr>
<td>Curb weight (lb)</td>
<td>&lt;3,000</td>
</tr>
</tbody>
</table>

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weight characteristic of current subcompact vehicles. This is regarded as a significant contribution to resource conservation.

MATERIAL CONSERVATION

The basis for a constituent material recycling emphasis within the program resulted from expected fuel economy demands and material conservation. The material conservation argument was just discussed relative to improved packaging efficiency while the fuel economy relationship is considered below. It is noted that these arguments are probably more suitable to the U.S. economy, where automotive fuel economy is considerably below worldwide standards, than to other industrialized nations.

One might, of course, argue that the United States should simply upgrade its fuel economy to worldwide standards. As noted earlier, however, it is our judgment that consumers do influence the kinds of cars that are produced and marketed. Previous experience on the part of U.S. consumers strongly suggests that there exists considerable reluctance to change to smaller, lighter weight cars. Although it is envisioned, and indeed highly recommended, that such change must occur in the U.S. economy, the transition will likely take place in a gradual manner.

Early in the RSV program, projected fuel economy requirement estimates for the U.S. economy for the next several years were made. These projections assumed, roughly, a continuation in current rates of growth in both the number of registered passenger cars and average mileage traveled for individual cars. One could seriously question these hypotheses; but, it was our judgment that American consumers will continue to demand increased mobility geared to housing and workplace relationships, and that manufacturers will attempt to fill this demand. Hence, substantial increases in miles traveled were assumed.

Within this framework, petroleum supply (availability) becomes the major controlling factor on required fuel economy. For the purposes of this study, a "best" condition of 2.6 percent annual growth in petroleum supply was assumed since such increases in production capacity have been occurring in recent years [3]. A "worst" condition was assumed where no growth would take place; that is, the petroleum supply would remain constant. These two estimates are shown in figure 2 as a performance range. It was postulated that the RSV, representing an average size passenger car for the mid-1980's, should generally fall within the median of this performance range.

When reviewing figure 2, it is important to note that all data are based to 1973. At that time, U.S. fuel economy was estimated to be 13.5 mi/gal [4] and projections are carried out for 32 years or until 2005. Also important, individual vehicle fuel economy should be related to the vehicle's operational lifetime. The problem with long-life cars when fuel economy is continuously improved is that early in the car's life its performance may be outstanding with respect to the overall fleet; but, near the end of its lifetime its relative performance may be poor.

Also illustrated in figure 2 are hypothetical relative positions of two RSV's introduced in 1985 (year 12) having respective 10-year and 20-year lifetimes. In the case of a 10-year lifetime car, a replacement car with improved fuel economy is shown for introduction in 1995 (dashed line at year 22). This difference between the two cars after 1995 represents propulsion energy savings as a result of introducing vehicles that would take advantage of advances in technology. The rejection of the longer-car-life approach mandates, however, that vital constituent materials be recoverable, implying the need for a recycling strategy.

In the previous discussion it was assumed that petroleum would be available for automotive transportation for the foreseeable future, well into the next century. Our investigations strongly suggest that alternative energy sources will be required near the end of this century. The impact of such alternatives on vehicle design is unknown. Thus, commitment of long-life cars beginning in the mid-1980's might well be counterproductive as new alternative energy sources are developed somewhere near the end of this century.
Figure 2. RSV fuel economy performance range.

Although recycling of materials is important to the RSV, its emphasis must be placed in proper perspective. Certainly, ferrous and some non-ferrous materials are readily recovered from automobiles today. Based upon the substantial progress the scrap processing industry has made in the last several years, considerable technical progress can be expected to also take place in the next twenty or more years. For these reasons, the recycling requirement posed for the RSV was that its design not degrade recovery possibilities from that of current production cars.\(^2\) Emphasis of recovery of material from obsolete vehicles results from a limited forecast of the U.S. material position during the next 25 years.

**PASSENGER CAR MATERIALS—ESTIMATED DEMANDS/SUPPLIES**

Projected vehicle downsizing furnishes one of the bases for developing estimates of materials required for passenger car production. Volume and composition are the other factors of demand. Retirement of obsolete vehicles will be included here to make a point about the potential for recycling.

Downsizing of future vehicles implies a weight differential between units being produced and units being retired—a rough projection of this situation is presented in figure 3. A smoothed estimate of units produced and units retired is shown in figure 4. Combining the unit weights and vehicle numbers gives a projection of the gross finished material used and scrapped shown in figure 5 and the net material balance in figure 6. The striking feature of figure 6 is the approximate integrated balance over the period 1980 to 2000. Of course this balance represents a difference of numbers based on a series of estimates and cannot be regarded as anything beyond the indication of a trend toward balance,\(^3\) but this trend justifies

\(^2\)In the context of our RSV program, comparative recycling studies are being performed with both the base vehicle and the RSV.

\(^3\)Especially since the scrap created during car production has not been taken into account in the calculation here.
further consideration of means for material recovery. Missing from this total picture is the matter of changing composition, which will now be considered.

Confidence can be placed only in one composition generalization: there will be an ebb and flow in the use of various materials rather than a monotonic trend. Decisions between materials for a given application will tend to hinge on price—and price savings can arise from a variety of unforeseen factors. The following assumptions influence the composition estimates:

- Crashworthiness requirements will not be reduced, and efficient crash energy absorption will entail participation by the body panels.
- Thermoplastic materials will become popular for soft front and rear applications.
- Plastic gasoline tanks are anticipated.
- Introduction of “alternative” engines will occur late in the time period considered and will not greatly distort the projections—the principal effect being on engine composition.
- Supplies of traditional automotive materials will not surrender their markets gracefully.
- The previously presented weight, production, and retirement trends are valid.

Resultant content curves for aluminum, plastics, and steel are presented in figures 7, 8, and 9. Inroads by aluminum and plastics by 1985 are projected at values appreciably lower than those presented elsewhere [5, 6].

Figure 3. Projected average weight of new production vehicles and retired vehicles.

Figure 4. Projected number of production and retired passenger vehicles.

Figure 5. Forecast of gross material weight of new cars and retired cars.

Figure 6. Gross passenger car material balance—production weight—retired weight.
Plateaus beyond 1985 for aluminum, plastics, and High-Strength Low-Alloy steel (HSLA) unit weights reflect the downsizing effect.

The projections for aluminum, plastics, and steel presented above give the impression of dramatic changes of car composition. However, when the effect of weight is introduced as a normalizing factor and other materials are included, the trend appears to be evolutionary (fig. 10).

Unit composition, weight, and production estimates combined give a projection for passenger car material demands. A few of these are summarized in figures 11 and 12. The HSLA component of steel is shown separately in figure 11 because of concerns about the availability of the characteristic trace-alloying elements—here taken to be columbium, vanadium, and titanium in addition to manganese. HSLA content is projected to rise rapidly to a plateau around 1985, while the remainder of the steel content exhibits a continuous erosion. Aluminum and plastics, figure 12, are estimated to show demand behaviors similar to that indicated for HSLA. Projected rapid rises in HSLA, aluminum, and plastic consumption reflect the belief that weight saving will be a part of the strategy adopted to meet fuel economy goals over the next decade. Leveling and reduction of demands beyond 1985 reflect the continued downsizing of vehicles and the relatively flat production rate forecast. The other traditional materials would show, at most, modest increases that peak in the 1980-1985 time interval.
HSLA, aluminum, and plastics are emphasized here because the projected rapid increases in their usage over the next ten years might signal a short term supply problem. It was assumed that columbium, vanadium, and titanium would share HSLA formulations roughly in proportion to price impact [7]. Maximum demand growth rates were estimated from the previously presented curves and conservative "supply" growth rates were derived from several sources. Rates are compared in table 2. Aluminum and vanadium automotive demand would be substantial customers for projected increased capacity—but the demand would be supportable. Plastics and titanium pose no problem; columbium is a special case. Projected imbalance for columbium is the result of the use of outdated "supply" information and this is indicated by the line through that number in table 2. In fact, reference 8 reports the recent addition of new supply capacity that approximately doubles the 1976 supply base; columbium will be available in the quantities needed. It is concluded that short-term material demand rates are supportable.

Similar demand analyses were carried out to determine if the passenger car domestic cumulative demand for resources\(^4\) represent...

\(^4\) Aluminum, chromium, columbium, copper, lead, nickel, plastics, steel, titanium, vanadium, and zinc.
sent a disproportionate share of domestic demand over all uses through the year 2000. It was concluded that the passenger car share of domestic demand is not excessive—a conclusion also documented in reference 9. However, when these demands (automotive and total) are referenced to mineral reserves, a more unsettling picture emerges. In particular, the dependence on imports and the additional factor of world competition for materials comes into focus.

Table 3 illustrates the point that the domestic requirements for automotive materials (at a price) would not appear to strain world reserves. At the same time, table 3

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Figure 11. Projected yearly content of passenger cars—steel.

Figure 12. Projected yearly content of passenger cars—aluminum and plastics.

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5 Mineral reserve data are ultimately traceable to Bureau of Mines estimates.
In summary, the perception of the materials demand/supply situation deteriorates as we progress through the various bases for assessment. At best, price competition for automotive materials can be expected—that is, increases in material availability by the mechanism of price increases that enable mining and/or recovery from currently uneconomical sources. Means for at least partially compensating for the foreseeable shortfall is recovery of materials from obsolete goods—a topic next considered with respect to obsolete road vehicles.

### RECYCLING

Arguments for the recovery of materials from obsolete goods have been advanced from a number of standpoints—such as environmental factors, materials cost, energy, balance of payments, and alleviation of potential shortages. Figure 13 illustrates U.S. import dependence for a variety of materials; the starred minerals are those expected to be used in quantity in automobile manufacture. Figure 14 shows that recycling of old scrap is a going business and this is a sure indicator that resource recovery is economically viable. It is accepted here, then, that materials recovery from obsolete motor vehicles is desirable and currently supportable (at least with respect to the ferrous

### Table 2. Projected automotive material demand rate of change and supply growth rate

<table>
<thead>
<tr>
<th>Materials</th>
<th>Projected</th>
<th>Conservative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>automotive</td>
<td>projected</td>
</tr>
<tr>
<td>maximum</td>
<td>growth rate</td>
<td>material</td>
</tr>
<tr>
<td>demand</td>
<td>growth rate</td>
<td>&quot;supply&quot;</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.16 X 10^6 st/yr</td>
<td>0.4 X 10^6 st/yr</td>
</tr>
<tr>
<td>Plastics</td>
<td>0.11 X 10^6 st/yr</td>
<td>1.1 X 10^6 st/yr</td>
</tr>
<tr>
<td>Columbium</td>
<td>0.34 X 10^6 lb/yr</td>
<td>0.24 X 10^6 lb/yr</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.22 X 10^6 lb/yr</td>
<td>0.66 X 10^6 lb/yr</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.19 X 10^6 lb/yr</td>
<td>1.5 X 10^6 lb/yr</td>
</tr>
</tbody>
</table>

NOTE. st = short tons.

### Table 3. Passenger car demands for cumulative materials to the year 2000/U.S. reserves/world reserves

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>United States</td>
<td>World reserves s</td>
</tr>
<tr>
<td>Aluminum, st</td>
<td>28 X 10^6</td>
<td>10 X 10^6</td>
</tr>
<tr>
<td>Chromium, st</td>
<td>0.7 X 10^6</td>
<td>–</td>
</tr>
<tr>
<td>Columbium, lb</td>
<td>41 X 10^6</td>
<td>–</td>
</tr>
<tr>
<td>Copper, st</td>
<td>4 X 10^6</td>
<td>90 X 10^6</td>
</tr>
<tr>
<td>Iron ore, st</td>
<td>580 X 10^6</td>
<td>2000 X 10^6</td>
</tr>
<tr>
<td>Lead, st</td>
<td>2 X 10^6</td>
<td>59 X 10^6</td>
</tr>
<tr>
<td>Nickel, st</td>
<td>0.3 X 10^5</td>
<td>Small</td>
</tr>
<tr>
<td>Titanium, lb</td>
<td>24 X 10^6</td>
<td>58 000 X 10^6</td>
</tr>
<tr>
<td>Vanadium, lb</td>
<td>0.27 X 10^6</td>
<td>230 X 10^6</td>
</tr>
<tr>
<td>Zinc, st</td>
<td>2.5 X 10^6</td>
<td>30 X 10^6</td>
</tr>
</tbody>
</table>

NOTE. st = short tons.

draws initial attention to deficiencies in the domestic reserves of aluminum, chromium, columbium, nickel, and possibly iron. Automotive needs, however, are only one component of resource use. These needs were previously shown to be realistic relative to overall domestic demands, but the potential for satisfying those overall demands was not discussed. If overall demands cannot be satisfied, then the car market must compete with other uses. Table 4 illustrates this basic problem. Domestic reserves do not balance projected cumulative domestic needs over all uses, even over the limited time period considered, with the exception of marginal coverage for copper, lead, and titanium. Furthermore, rising world consumption may well provide price competition for those materials now imported. Table 4 indicates that at least copper, lead, nickel, and zinc reserves already appear to be marginal on a worldwide scale.

### Table 4. Recoverable reserves (1973 prices) compared to cumulative demand over the period 1973-2000

<table>
<thead>
<tr>
<th>Commodity</th>
<th>U.S. reserves (1973 prices) to cumulative demand, 1973-2000</th>
<th>World reservesa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>Small</td>
<td>3.6</td>
</tr>
<tr>
<td>Chromium</td>
<td></td>
<td>5.1</td>
</tr>
<tr>
<td>Columbium</td>
<td></td>
<td>9.4</td>
</tr>
<tr>
<td>Copper</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Iron ore</td>
<td>0.7</td>
<td>4.4</td>
</tr>
<tr>
<td>Lead</td>
<td>1.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Nickel</td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>Titanium</td>
<td>1.1</td>
<td>3.3</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.2</td>
<td>7.1</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.5</td>
<td>0.6</td>
</tr>
</tbody>
</table>

aIncluding the United States.
Figure 13. Imports supplied a significant percentage of total U.S. demand in 1974 (from ref. 10).

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Percentage imported</th>
<th>Major foreign sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strontium</td>
<td>100</td>
<td>Mexico, United Kingdom, Spain</td>
</tr>
<tr>
<td>Columbium</td>
<td>100</td>
<td>Brazil, Malaysia, Zaire</td>
</tr>
<tr>
<td>Mica</td>
<td>99</td>
<td>India, Brazil, Malagasy</td>
</tr>
<tr>
<td>Cobalt</td>
<td>98</td>
<td>Zaire, Belgium, Luxembourg, Finland, Norway, Canada</td>
</tr>
<tr>
<td>Manganese</td>
<td>98</td>
<td>Brazil, Gabon, South Africa, Zaire</td>
</tr>
<tr>
<td>Titanium</td>
<td>97</td>
<td>Australia, India</td>
</tr>
<tr>
<td>Chromium</td>
<td>91</td>
<td>USSR, South Africa, Turkey, Philippines</td>
</tr>
<tr>
<td>Tantalum</td>
<td>88</td>
<td>Australia, Canada, Zaire, Brazil</td>
</tr>
<tr>
<td>Aluminum</td>
<td>88</td>
<td>Jamaica, Australia, Surinam, Canada</td>
</tr>
<tr>
<td>Asbestos</td>
<td>87</td>
<td>Canada, South Africa</td>
</tr>
<tr>
<td>Platinum group</td>
<td>86</td>
<td>United Kingdom, USSR, South Africa</td>
</tr>
<tr>
<td>Tin</td>
<td>86</td>
<td>Malaysia, Thailand, Bolivia</td>
</tr>
<tr>
<td>Fluorine</td>
<td>86</td>
<td>Mexico, Spain, Italy</td>
</tr>
<tr>
<td>Mercury</td>
<td>82</td>
<td>Canada, Algeria, Mexico, Spain</td>
</tr>
<tr>
<td>Bismuth</td>
<td>81</td>
<td>Peru, Mexico, Japan, United Kingdom</td>
</tr>
<tr>
<td>Nickel</td>
<td>73</td>
<td>Canada, Norway</td>
</tr>
<tr>
<td>Gold</td>
<td>69</td>
<td>Canada, Switzerland, USSR</td>
</tr>
<tr>
<td>Silver</td>
<td>68</td>
<td>Canada, Mexico, Peru, Honduras</td>
</tr>
<tr>
<td>Selenium</td>
<td>63</td>
<td>Canada, Japan, Mexico</td>
</tr>
<tr>
<td>Zinc</td>
<td>61</td>
<td>Canada, Mexico, Peru, Australia, Japan</td>
</tr>
<tr>
<td>Tungsten</td>
<td>60</td>
<td>Canada, Bolivia, Peru, Thailand</td>
</tr>
<tr>
<td>Potassium</td>
<td>58</td>
<td>Canada</td>
</tr>
<tr>
<td>Cadmium</td>
<td>53</td>
<td>Mexico, Canada, Australia, Japan</td>
</tr>
<tr>
<td>Antimony</td>
<td>46</td>
<td>South Africa, Mexico, P.R. China, Bolivia</td>
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<tr>
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<td>41</td>
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<td>Canada, Mexico, Jamaica</td>
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<td>Canada, Venezuela, Nigeria, Netherlands, Iran</td>
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<tr>
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<td>23</td>
<td>Canada, Venezuela, Japan, Common Market (EEC)</td>
</tr>
<tr>
<td>Titanium</td>
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<td>Canada, Peru, Australia, Mexico</td>
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<td>18</td>
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<tr>
<td>Pumice</td>
<td>8</td>
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</tr>
<tr>
<td>Salt</td>
<td>7</td>
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<tr>
<td>Magnesium</td>
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<td>Greece, Ireland, Austria</td>
</tr>
<tr>
<td>Cement</td>
<td>4</td>
<td>Canada, Bahamas, Norway, United Kingdom</td>
</tr>
<tr>
<td>Natural gas</td>
<td>4</td>
<td>Canada</td>
</tr>
</tbody>
</table>

1 Sheet mica
2 Rutile
3 Ores and metal
4 Includes natural gas liquid
5 Impermeable
6 Nonmetallic

SECTION 4: TECHNICAL SEMINARS

<table>
<thead>
<tr>
<th>Metals</th>
<th>Short tons</th>
<th>U.S. consumption, 1974 (%)</th>
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</thead>
<tbody>
<tr>
<td>Iron</td>
<td>132 000 000</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>508 000</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>483 000</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>265 000</td>
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</tr>
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<td>Zinc</td>
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</tr>
<tr>
<td>Chromium</td>
<td>54 000</td>
<td></td>
</tr>
<tr>
<td>Nickel</td>
<td>34 000</td>
<td></td>
</tr>
<tr>
<td>Tin</td>
<td>12 900</td>
<td></td>
</tr>
<tr>
<td>Antimony</td>
<td>22 400</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td>4 500</td>
<td></td>
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<tr>
<td>Mercury</td>
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<tr>
<td>Tungsten</td>
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<td>Tantalum</td>
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<td>Cobalt</td>
<td>240</td>
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</tr>
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<td>Selenium</td>
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<td>Silver</td>
<td>1 893</td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Platinum group</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

1Includes exports.

Figure 14. Old scrap recycled in the U.S. (from ref. 10).

content). Facilities are already in place for processing the volumes of cars expected to be retired in the time period of interest (1980 to 2000). It is vital that the promise of the recovery of materials not be impeded, and it is this aspect that will be discussed.

Several potential problem areas have been identified in the reclamation of materials from future obsolete cars. They are, in the end, based on the economics of recovery. It is paradoxical that questions about efficient recovery of materials from junk cars persist in spite of favorable developments in the steel industry—1975 was the first year in which more steel was produced in electric furnaces than in Bessemer furnaces and electric furnaces can efficiently accept shredder obsolete scrap. Furthermore, scrap recovery plants are being modified to permit economical reclamation of non-ferrous metals and various methods of utilizing plastic scrap are under study. In spite of these favorable indicators, efficient reclamation of obsolete vehicles is still problematical because of the following factors:

- As cars become smaller, the scrap yield per unit bulk decreases.
- Transportation (energy) costs of moving bulk are increasing.
- Transportation costs of moving shredded scrap are increasing.
- The changing composition of cars probably requires that materials other than ferrous be recovered—capital is required for these improvements.
The changing composition of cars and new design practices may produce a degradation of the ferrous material through additional contamination (such as the capture of "tramp" elements during magnetic separation).

The mix of sheet and cast aluminum probably will be reused only in castings.

The sorting out of possible end uses of shredded plastics in obsolete cars is incomplete.

Nearly all the above factors are under investigation by various organizations—principally the Bureau of Mines.°

In addition, the scrap industry has a stake in the prescriptions customers present to materials suppliers since the percentage of scrap in the charge may be limited by this specification. Sample allowables for drawing quality steels and ferrous foundry metal are given in tables 5 and 6. This particular aspect will become more important if the current trend toward the introduction of scrap melters in the basic oxygen steel cycle develops.°

Finally, the presence of the "white metals," that is, tin and zinc, can cause deterioration of furnace refractories; columbium, vanadium, and aluminum content of the scrap are generally oxidized and lost to the slag. Detailed consideration of these important metallurgical aspects are outside the RSV Phase II scope and attention is now turned to some aspects of vehicle design that can impact material recovery.

It will be recalled that substantial increases in aluminum, plastics, and HSLA car content were forecast. A simple set of shredding experiments—not yet complete—is being made to obtain a preliminary assessment of the effect these might have on material recovery:

- Shredding of a joined aluminum/steel structure (hoods)
- Shredding of a base vehicle (Simca 1308)
- Shredding of an RSV

To date, the hoods and the base vehicle have been processed, but only the hood experiment is discussed in detail here. The test articles were introduced "on-line" at the Roblin Scrap Products Facility—that is, no special attempt was made to clean and flush the system prior to the experiment. Eight steel/aluminum hoods were fed as a bundle and the outputs of the air separation chutes, the magnetic belt conveyor, and the non-magnetic belt conveyor were collected. The same procedure was followed with the base vehicle.

The hoods consisted of steel outer panels and aluminum inner panels joined by: 14 steel sheet metal screws along the front flange, 32 mechanical upset locks (clinch spots) along the side and rear flanges, and 47 plastic bond spots (see fig. 15). It was postulated that aluminum might be entrained with the ferrous outflow or steel might be entrained with the non-ferrous outflow. Results are presented in table 7. Of 238 pounds of steel input, 195 pounds were initially recovered at the ferrous outlet, one quarter of a pound showed up in the non-ferrous outlet, and a little over 3 pounds was captured by one of the air separators. An additional 30 pounds of hood steel was subsequently returned when the car shredding pass was made—and this is consistent with the 29 pounds of ferrous material that appeared as a "gift" from the mill (steel that had not been put in). Identified recovery at the ferrous belt, then, was at least 95 percent of the input and even the "refuse" was ferrous. Aluminum is a different story. Only

### Table 5. Permissible contaminants in drawing quality steel (from ref. 11)

<table>
<thead>
<tr>
<th>Element</th>
<th>Upper limit in percent by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>0.09</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.04</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.01</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.04</td>
</tr>
<tr>
<td>Tin</td>
<td>0.01</td>
</tr>
<tr>
<td>Total of all five when mixed</td>
<td>0.19</td>
</tr>
</tbody>
</table>

°See Part Two of reference 10 for program descriptions.
°Scrap charge in the BOF process is now limited by heat requirements because the scrap is cold. Scrap melters furnish a molten charge.

°°Standard stripping practice was followed except the engine and drivetrain were not removed.
Table 6. Composition tolerances for tramp elements in ferrous foundry metal (from ref. 12)

<table>
<thead>
<tr>
<th>Element</th>
<th>Steela</th>
<th>Malleable</th>
<th>Gray iron</th>
<th>Ductile iron</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>One-half inch and up</td>
<td>One-half inch and down</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Antimony</td>
<td>0.02</td>
<td>0.01</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.10</td>
<td>0.003</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>Bismuth</td>
<td>0.02</td>
<td>0.02</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Boron</td>
<td>0.02</td>
<td>0.02</td>
<td>0.005</td>
<td>0.005</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.02</td>
<td>0.01</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>Chromium</td>
<td>1.00</td>
<td>0.05</td>
<td>0.50</td>
<td>0.20</td>
</tr>
<tr>
<td>Cobalt</td>
<td>0.50</td>
<td>0.15</td>
<td>1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>Copper</td>
<td>0.020</td>
<td>0.02</td>
<td>0.001</td>
<td>0.004</td>
</tr>
<tr>
<td>Lead</td>
<td>0.40</td>
<td>0.40</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Manganese</td>
<td>NL</td>
<td>0.40</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>NL</td>
<td>0.02</td>
<td>1.00</td>
<td>0.25</td>
</tr>
<tr>
<td>Nickel</td>
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<td>0.15</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>Phosphorus</td>
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<td>0.05</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.10</td>
<td>0.001</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.05</td>
<td>0.05</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Tellurium</td>
<td>0.10</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Tin</td>
<td>0.020</td>
<td>0.01</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.10</td>
<td>0.01</td>
<td>0.50</td>
<td>0.10</td>
</tr>
<tr>
<td>Tungsten</td>
<td>0.10</td>
<td>0.01</td>
<td>0.20</td>
<td>0.10</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.02</td>
<td>0.01</td>
<td>0.10</td>
<td>0.10</td>
</tr>
</tbody>
</table>

aN = no limit but range should be shown.

Figure 15. Example of combined steel-aluminum automobile hood.
25 pounds of the 77 pounds of input initially reported to the expected station—the nonferrous belt output (about 4 more pounds were recovered later with the car materials) and 4 pounds of assorted nonmetallic refuse and one quarter of a pound of steel were also collected. Over 43 pounds of the hood aluminum were caught by the last air separator and about 2 pounds were eventually found in the wet scrubber container (air chute #2). The outlet of air chute number 4 contained a large volume of nonmetallic residue and a few wires that didn’t come from the hoods.

One further factor was investigated concerning possible aluminum capture in the ferrous fraction—mechanical entrainment of aluminum fragments inside the balled steel output. A melt and an analysis were made of candidate steel fragments; no aluminum was detected.

In summary, the shredding of the steel/aluminum assembly showed the following:

- Separation of the steel and aluminum was successful.
- The small amount of aluminum entrained with the steel was captured by the magnet because steel nuts were mechanically implanted in these pieces.
- More aluminum sheet was captured by the air separators than by the nonferrous belt.

It is clear that the use of aluminum sheet in automobiles will require an adjustment of the shredding process. Conversations with shredder operators and the early results from the base vehicle shredding developed the following points:

- Reduction of chromium content in the vehicle is desirable since it would increase the salability of scrap.
- Presence of high strength steels is not expected to cause difficulties.
- Elimination of seat wires would enhance efficient operation (seat wires and cables tend to block air separation chutes).
- The nonmagnetic metals that are recovered are diluted (50-60 percent metal content) by rubber, heavy plastics, and other debris and this ultimately increases the cost of current recovery.

Realization of material conservation through recycling of obsolete vehicles is deserving of a unified effort involving vehicle design, dismantling to save reusable elements, shredding operations, and secondary reduction to return the constituents to the supply stream.

**RSV MATERIALS RESOLUTION**

The use of materials in the RSV must be viewed in relationship to the basic approach

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9 The Roblin Scrap Products facility was upgraded in the spring of 1976 and is now considered to be a modern installation.
taken in its development. As stated previously, the RSV is being derived from a base vehicle (Chrysler Simca 1308) that is believed to embody a number of design features expected to be common on future American automobiles. For the most part, changes in the vehicle reflect an attempt to significantly upgrade the crash safety performance of this vehicle. It is noted that the program recognized that some increase in weight (over that of the base vehicle) would be necessary in order to achieve this objective.

A basic guideline to the program, however, was that vehicle road performance would not be upgraded in relation to total weight increases. The reason for this was that our forecasting studies suggested that, as a result of fuel economy requirements, performance characteristics of future automobiles would tend to decrease from current practice. Thus, in the RSV design, the engine/drive system (and, hence, the material content) was left unchanged from that of the base vehicle. Table 8 shows the groupings of material weight compositions for the base vehicle and the RSV. It is noteworthy that as shown in table 8, the body weight of the RSV is 403 pounds greater than that of the base vehicle. This change was expected because crash safety systems have a major effect on body component weight. The RSV chassis actually shows a decrease of 30 pounds from that of the base vehicle. This results because, as noted above, vehicle performance was not upgraded to correspond to the increased vehicle weight. But, more importantly, the method of grouping chassis and body parts are somewhat different for the two vehicles. The base vehicle bumpers were included with the chassis, while in the RSV these are included with the body

Table 8. Constituent material weights [lb]

<table>
<thead>
<tr>
<th>Material</th>
<th>Body Base vehicle</th>
<th>Body RSV</th>
<th>Chassis Base vehicle</th>
<th>Chassis RSV</th>
<th>Total Base vehicle</th>
<th>Total RSV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>707</td>
<td>1 004</td>
<td>594</td>
<td>584</td>
<td>1 301</td>
<td>1 588</td>
</tr>
<tr>
<td>Cast iron</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>242</td>
<td>242</td>
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<tr>
<td>Aluminum</td>
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<td>65</td>
<td>68</td>
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<tr>
<td>Zinc</td>
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<td>11</td>
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<td>2</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Copper</td>
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<td>16</td>
<td>10</td>
<td>10</td>
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</tr>
<tr>
<td>Lead</td>
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<td>-</td>
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<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
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<td>87</td>
<td>60</td>
<td>112</td>
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</tr>
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<td>-</td>
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<td>14</td>
<td>14</td>
<td>14</td>
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<td>119</td>
<td>-</td>
<td>-</td>
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<td><strong>1 442</strong></td>
<td><strong>1 096</strong></td>
<td><strong>1 066</strong></td>
<td><strong>2 135</strong></td>
<td><strong>2 508</strong></td>
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<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>2 317</strong></td>
<td><strong>2 655</strong></td>
</tr>
</tbody>
</table>

*a321 HSLA steel.*
EXPERIMENTAL SAFETY VEHICLES

group. Furthermore, to enhance luggage capacity, the fuel tank volume was slightly reduced in the RSV, resulting in a reduction in fluid weight. Suspension component changes consistent with the increased weight were, however, made in the RSV chassis. In any event, in the following section we focus attention on the changes in material composition between the RSV and the base car.

Before leaving the topic of weight, it should be noted that transition of the base vehicle to the RSV resulted in a net estimated weight increase of 338 pounds.\(^\text{10}\) To place this weight increase in proper perspective relative to the American economy requires further consideration of the base vehicle. The Simca 1308 is not marketed in the United States and accordingly was not designed to meet U.S. regulations. If the vehicle were made to conform to U.S. regulations, the most notable design changes affecting weight would be in the bumper and door structures. It is our estimate that using current automotive practice in upgrading the Simca to current Federal regulations in these two areas would result in at least a 150-pound weight increase in the base vehicle. Thus, the RSV weight should be viewed as an approximate 200-pound increase over that of similarly packaged automobiles that could currently be marketed in the United States.

As is evident in table 8, the major differences in material application between the base vehicle and the RSV relate to plastics (urethane), aluminum, and steel. In each case a growth in the particular materials is evident when the RSV is contrasted with the base vehicle (see table 8). Selection of a given material for a particular application was based upon component function and recycling effects.

Increased plastic (urethane) for the RSV results mainly from the bumper system. Because of the pedestrian safety requirement, it was necessary to have a soft facia on the RSV. Urethane-covered, foam energy-absorbing media appeared to be the only possibility.\(^\text{11}\) From a recycling standpoint, however, the vehicle was designed so the bumper could be either manually removed prior to shredding or would not be entrapped in metal components if shredded with the vehicle hulk. Although plastics are not now economically recovered, their value as either a fuel or a recycled structural material may well make their recovery economically feasible in the 1990's.

Aluminum is not extensively used in the RSV. There are two reasons for this: (1) domestic supplies of aluminum (at a competitive price) are not as plentiful as iron ore, and (2) there was considerable concern about the feasibility of recovering aluminum from obsolete hulks. Because aluminum does have significant weight-saving potential, this material is used in the hood and deck lids. In this application, if necessary, these structures could be manually removed from hulks prior to shredding. But, more importantly, the aluminum in these structures is expected to separate during the typical shredding process.

The major new material used in the RSV was High-Strength Low-Alloy (HSLA) steel where, as noted in table 8, 321 pounds are used in the RSV compared to no usage in the base vehicle. The HSLA steel does provide for lighter weight structures (when compared to mild steel) that have improved strength and crash energy-absorbing characteristics.\(^\text{12}\) From a recycling viewpoint, the HSLA steel is attractive because during the recovery process it is metallurgically compatible with the other ferrous elements. Thus, no problems relative to ferrous material recovery were envisioned with this application.

Another factor influencing RSV appearance is the lack of brightwork such as chrome bumpers and accent strips. Because of possible adverse effects of chrome in ferrous metal recycling and the total dependence of the U.S. on foreign supply, it was decided that such applications would be

\(^{10}\)Because the RSV will not be completely fabricated until Phase III, the weights given here are estimates. Data obtained on components that have already been fabricated have generally confirmed the estimates, however.

\(^{11}\)See reference 13 for a detailed discussion on the bumper design.

\(^{12}\)See reference 14 for a detailed discussion on the RSV structural design.
avoided with the RSV. It is pointed out that the base vehicle does not have the brightwork that is characteristic of typical U.S. production vehicles. Thus, differences in this area between the RSV and the base vehicle are not evident from an examination of table 8. Nevertheless, it is our judgment that future U.S. cars must be attractively designed without excessive use of such limited vital resources. In this respect, we believe the RSV style as shown in figure 16 reflects this trend.

Discussion

It was stated that an objective of the RSV design was to develop a vehicle with recovery potential not degraded from that of current practice. Within the study, the success of achieving this objective will be determined through recycling experiments with both the base vehicle and the RSV. The former has already been performed (see earlier discussion) while the latter will be undertaken when a suitable crashed vehicle hulk is available. Detailed results on these experiments will then be reported.

In this initial RSV development, joining of dissimilar metals (such as aluminum and steel) was avoided because of potential separation problems. Current automotive practice is to use mechanical joints (locks) in manufacturing aluminum inner and steel outer body panels such as hoods and trunk lids. Others have suggested adhesive bonding as a means for joining such dissimilar metals. Although these techniques were avoided in the RSV because of potential recycling implications, they are under study in the program (note aluminum/steel hood shredding experiment described previously). It is anticipated that prior to the completion of the project, some redesign in the RSV might well occur. If these studies suggest recycling is not retarded, such designs may well be applied in future weight reduction schemes for the RSV.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of their colleagues at Calspan who are participating in the RSV program, members of the Chrysler RSV group, and especially Roblin Industries for performing the shredding experiments.

Figure 16. Clay mockup of the RSV.
REFERENCES


Calspan/Chrysler Research Safety Vehicle
Front Impact Structure Development

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THOMAS L. TREECE
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ABSTRACT

The Calspan/Chrysler RSV is a practical safety vehicle for the 1980’s that can be produced within the projected limits of technology and materials at a rate of 300,000 units per year. It must have consumer appeal and has the major restriction of a base vehicle weight less than 3,000 pounds.

Within these limits the front impact structure is being developed to maximize occupant protection for both the striking and struck vehicles.

This paper describes the front impact structural concept and details the complete vehicle static crush and computer impact simulation work accomplished to this point in the development.

The computer simulation based on complete car static crush data is verified through comparisons of simulated versus actual impact data for the Simca 1307 base car.

The value of the analysis method in defining structure that must meet high speed front barrier impact criteria as well as front to side vehicle impact compatibility and pedestrian impact requirements is demonstrated. The static crush and analysis of two modified vehicles is described in detail.

BACKGROUND

The Calspan/Chrysler Research Safety Vehicle (RSV) development program is currently in the second phase of a three phase total program. During this phase, the structural concepts developed in Phase I must be demonstrated through vehicle testing. At this point in Phase II static testing and computer simulations used to develop the structure have been completed. Dynamic impact testing of modified vehicles has not started but is scheduled to begin by the time this paper is published. Phase III of the program will consist of final development of Phase II concepts and building the developed RSV in sufficient quantities for thorough evaluation.

FRONT STRUCTURE CONCEPT

The front end structure of the RSV has been developed to provide three distinct zones of protection [1]. The front 10-inch (254 mm) zone I provides improved pedestrian protection and damage protection. Zone II has the primary purpose of providing compatibility with the side and rear of struck vehicles. From a total vehicle systems standpoint, zone II becomes a necessary part of the side and rear protection structure, controlling impact force levels for compatibility with these parts of the struck vehicle. Zone III is the primary energy absorbing section, providing the higher forces necessary to prevent passenger compartment intrusion in high-speed impact while limiting maximum g’s to levels compatible with the occupant restraint system. The relative locations and lengths of the three zones are shown in figure 1.

PERFORMANCE GOALS

Zone I

The front 10 inches (254 mm) must provide pedestrian protection up to 20-mi/h impact speed. This is accomplished by developing a front end shape to control struck pedestrian kinematics and limiting front end stiffness to approximately 20 psi. Performance demonstrations have consisted of three dimensional computer simulations using the CAL-3D occupant model and a laboratory 22-mi/h impact by a 100-pound, 9-inch diameter cylinder in which accelerations are limited to less than 60 g’s. The pedestrian protecting bumper is the subject of a separate paper.
EXPERIMENTAL SAFETY VEHICLES

Zone I must also provide 8-mi/h barrier property protection. The requirements of current U.S. bumper standards have been waived in favor of a systems approach providing equivalent car-to-car impact compatibility while maintaining compatibility with the soft front required for pedestrian protection. Car-to-car, front-to-rear impact damage-ability goals are set at a closing speed of 13 mi/h. This level is achievable with current 5-mi/h rear end systems.

Zone II

This zone has the primary purpose of providing intervehicular compatibility during front-to-side and front-to-rear collisions [2]. Primary emphasis is on front-to-side compatibility since this mode has greater importance based on accident statistics. All structures for side impact protection must be duplicated on both sides of the vehicle generating large weight increases for each improvement in impact capability. Transferring a portion of this burden to the front end results in greater weight efficiency.

It has been projected that cars in the 1985 era will have 20 g or 60 000-pound side crush capability for cars in the 3 000-pound category [3]. Zone II force levels must be limited below this level to assure front end crush, and thereby reduce side structure intrusion and impact g levels.

Zone III

The front end structure immediately for-
final analysis showed that the Simca 1307 offered a high level of overall compliance to the RSV specifications. The 1307 was chosen as the base structure. The elements of the selection process are detailed in the Calspan Phase I RSV reports.

Within the general confines of the base car geometry, the task of developing a front end structure capable of achieving the interacting performance goals described above was begun.

**DESIGN PROCEDURE**

Previously, the typical approach to designing front structure for increased barrier performance was the buildup of modified cars and dynamic testing. The results are then compared to the design criteria. This approach can be effective when the design criteria is to limit the total body crush or passenger compartment intrusion, but does not yield the relatively detailed information required to design the three zones of the front structure as specified for the Calspan/Chrysler RSV.

The force levels and the interaction of the major front structural components must be known to effectively design the three levels of energy management characteristics desired in the front structure. For this reason the design procedure used for the RSV front structure consists of static crush testing of the major components for their individual force-deflection properties, a computer math modeling technique for simulating impact and finally dynamic impact of the developed structure. The design process is depicted in figure 2.

**BASELINE TESTS**

**Static Test**

A Simca 1307 was statically tested on the Calspan Corporation static crush machine to determine the force deflection properties of the major front structural components. The following components were tested:

- Front of front rails—from engine mounts forward
- Rear of front rails and dash—from engine mounts rearward
- Sheet metal—from A-pillar forward
- Radiator and engine crush—structure forward of engine
- Engine mounts—forward and rearward

The static force-deflection properties for the components are shown in figures 3 through 9.

The test setup and test method are shown in figure 10. The body minus the engine and transmission is positioned on the crusher rails and reacted as shown. The ram, which is hydraulically controlled, has four loading plates. The horizontal split between the upper and lower plates is positioned so that the lower plates will record the rail force and the upper plates will record the sheet metal force. All five reactions are present for the front of front rail and sheet metal test. For the rear of the front rail and sheet metal test, the engine and transmission are installed and reaction number two is removed. The radiator and engine crush
Figure 3. Simca 1307 engine mount rearward static force deflection properties.

Figure 4. Simca 1307 front of front rails static force deflection properties.
SECTION 4: TECHNICAL SEMINARS

Figure 5. Simca 1307 rear of front rails static force deflection properties.

Figure 6. Simca 1307 front sheet metal static force deflection properties.
Figure 7. Simca 1307 engine crush static force deflection properties.

Figure 8. Simca 1307 radiator crush static force deflection properties.
force are obtained by pushing the engine into the front grille and radiator structure. The engine mounts are tested as a separate component in both directions.

Dynamic Test

A dynamic flat-barrier test was conducted on the baseline Simca 1307 at 35-mi/h impact speed. The purpose of this test was to determine the base vehicle’s ability to meet the RSV specification of occupant egress (half of the doors should open manually) and injury criteria at all seating positions at a barrier impact speed of 30-35 mi/h. The base vehicle did satisfy these conditions. The second purpose was to obtain the necessary data for correlating the computer math model to the base car barrier impact.

Baseline Vehicle Computer Simulation

A computer math model was constructed to verify that a model could be used to reproduce the barrier test results.

The computer program MINIBASH [5] is a general dynamic impact model that can be used for both barrier and car-to-car impact simulations. A general model consisting of up to 10 masses and 20 resistances can be simulated. Nonlinear static force-deflection properties can be specified for each resistance. The mass displacements, velocities, accelerations, and forces are calculated at each increment. The static force, dynamic force, and crush are also calculated at each time increment for each resistance. The MINIBASH solution for each time increment is as follows:

- Calculates new mass displacement from previous displacement, velocity, and acceleration

\[ x_{new} = x_{old} + V_{old} (\Delta t) + \frac{1}{2} a_{old} (\Delta t)^2 \]

- Calculates relative position of all masses and determines the crush of each resistance
Figure 10. Calspan's static crush machine—reaction system.
• Calculates static force of each resistance and applies specified dynamic rate factor to calculate dynamic force in each resistance.
• Sums the dynamic loads (including inertia loads) on all masses and calculates the mass acceleration:
  \[ a_{\text{new}} = \sum F_{\text{dyn/m}} \]
• Calculates velocity for all masses:
  \[ V_{\text{new}} = V_{\text{old}} + \frac{(a_{\text{new}} + a_{\text{old}})}{\Delta t} \] (2)

These equations define the system at each time increment.

A MINIBASH front impact model (fig. 11) was constructed consisting of five masses and seven resistances. The five masses are the body, engine and transmission, suspension and crossmember, radiator and yoke, and the barrier mass. The seven resistances are the front of front rails, rear of front rails, sheet metal, engine, radiator, engine mount forward, and engine mount rearward.

The front impact model was executed for the same speed and weight as the baseline dynamic test. The results comparing the test and simulation are shown in table 2 and in figures 12 through 17.

**Figure 11. Simca 1307 MINIBASH front impact model.**

<table>
<thead>
<tr>
<th>Masses</th>
<th>Resistances</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Body</td>
<td>A Front of front rails</td>
</tr>
<tr>
<td>2 Engine</td>
<td>B Rear of front rails</td>
</tr>
<tr>
<td>3 X-member</td>
<td>C Sheet metal</td>
</tr>
<tr>
<td>4 Radiator</td>
<td>D Engine</td>
</tr>
<tr>
<td>5 Barrier</td>
<td>E Radiator</td>
</tr>
<tr>
<td></td>
<td>F Engine mount forward</td>
</tr>
<tr>
<td></td>
<td>G Engine mount rearward</td>
</tr>
</tbody>
</table>

**RSV Front Structure Force Levels**

Using the impact model we now can arbitrarily change any or all of the front structural components and determine what effect the changes have on the vehicle dynamic response.

The RSV math model (fig. 18) has one additional resistance between the yoke and barrier mass. This resistance represents the soft front bumper that will be used for pedestrian protection in the zone I structure. The rest of the model is the same as the base Simca 1307.

The preliminary force-deflection properties were assumed to be square wave curves estimated from the available crush distance of each resistance and the amount of energy each resistance had to dissipate. The model was exercised repeatedly with adjustments to the components until the desired vehicle dynamic response was achieved.

The next estimate for the static force-deflection properties was more realistic in the shape of the force-deflection curves. Typically, a steel member loaded in compression will have a peak elastic load with a load drop as it deforms plastically. From previous testing of beam members in axial compression, the load drop from the peak
value has been approximately 50 percent. The base line static test results and a one-quarter scale drawing of the front structure were used to determine the physical stackup and interaction of the different components. Final estimates were then made for the static force-deflection properties. These estimates were then fed into the model and adjusted until again the desired vehicle dynamic response was obtained. The estimated force levels that must be built into the front structure are shown in figures 19 through 26.

**Sizing of the Front Structure**

The force levels of the front structure are now known. The next step is to size the front structure to achieve the desired loads. Because of the significant force level difference in zones II and III and the limitation of the base Simca 1307 environment, the sizing was accomplished with a combination of section shape, size, material properties, and structural configuration.

The Chrysler developed computer program SECRIP was used as an aid in obtaining the section shape, size, gage, and material selection.

**Figure 12. Simca 1307 body deceleration comparison.**

---

### Table 2. Base Simca 1307 35.3-mi/h front barrier impact—comparison of dynamic test results with computer results

<table>
<thead>
<tr>
<th>Item</th>
<th>Test</th>
<th>Simulation</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body dynamic crush (in)</td>
<td>33.8</td>
<td>33.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Right sill, 33.0</td>
<td>33.8</td>
<td>33.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Left sill, 30.4</td>
<td>33.8</td>
<td>33.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Rear deck, 34.5</td>
<td>33.8</td>
<td>33.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Center console, 32.4</td>
<td>33.8</td>
<td>33.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Average, 33.8</td>
<td>33.8</td>
<td>33.1</td>
<td>2.1</td>
</tr>
<tr>
<td>Engine displacement (in)</td>
<td>14.2</td>
<td>14.2</td>
<td>0</td>
</tr>
<tr>
<td>Dash crush (in)</td>
<td>12.0</td>
<td>13.4</td>
<td>11.6</td>
</tr>
<tr>
<td>Front rail crush (in)</td>
<td>16.7</td>
<td>16.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Rear rail crush (in)</td>
<td>17.1</td>
<td>16.5</td>
<td>2.9</td>
</tr>
<tr>
<td>Duration (ms)</td>
<td>108.0</td>
<td>96.0</td>
<td>11.1</td>
</tr>
<tr>
<td>Peak deceleration &gt; 3 ms (g)</td>
<td>27.0</td>
<td>22.0</td>
<td>18.5</td>
</tr>
</tbody>
</table>
Figure 13. Simca 1307 body velocity comparison.

Figure 14. Simca 1307 body displacement comparison.
Figure 15. Simca 1307 engine deceleration comparison.

Figure 16. Simca 1307 engine velocity comparison.
SECTION 4: TECHNICAL SEMINARS

Figure 17. Simca 1307 engine displacement comparison.

Figure 18. RSV MINIBASH front impact model.

Masses
1. Body
2. Engine
3. X-member
4. Radiator
5. Yoke
6. Barrier

Resistances
A. Front of front rails
B. Rear of front rails
C. Sheet metal
D. Engine
E. Radiator
F. Engine mount forward
G. Engine mount rearward
H. Bumper
Figure 19. RSV Car 1 front of front rail static force deflection properties.

Figure 20. RSV Car 1 rear of front rail static force deflection properties.
Figure 21. RSV Car 1 front sheet metal static force deflection properties.

Figure 22. RSV Car 1 radiator static force deflection properties.
Figure 23. RSV Car 1 engine crush static force deflection properties.

Figure 24. RSV Car 1 engine mount forward static force deflection properties.
Figure 25. RSV Car 1 engine mount rearward static force deflection properties.

Figure 26. RSV Car 1 soft front bumper static and dynamic force deflection properties.
Computer program SECRIP calculates the allowable axial load and allowable bending moments about the horizontal and vertical axes for any thin-walled section that can be defined by a series of flat and/or curved elements. Empirical data are used to determine the allowable loads accounting for local type failures inherent to thin-walled sections. The basic allowables are determined for the geometric shape, then corrected by a material correction factor determined from the specific material compressive stress allowable and compressive modulus of elasticity. Because each cross-sectional element is calculated individually, a mixture of materials can be calculated in the same section.

Program SECRIP will calculate the peak elastic load in a beam element for a combined axial compressive load and moments about two orthogonal axes. The program calculates the allowable internal resisting moments which allow for a nonlinear bending stress across the section (plastic bending moments). When the point of external load application is known exactly and all external supports are accounted for, the predicted loads from the computer program have consistently been within a ±10 percent of the test results. For a complicated structure where the external point of load application can only be approximated and the external supports (such as a sheet metal panel welded to the beam) are ignored, the predicted results will likely deviate by a greater percentage from test results. The peak elastic load is the only load obtained from the program. Any sustained plastic crush must be estimated by other methods.

Using program SECRIP, the front structure for the first modified vehicle was identified. Figure 27 shows the areas of modification.

The front portion of the front rails was left open and the upper load beam was cut short to keep the force levels within the zone II requirements. For the zone III structure full rail and upper load beam sections were used. Additional structure was added in the center floor pan area to resist engine and steering rack rearward motion. Side structure was added to provide a load path for the increased upper load path forces. The side structure provides both longitudinal support for front impact loads and lateral strength for side impact modes.

Build of First Modified Front Structure

The modified vehicles were built by Modern Engineering in Troy, Michigan. Temporary tools were built and used in stamping the unique parts (fig. 28).

The front longitudinals or front rails, which are all-new, were made from HSLA steel. The longitudinals are approximately 3 inches (80 mm) longer than the base 1307 part. The increased length was added to the wheelbase forward of the dash. The engine and suspension were moved as a unit forward. The length increase was based on early Phase I simulation studies which showed the need for additional sheet metal crush to manage the energy of a 40- to 50-mi/h barrier crash.

The front yoke panel was revised to provide attachment for the soft front end. A flat plane is provided with two lateral and two vertical reinforcements.

The upper load path beam is made from two stampings. The beam was tooled full length from yoke panel to dash to provide for flexibility in structural definition. The beam can be cut to any length providing significant variation in sheet metal force level.

The floor pan center tunnel reinforcement welds directly to the HSLA floor pan. The small clearances to the lower suspension crossmember and steering rack are provided
SECTION 4: TECHNICAL SEMINARS

to support these members and hold them off the dash panel during impact. The tunnel reinforcement provides a third major load path into the floor pan to supplement the paths provided by the front longitudinals.

The sills have been extended to the chain clearance line for this front-drive vehicle. After only a small rearward motion of the front wheels, the tires load the sill extensions and heavily reinforced structure of the sill.

The front structural modifications have been developed with close attention to typical assembly line techniques. The assembly process of the 1307 is disturbed only by the additional parts and the increased welding required. Current welding practices have been followed with spot welding as the primary attaching means. Special precaution and increased weld nugget size are necessary in joining HSLA parts to other HSLA components.

Front Static Test of First Modified Structure

A static front crush test was conducted on the modified structure. The test setup and procedure was the same as the base Simca 1307. The RSV actual force-deflection properties are shown in figures 19 through 26 along with the estimated curves.

There were several areas in the front structure that did not yield the desired load. The front rail elastic force was lower than expected and had a much higher plastic load drop than desired (fig. 19). This was because the rail was an open section with additional slots in the top and bottom flanges. The plastic crush load was much lower than the assumed 50-percent drop from the elastic peak load.

The rear of front rail force peak value was approximately as estimated; however, the floor pan between the rail and sill sheared from the sill before the peak rail force was

Figure 28. Structural changes.
reached. The end of the rear rail curve was lower than estimated because the sill was no longer loaded. The static force-deflection curves for the estimated and actual test results are shown in figure 20.

The sheet metal peak force was higher than estimated. Due to material availability, the upper beam was made from .048-gage material instead of the specified .038 gage. As a result, the A-pillar and cowl side structure was not capable of reacting the upper beam force. There was excessive A-pillar and cowl side crush that was not considered acceptable. The static force deflection curves for the estimated and actual test results are shown in figure 21.

The radiator crush, engine crush, and engine mounts, which are not significantly different from the base car, are shown in figures 22 through 26 along with the estimated curves.

Structure Definition for the Second Front Static Test Vehicle

During the first front static test the A-pillar reaction loads were recorded utilizing load cells at reaction number 5 (fig. 10). Before the second front static test vehicle was built, a side structure vehicle was tested in the longitudinal direction to determine at what force level the side structure was capable of reacting at the A-pillar belt line. With the front static test and the longitudinal test information available, the front structure was adjusted to bring the vehicle dynamic response within the desired envelope.

The front rail was boxed and the lower two slots were removed from the front rail to increase the force level and maintain a higher average crush load. Figure 29 shows this change.

The following changes were made in the structure which are included in the rear rail resistance. A notch was added to the bottom of the rail at the steering linkage access hole to promote rail buckling in this area. A shear panel was added between the rail and sill to prevent floor pan shearing from the sill. The center floor pan tunnel reinforcements were reduced in gage. Figure 30 shows these changes.

Figure 29. Front structure—second modified vehicle.
The upper load beam was reduced in gage and material strength to eliminate the high peak force. From the previous longitudinal testing the A-pillar and cowl side should react the load with minimum body deformation.

The sheet metal force dropped after the initial peak load and remained at a lower force level for a longer distance than desired. To eliminate this condition the full upper beam was extended 3 inches, and the outer half of the beam was extended another 3 inches.

Front Static Test of Vehicle Number 2

The structural changes were incorporated into the build of the second front static crush vehicle. This vehicle was crush tested for front energy management characteristics. The test setup and procedure for the front of front rails, rear of front rails, and sheet metal were the same as for the base Simca 1307 and first modified vehicle. The static force curves as estimated for the second crush vehicle and the actual test results are shown in figures 31 through 33.

The front of front rail elastic force was higher than desired and also, because of welding quality problems, the closure panel sheared from the rail at a relatively low load, leaving an open rail section. The average plastic crush load again was lower than desired.

The rear of the front rail and sheet metal forces were approximately as desired.

Structural Changes for Dynamic Impact Vehicle Build

The only change from the second static test vehicle to the dynamic impact vehicle build will be a reduction in gage and material for the front of front rail closure panel. This will reduce the peak elastic force and should maintain a higher average plastic crush load. The estimate for the dynamic impact vehicle front of front rail is shown in figure 31. The other component force-
Figure 31. RSV Car 2 front of front rails static force deflection properties.

Figure 32. RSV Car 2 rear of front rails static force deflection properties.
deflection properties will be unchanged from the second front static crush vehicle.

**Dynamic Impact Vehicle Barrier Simulation**

A computer simulation was made for the dynamic impact vehicle structure for a front barrier impact. The maximum body crush that has been assumed for the RSV is 37.5 inches. The maximum front flat fixed barrier impact capability for the dynamic impact vehicle is 46 mi/h. The simulated body crush versus body deceleration superimposed on the design deceleration envelope is shown in figure 34. Additional simulated results are shown in figures 35 and 36.

**SUMMARY**

Based on the static crush data available at this point in the development of the Cal-span/Chrysler RSV, it is felt that the front structure will provide the desired performance. Additional static testing to supplement and improve dynamic testing would be desirable, but program timing and budget are limited.

Zone I of the front structure has been dynamically tested for property protecting capability in a 5-mi/h barrier test with no damage. Front ends of somewhat greater stiffness are being produced to bring the 100-pound, 22-mi/h cylindrical impactor within the 60 g limit. Computer simulations of pedestrian kinematic response have shown desirable performance.

Zone II static force levels are approximately 36 000 pounds. This compares to 43 000 pounds statically for the side of an RSV. Regardless of the rate factors applied, the front to side relationship is sufficient to make good use of the front structure in absorbing the energy of a front to side impact.

Zone III statically has shown a maximum force capability of 70 000 pounds. This is sufficient to raise the maximum impact speed of the RSV to approximately 46 mi/h while controlling maximum g’s to acceptable levels. Total crush at this speed is limited to
Figure 34. Dynamic impact vehicle body crush versus body deceleration.

Figure 35. Dynamic impact vehicle body deceleration velocity and displacement versus time.
37.5 inches, which is considered acceptable for passenger compartment crush.

The final proof will be in the dynamic test phase and subsequent development. It has been our purpose in this presentation to show the systematic application of the static crush/computer simulation technique. It is obvious that the approach is not a simple solution to impact structure development. A certain amount of cut-and-try, along with a large helping of engineering judgment, is involved. We feel that the insight gained into the complicated events involved in the high speed vehicle impact is invaluable in developing a structure capable of meeting the RSV specifications.

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EXPERIMENTAL SAFETY VEHICLES

Calspan-Chrysler Research Safety Vehicle
Front End Design For Property and Pedestrian Protection

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Research Safety Vehicle Staff
Chrysler Corporation

ABSTRACT

Currently, over 20 percent of traffic fatalities in the United States are pedestrians. Very little, if any, protection is offered to the pedestrian by present day automobiles whose exterior design is dictated by exterior damage protection performance requirements. During the Research Safety Vehicle (RSV) program, a soft front bumper system was developed for the Calspan-Chrysler RSV that provides improved levels of pedestrian protection and exterior vehicle damage protection. This lightweight bumper system consists of a flexible fascia filled with a low-density, energy-absorbing urethane foam.

Contained herein is a discussion of the rationale for selecting this type of a system as well as the design considerations and analytical methods used to develop the soft bumper system. The results of some preliminary performance tests are included.

INTRODUCTION

Studies of traffic accidents in the United States show that pedestrians account for approximately 20 percent of the fatalities. In some European countries, where pedestrian traffic is heavier, the percentage of pedestrian fatalities is in the range of 40 percent. In the past very little effort has been expended to design a vehicle structure that affords some degree of protection for the pedestrian. The primary objective of current front end and bumper designs is to meet low speed vehicle damageability requirements. During Phase II of the Research Safety Vehicle program, Chrysler in partnership with the Calspan Corporation has undertaken the task of developing a soft front structure that provides an improved level of pedestrian protection and is compatible with low-speed impact, no-damage requirements for the vehicle.

DETERMINATION OF PERFORMANCE CRITERIA

During Phase I of the RSV program, studies were conducted to identify vehicle related factors that affect pedestrian injury levels and the degree of damage incurred by the vehicle during low-speed impacts. The information gathered during these studies was used to formulate a performance criteria which dictated the design of a nonconventional front structure. A discussion of the rationale used to formulate the performance criteria follows.

The Pedestrian Problem

An understanding of the pedestrian impact event and the injury-producing mechanism is necessary before an effective pedestrian protection system can be designed. Analysis of pedestrian accident studies by various researchers has identified the primary vehicle related factors that affect the pedestrian injury level.

Vehicle Speed. The speed at which the pedestrian is struck by the vehicle is the single most important variable that influences the injury level. A Toronto study [1] showed that at a speed less than 20 mi/h only 7.5 percent of all pedestrian injuries were at serious or fatal levels. Except for some unique accidents, all serious and fatal injuries occurred at a speed greater than 15 mi/h. Above 20 mi/h, 48 percent of all pedestrian injuries were serious or fatal. Results of an Australian study [2], shown in table 1, substantiate these findings. The threshold speed at which serious injury begins to occur appears to be in the range of 15 to 20 mi/h. Through extrapolation, it can be seen that over 50 percent of the pedestrian accidents occurred at speeds less than 22 mi/h. Therefore, a pedestrian-protecting vehicle design that is effective up
Table 1. Pedestrian casualties associated with car speeds

<table>
<thead>
<tr>
<th>Speed interval (mi/h)</th>
<th>Number of crashes</th>
<th>Number of injuries</th>
<th>Number of fatalities</th>
<th>Average injury per crash</th>
<th>Average fatality per crash</th>
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<tr>
<td>1-10</td>
<td>376</td>
<td>611</td>
<td>6</td>
<td>1.63</td>
<td>0.016</td>
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<tr>
<td>11-20</td>
<td>495</td>
<td>896</td>
<td>8</td>
<td>1.81</td>
<td>0.016</td>
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<tr>
<td>21-30</td>
<td>736</td>
<td>1400</td>
<td>43</td>
<td>1.90</td>
<td>0.058</td>
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<tr>
<td>31-40</td>
<td>275</td>
<td>558</td>
<td>35</td>
<td>2.03</td>
<td>0.127</td>
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<tr>
<td>41-50</td>
<td>29</td>
<td>70</td>
<td>8</td>
<td>2.41</td>
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<td>51-60</td>
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<td>17</td>
<td>2</td>
<td>2.43</td>
<td>0.285</td>
</tr>
</tbody>
</table>

do to a speed slightly greater than 20 mi/h would reduce injury severity in the majority of pedestrian accidents.

Vehicle Direction of Travel

Table 2 [3] shows that the vast majority of fatal pedestrian accidents occur with the vehicle traveling in a straight forward direction. A relatively small percentage of fatal pedestrian accidents occurs while the vehicle is backing or turning. Figure 1 [3] shows that approximately 90 percent of all pedestrian injuries caused directly by the vehicle are due to contact with components on the front of the vehicle. A pedestrian protection system on the front of the car would be most beneficial, and improving the pedestrian-protecting capabilities of the side or rear end of the automobile would do very little to decrease the total number of serious and fatal pedestrian injuries.

Injury Producing Mechanism

Analysis of injury patterns for pedestrians indicates that the highest frequency of bodily injury occurs in the area of the head and lower extremities. A study by Vaughan [4] showed that most head and upper limb injuries are caused by secondary impact with the road, while the majority of thoracic, abdominal, pelvic, and lower limb injuries are due to primary contact with the vehicle. As seen in figure 1, the cause of injury is almost equally divided between ground and vehicle contacts. However, when only serious and fatal injuries are considered, contact with the front of the vehicle seems to be the most important contributor.

The function of an effective pedestrian protection must, therefore, be two-fold. First, it must be “friendly” to the pedestrian by minimizing the initial contact forces to prevent serious lower body injuries. Most present day, front end structures impose a high, localized loading on the lower extremities due to initial contact with the non-deforming, steel bumper face bar and the sharp front edge of the hood. Distribution and reduction of initial pedestrian-vehicle contact forces can be achieved through the use of a full-face soft front bumper. A front end collapse pressure in the range of 20 psi would limit the initial contact force to approximately 4 000 pounds, assuming enough deformation of the soft bumper occurred to spread the load over a 20-m² area. Another advantage of a full-face, soft front end is that hard, sharp components such as the grille, moldings, and
associated mounting components can be eliminated, and headlamps can be recessed into the bumper.

Secondly, the pedestrian protection system must effectively control the pedestrian’s post-impact kinematics to prevent hard contact with the ground or the windshield structure. The principal factor that controls the post-impact motion is the vehicle’s front profile. Vaughan [4] states that a low-sloping profile decreases initial contact forces, but increases upward projection of the pedestrian’s body; whereas a high, blunt profile decreases upward projection, but produces higher initial impact forces. The Australian study [3] reported that there was a higher fatality rate associated with low-sloping profile vehicles than vehicles with high, blunt profiles. Other researchers have found that for a low-sloping profile, head acceleration and rearward projection onto the hood of the car increase significantly as the speed of the vehicle increases. Thus, an effective front bumper should pick up the pedestrian and carry him along until the vehicle stops while minimizing upward and rearward projection of his body.

Vehicle Damageability and Repairability

Location of Damage. Analysis of accident data shows that 90 percent of all vehicle damage-producing accidents involve vehicle-to-vehicle collisions, and the front of one vehicle is involved in almost all multi-vehicle collisions. Forty to 60 percent of all repair costs are associated with the fenders, front bumper, headlights, grille, hood, and radiator. Reduction of vehicle exterior damage could thus be best accomplished by improving the front end damage resistance characteristics of the vehicle.

The intent of Federal Motor Vehicle Safety Standard (FMVSS) 215, which regulates bumper performance during low speed impacts, was to reduce low-speed collision costs. The approach taken by the auto industry to meet this standard was the development of a bumper system that consisted of a conventional steel face bar attached to uniaxial hydraulic energy absorbers that were bolted to the front structure. This system, while performing adequately when impacted in a longitudinal direction between the hydraulic.
units, does not offer good protection during low corner hits. Compared to 1972 and 1973 cars, which did not have an energy absorbing bumper system, 1974 model cars with energy absorbing units had a lower damage claim frequency. When damage did occur, however, repair costs were higher for vehicles equipped with hydraulic energy absorbing units. The higher initial cost plus higher repair costs for this type of system greatly reduces any benefit realized by the consumer.

Significant reduction of low-speed collision damage to front components can be accomplished through the use of a full-face soft front bumper system. This type of bumper system places a soft recoverable material between colliding vehicles which spreads the impact loads over a large contact area and does a better job of controlling kinetic energy dissipation. Since the soft bumper can be wrapped around the corner of the car, it offers good protection for low corner units. Upgrading the vehicle damage protection capability of the rear bumper system above current levels does not appear to be cost effective. It is anticipated that by the mid-1980’s a large percentage of the car population will be equipped with a soft front bumper. Since almost all vehicle-to-vehicle collisions involve the front end of one car, the soft front of one car will provide a high degree of protection for the conventional rear bumper system. Also, the soft bumper system affords greater protection than a conventional bumper when colliding with the side of another car since the impact load is spread over a much larger area of the sheet metal structure, and the probability of engaging the door side beam increases.

Vehicle Speed. The distribution of exterior damage repair costs with respect to impact speed is difficult to attain from statistical data since minor damage due to slow speed impacts is often unreported by the car owner. Low speed barrier tests, conducted by the Insurance Institute for Highway Safety (IIHS) [5], were used to estimate average repair costs. Results of these tests are summarized in table 3. While not representing actual losses, the results indicate the expected range of low-speed damage repair costs. Other independent studies have shown that approximately 80 percent of all repair costs are below $500, and 15 to 20 percent are below $100. By comparing these findings with the results of the IIHS study, it becomes apparent that damage caused by collisions at less than 10 mi/h accounts for the bulk of total repair costs.

<table>
<thead>
<tr>
<th>Model year</th>
<th>5 mi/h front into barrier</th>
<th>5 mi/h rear into barrier</th>
<th>10 mi/h front into barrier</th>
<th>15 mi/h front into barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>200</td>
<td>214</td>
<td>652</td>
<td>976</td>
</tr>
<tr>
<td>1970</td>
<td>215</td>
<td>218</td>
<td>541</td>
<td>728</td>
</tr>
<tr>
<td>1971</td>
<td>256</td>
<td>291</td>
<td>642</td>
<td>983</td>
</tr>
<tr>
<td>1972</td>
<td>243</td>
<td>229</td>
<td>712</td>
<td>993</td>
</tr>
<tr>
<td>1973</td>
<td>15</td>
<td>117</td>
<td>389</td>
<td>985</td>
</tr>
</tbody>
</table>

A soft-front structure whose collapse pressure is approximately 20 psi along the front of the vehicle can provide enough energy absorption to eliminate vehicle damage at barrier impact speeds near 10 mi/h. Straight forward calculations show that for a frontal contact area of 1 200 in$^2$ the resulting force would be 24 000 for a car weighing nearly 3 000 pounds. At this force level approximately 5 inches of bumper deformation would result in a 10-mi/h front barrier impact of a 3 000-pound car. Of course, in collisions where only partial engagement of the front occurs, reduced energy absorption capability in direct proportion to the surface contact area would result. Thus, a full face, soft front bumper with a collapse pressure of about 20 psi makes the no-damage vehicle and pedestrian protection objective compatible.

Given the barrier impact performance for front and rear systems, the expected performance for front to rear impacts can be calculated. Assuming equal car weights, the governing equations for conservation of momentum and conservation of energy respectively are:

\[ mV_1 + mV_2 = 2mV_f \]
\[ \frac{1}{2}mV_1^2 + \frac{1}{2}mV_2^2 = mV_f^2 + E_{abs} \]

where \( V_f \) is the velocity of the vehicles at the separation point, and \( E_{abs} \) is the total energy.
absorbed by the two systems. Expansion of these equations yields:

\[ V_f^2 = \frac{1}{2} \left( V_1^2 + V_2^2 \right) - \frac{E_{\text{abs}}}{m} = \frac{(V_1 + V_2)^2}{4} \]

\[ E_{\text{abs}} = \frac{(V_1^2 + V_2^2)^2}{2} - \frac{(V_1 + V_2)^2}{4} = \frac{1}{4} (V_1 - V_2)^2 \]

where \( V_o = (V_1 - V_2) \) and is the closing velocity.

It is assumed that during a front-to-rear collision, the energy absorbing capability of both the front and rear systems are exhausted, then:

\[ E_{\text{abs}} = E_{\text{frt}} + E_{\text{rr}} \]

\[ \frac{1}{2} m V_{\text{frt}}^2 + \frac{1}{2} m V_{\text{rr}}^2 = \frac{1}{4} m V_o^2 \]

\[ V_{\text{frt}}^2 + V_{\text{rr}}^2 = \frac{1}{2} V_o^2 \]

where \( V_{\text{frt}} \) and \( V_{\text{rr}} \) are the maximum front and rear barrier impact speeds respectively.

By letting \( k \) be a radius vector so that \( k^2 = V_{\text{frt}}^2 + V_{\text{rr}}^2 \) and \( \sqrt{2k} = V_o \), graphic representation of front-to-rear impact performance can be accomplished and is shown in Figure 2. Point “A” corresponds to 1973 bumpers (5 mi/h front, 2½ mi/h rear) and represents a 7.9-mi/h system. Point “B” represents a 10-mi/h system for 1974 bumper systems (5 mi/h front, 5 mi/h rear). It is anticipated that the RSV soft front bumper will achieve an 8 mi/h barrier performance; and with the carryover 2½-mi/h Simca C-6 rear bumper system, RSV front to RSV rear no-damage impact performance would correspond to a 12-mi/h system. For a collision involving an RSV front and a 5-mi/h rear system, the upper bound for the closing speed would be slightly greater than 13 mi/h.

RSV Soft Front Bumper System Performance Criteria

The above discussion was intended to set forth the rationale for selecting a soft front bumper system for the Calspan-Chrysler Research Safety Vehicle. While the primary reason for selecting a soft, recoverable bumper was to improve pedestrian protection, this objective is consistent with improving low speed damage protection. The specific performance criteria developed during Phase I of the RSV program are delineated below.

- When impacted at 22 mi/h, the acceleration of a vertically oriented body block weighing 100 pounds shall not exceed 60 g's for a time interval of more than 3 milliseconds.
- Eliminate all non-functional surface protrusions and provide a smooth contour and breakaway properties for all functionally necessary components.
- Collapse along the face of the bumper should occur at 20 psi and shall not increase significantly up to 6 inches of deformation to reduce contact forces on the pedestrian’s torso and lower extremities.
- The profile of the front bumper shall effectively control the pedestrian’s kinematics and match his post-impact forward velocity as closely as possible to that of the vehicle.
- For flat fixed barrier speed of at least 8 mi/h and for front-to-rear impact speed up to 12 mi/h, no damage shall occur on the vehicle structure. Damage is allowable on the bumper contact surface and energy
absorbing mechanisms; however, the subsequent cost to repair this damage shall be less than the cost of providing a completely damage resistant system.
- Air flow through the bumper cooling slots shall be adequate for engine cooling.
- Reduction of aerodynamic drag shall be considered in selecting the bumper shape.
- The bumper shall allow for proper mounting of the headlamps.
- The bumper material shall be compliant and retain its shape in the temperature range of -20°F to +120°F.
- The front bumper design shall be consistent with the general cost, weight, producibility, and material reclamation goals of the RSV program.

**BUMPER DESIGN**

Using the performance criteria established in Phase I, several candidate soft bumper systems were evaluated. The ability of the bumper material to recover its original shape after impact dictates that a plastic material such as polyurethane, neoprene, or polyvinyl buterate be used. To achieve a low collapse pressure the bumper would have to have a honeycomb construction, be air pressurized, or consist of a thin shell filled with an energy-absorbing material. Existing air pressurized systems have collapse pressures that are too high (60 psi). Cost, manufacturing, and appearance limitations precluded the use of a honeycomb material. Therefore, these two types of bumpers were eliminated as possible candidates, and design effort was concentrated on developing a bumper system consisting of thin fascia filled with a homogeneous energy-absorbing material.

**Materials and Processes Considerations**

The primary consideration for proper material selection is the achievement of low collapse pressures for pedestrian protection; however, other practical considerations are:
- Temperature effect
- Dimensional stability
- Producibility, availability
- Finish
- Cost
- Recycling

Three types of polymeric material that are used or being developed for flexible parts in automotive applications are thermosetting urethane foam, EPDM elastomer, and thermoplastic urethane. Characteristics for these materials are shown in Table 4. Currently, material, process, and application technology is more advanced for thermosetting urethane foam, as regards flexible fascia for automotive front ends, and the use of low pressure reaction injection molding is feasible for

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Thermosetting urethane foam</th>
<th>EPDM elastomer</th>
<th>Thermoplastic urethane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>1.0</td>
<td>1.25</td>
<td>1.18</td>
</tr>
<tr>
<td>Tensile strength (psi)</td>
<td>2 400</td>
<td>1 800</td>
<td>3 200</td>
</tr>
<tr>
<td>Unsupported sag (heat effect)</td>
<td>Good</td>
<td>Fair</td>
<td>Fair</td>
</tr>
<tr>
<td>Formula flexibility</td>
<td>Yes (rigid crushable, semi-rigid, flexible)</td>
<td>No (glass filler additions)</td>
<td>Somewhat</td>
</tr>
<tr>
<td>Relative raw material cost ($/lb)</td>
<td>1.25</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Process employed</td>
<td>Casting, low pressure</td>
<td>High-pressure injection</td>
<td>High-pressure injection</td>
</tr>
<tr>
<td></td>
<td>injection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tooling employed</td>
<td>Epoxy, aluminum, electro-formed molds</td>
<td>Machined steel</td>
<td>Machined steel</td>
</tr>
<tr>
<td>Equipment needed</td>
<td>High-pressure impingement</td>
<td>High-pressure injection</td>
<td>High-pressure injection</td>
</tr>
<tr>
<td></td>
<td>mixer, low pressure fill 100 psi</td>
<td>fill 4 000 psi</td>
<td>fill 4 000 psi</td>
</tr>
<tr>
<td>Cycle time (min)</td>
<td>4 (now)</td>
<td>3</td>
<td>1.2-1.5</td>
</tr>
<tr>
<td></td>
<td>2.5 (near future)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness limitation (in)</td>
<td>0.120 min</td>
<td>0.150 min</td>
<td>0.120 min</td>
</tr>
<tr>
<td>Recyclable</td>
<td>?</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
production parts. With respect to automotive processing, cycle time, producibility, and minimum gauge, all three materials are competitive. Thermoplastic urethane has a distinct advantage over EPDM elastomers from a reclamation standpoint, while the recycling possibilities of thermosetting urethane foam are not known at this time.

Shape and Styling Considerations

Geometric design of the bumper interacts strongly with the material properties in fixing the collapse loads. Also, the shape of the bumper is the single most important variable influencing the pedestrian’s post-impact kinematics. During Phase II several different front profiles were developed and evaluated from aesthetic as well as from functional standpoints. Size and location of cooling slots were determined. The feasibility of recessing headlamps and providing axial motion freedom under loading to eliminate the headlamp lens and fixtures as an injury producing source was investigated. Further evaluation of optimum bumper shape and material properties for pedestrian protection was accomplished through computer simulation of pedestrian impacts.

Computer Simulation of the Pedestrian Impact Event

Determination of optimum RSV front bumper shape and compliance for pedestrian protection was accomplished by using the CAL-3D crash victim simulator [6]. By using a mathematical model to simulate pedestrian impacts, a large number of variables could be analyzed at a relatively low cost compared to full scale tests. Also, the analytical model eliminates repeatability problems that are often encountered when using anthropometric test devices. The CAL-3D three dimensional model was chosen for use over its two dimensional counterparts to achieve the accuracy necessary to describe the pedestrian’s non-planar, non-symmetrical post impact motion.

The pedestrian-vehicle model configuration is shown in figures 3 and 4. Data for a 50th-percentile male dummy was used to describe the pedestrian [7]. The pedestrian was placed in a crossing attitude at the centerline of the car such that initial bumper contact was made with the leading leg. Initial vehicle speed was 20 mi/h and a constant 0.8 g’s braking deceleration was applied to the vehicle. The two primary parameters that were varied were the shape of the ellipsoids approximating the front bumper and the force-deflection curves for these ellipsoids.

Effect of Front Bumper Shape. Four unique front nose shapes, shown in figures 5-8, were approximated with two contact
SECTION 4: TECHNICAL SEMINARS

Figure 5. RSV front bumper configuration 1.
Figure 6. RSV front bumper configuration 2.
Figure 7. RSV front bumper configuration 3.
Figure 8. RSV front bumper configuration 4.
ellipsoids. Contact sensing switches in the model were set to allow contact between the vehicle ellipsoids and the pedestrian’s legs and lower torso. Blunt nose configurations, such as configurations 2 and 3, appeared to do a poor job of controlling pedestrian kinematics. Initial contact caused a high projection of the lower torso and legs, resulting in head contact on the forward portion of the hood. Lower sloping profiles, such as configurations 1 and 4, resulted in a lower contact point on the legs, causing hood-to-head contact to occur further rearward on the hood. At 400 milliseconds the forward velocity of the pedestrian’s body with respect to the vehicle was greater for the blunt profile than for the sloping profile. Head-to-hood contact occurred for all four front profiles, and the value for Head Injury Criteria (HIC) through 400 milliseconds was below 500 for all four runs. In all cases chest acceleration was below 60 g’s. Although there was no indication that one particular profile minimized head and chest acceleration, configuration 4 did the best job of controlling pedestrian kinematics. This shape matched the pedestrian’s forward velocity closely with that of the vehicle and positioned him over the hood of the car without pitching him high into the air.

Effect of Front Bumper Compliance. At the time the simulation work was being conducted, no exact data existed for the compliance characteristics of a soft bumper system. The force-deflection curves for the bumper inputted into the CAL-3D model were approximated. The contact force level was assumed to be constant between one and eight inches of deformation, after which the bumper would bottom out against the hard support structure and the force levels would become very large. Collapse pressures of 10, 20, and 30 psi were used, and by estimating the contact surface area between the bumper and any given body segment, a force level could be calculated. The force-deflection curves for the so-called soft, normal, and hard bumper materials is shown in figure 9.

Simulation results showed that the soft

Figure 9. Force versus deflection curves for contact ellipsoids.
material with a collapse pressure of 10 psi was compressed over eight inches by the pedestrian’s legs and caused the bumper to bottom out. The resulting high force on the lower extremities pitched the pedestrian high into the air with a large component of forward velocity. For the normal and hard front nose properties the pedestrian kinematics were controlled much better than for the soft material. As the material became harder, the forward velocity of the pedestrian with respect to the vehicle increased. The maximum value for bumper deflection due to contact with the pedestrian’s upper leg was 9.25, 4.8, and 1.9 inches for the soft, normal, and hard materials. It is apparent, therefore, that the compliance for the optimum pedestrian protecting bumper should allow as much collapse as possible without bottoming out against the hard support structure. Based on simulation results, a soft bumper collapse pressure of 20 psi with a resultant deformation of 5 inches provides the greatest degree of pedestrian impact protection. The simulated pedestrian’s kinematics for bumper configuration 4 with a 20 psi collapse pressure are shown in figures 10-15.

Other Simulations

An additional simulation was made to determine the effect of vehicle attitude due to brake dive on pedestrian kinematics. A suspension math model was used to calculate the change in vehicle attitude resulting from a constant 0.8 g’s braking deceleration. When brake dive was simulated, initial contact with the pedestrian’s leg occurred 4 inches lower than in previous simulations.

Lower leg contact produced a very pronounced twisting and rotating motion of the pedestrian’s body. Head-to-hood contact occurred further rearward at the base of the windshield. Compared to simulations where brake dive was not simulated, the torso rotated more so that at 400 milliseconds, the torso was positioned laterally above the body.
Figure 11. CAL-3D pedestrian simulation—50th-percentile male dummy—front configuration 4 (time = 80 ms).

Figure 12. CAL-3D pedestrian simulation—50th-percentile male dummy—front configuration 4 (time = 160 ms).
Figure 13. CAL-3D pedestrian simulation—50th-percentile male dummy—front configuration 4 (time = 240 ms).

Figure 14. CAL-3D pedestrian simulation—50th-percentile male dummy—front configuration 4 (time = 320 ms).
hood of the car. Forward velocity of the pedestrian's body to the vehicle did not change significantly. These differences in the simulated pedestrian kinematics due to a change in vehicle attitude point out the repeatability problem that may be encountered in full-scale tests. Small variation in dummy or vehicle parameters can grossly affect the outcome of the test.

Throughout the entire modeling exercise, a 50th-percentile male dummy was simulated; however, a significant portion of real world pedestrian accident victims are children. Since a child's center of gravity is lower and initial contact with the vehicle occurs on his torso rather than the legs, a potential hazard exists that the child will be thrown violently to the ground upon initial impact and be run over by the vehicle. To determine the effectiveness of the soft front bumper in controlling the kinematics of a child pedestrian, an additional simulation was made in which a 50-pound, 6-year-old child was modeled. Data describing the child pedestrian was obtained from the Generator Of Occupant Data (GOOD) program [8]. Nose configuration 4 and normal force deflection curves were used to describe the front of the vehicle. Since a high initial contact on the child's body was anticipated to be the worst condition, vehicle brake dive was not simulated.

Results of the simulation show that the child's body stayed in contact with the front bumper for a longer period of time than did the 50th-percentile pedestrian. His body eventually rotated upward to the height of the hood, and head contact occurred with the rear edge of the bumper and front edge of the hood. Analysis of torso velocity and acceleration with respect to the vehicle at the final simulation time point indicated that the child would eventually contact the ground in front of the vehicle, but there was
SECTION 4: TECHNICAL SEMINARS

no apparent danger of being run over by the vehicle providing the vehicle braking deceleration remained at 0.8 g's. Kinematics of the child pedestrian simulation are shown in figures 16-21.

Model Validity. Although the CAL-3D crash victim simulator is a powerful analytical tool, it must be remembered that simplifying assumptions had to be made to model the pedestrian impact event. For example, the exact shape of the front bumper could not be modeled and had to be approximated with ellipsoids. Discontinuities across the front face of the bumper, such as cooling slots and headlamp openings, could not be accounted for in the force-deflection curve for the front bumper. Despite these and other factors that could cause simulation results to deviate from real world results, trends regarding bumper shape and compliance which provided valuable design direction were identified. Further evaluation of the pedestrian protection performance of the Calspan-Chrysler RSV soft-bumper system as well as the CAL-3D crash victim simulator will be accomplished through full scale testing.

Prototype Build

Based on the results of the pedestrian simulations and other practical considerations, bumper configuration 4 was selected for the prototype bumper system. From a cost and material properties standpoint, thermoplastic urethane appeared to be the best choice for the bumper material; however, thermosetting urethane foam was used for the production of the prototype parts since an inexpensive, low-cost epoxy tool could be utilized. The material's chemical composition for the prototype bumpers, fabricated by the Davidson Rubber Company, was judiciously chosen to match as closely as possible the desired 20 psi collapse pressure through 5 inches of deformation. The fascia and energy-absorbing core were reaction injection molded separately and were then bonded together by means of an adhesive. In actual production the fascias would be fabricated by the RIM process and core would be cast directly into the fascia. Primary specifications of the soft bumper are:

- Fascia thickness: .137 in
- Fascia density: 50 lbs/ft³

Figure 16. CAL-3D pedestrian simulation 6-year-old child (time = 0).
- Core density: 5 lbs/ft$^3$
- Bumper weight: 31 lbs

Mounting brackets were molded directly into the bumper and bolted to a full face sheet metal yoke on the front structure. Rectangular holes above the front ridge and on the drag dam allow sufficient air flow for engine cooling. Headlamps are recessed 7 inches from the front edge of the bumper and mount to the yoke panel. An illustration of the Calspan-Chrysler RSV front bumper system is shown in figure 22. During Phase II of the RSV program 10 prototype bumper systems were fabricated for testing and evaluation purposes.

**SOFT BUMPER PERFORMANCE**

At this time very little test data exists to evaluate the pedestrian and vehicle exterior
Figure 19. CAL-3D pedestrian simulation 6-year-old child (time = 150 ms).

Figure 20. CAL-3D pedestrian simulation 6-year-old child (time = 200 ms).

Pedestrian Protection Performance

Sled tests were conducted at Calspan Corporation in which a 100-pound, 8-inch diameter hardwood body form covered with a one-half inch sheet of ensolite was impacted at various speeds into a simulated soft front bumper. The bumper test specimens consisted of urethane foam blocks that were
Evaluation of pedestrian kinematics has been performed by Battelle Columbus Laboratories under a separate NHTSA contract. A RSV soft front bumper was mounted on a modified Simca C-6 front structure for use in these dummy tests. The test matrix included impact speeds of 20 and 25 mi/h; dummy sizes of a 50th-percentile male and a 50-pound, 6-year-old child; and facing and crossing attitudes for the dummy position. Analysis of pedestrian protection performance and the CAL-3D pedestrian computer model validity will be made when this test data become available.

Vehicle Exterior Protection Performance

Preliminary low-speed barrier tests indicate that the no-damage, 8-mi/h front barrier impact performance goal for the soft bumper system is realistic. Two independent 5-mi/h front barrier impact tests were performed using vehicles that were modified to accommodate mounting of prototype soft bumpers. No discernible damage to the soft bumper or the vehicle’s front structure resulted in either impact. Tests at 8 mi/h will be performed when prototype cars become available late in Phase II of the program. The RSV soft front bumper system was also tested for compliance with FMVSS...
215. The full face soft bumper allowed loading to be well distributed between the impact ridge and planes A and B. Loads on planes A and B were well below the 2,000-pound maximum required by Part 581. Bending of the sheet metal mounting yoke and tearing of the foam at the centerline of the car were the only damaged parts of the system. This damage can be eliminated by reinforcing the center portion of the mounting yoke and in no way reflects a deficiency in the soft front bumper.

SUMMARY

It has been established that the goals of pedestrian protection and improved vehicle exterior damage protection are compatible for a full face soft bumper system. During Phase II of the Calspan-Chrysler RSV program, a soft front bumper system was developed to provide pedestrian protection at speeds over 20 mi/h and prevent vehicle exterior damage during an 8-mi/h barrier impact. Analytical modeling and preliminary component tests have shown that these goals are attainable. Further evaluation of the soft bumper design concept will take place during the remainder of the RSV program.

REFERENCES


Safety Test Performance Levels

JOHN VERSACE
Ford Motor Company

ABSTRACT

All products show some variability in test performance. Because of that, manufacturers do their developmental testing after imposing a margin of clearance below the criterion level specified in a mandatory standard. This provides some assurance that future test variation will not drive some individual units beyond the mandatory level. This paper briefly discusses the difficulties in establishing a practical design limit and shows how a standard intended to impose only minimum requirements can end up forcing something more like maximum requirements when statistical variation in test results are taken into account. The matter is illustrated by calculating clearance margins and design limits based on the results of full-scale barrier crash tests of 33 airbag-equipped Mercury cars.
INTRODUCTION

The purpose of this paper is to describe the manufacturer’s problem of establishing a practical design limit for safety test performance for use in his engineering development work, and to examine the effect it will have on assuring that the results of any given test will indicate that the product will conform to a requirement.

PRODUCER’S DESIGN LIMITS

The Analogy to Quality Control

Test performance criteria in the Federal Motor Vehicle Safety Standards (FMVSS) are analogous to specification limits on a manufactured item. A specification for the manufacture of a part may be stated, for example, as 27.00 ± 0.05 mm. The upper specification limit is 27.05 mm. It is intended that no item of production should fall outside the limits. If test performance is not precisely predictable, the producer must establish conservative working limits in product development and manufacturing, limits that give him some margin of clearance to the mandatory limit.

In quality control, there are two types of limits the manufacturer may impose. The first type of limit is appropriate when the process is fairly stable, with small and predictable variations; but when drift or sudden shifts might occur the manufacturer may wish to take corrective action whenever the process begins to shift to some new level. If he is interested in detecting that it is happening, regardless of whether the shift is large enough to significantly encroach upon the specifications or not, he would construct control limits and take remedial action when sample tests fall beyond them. The other type of limit is appropriate if the natural scatter in output is very narrow compared to the span of the limits; the producer can be tolerant of shifts in the process, provided he can detect when production is getting too close to the specification limits. To do this, he uses modified control limits, sometimes known as reject limits. Both kinds of limits are calculated from a historical sampling of test results, using statistical procedures. They are shown in figure 1.

It has become conventional to consider that for most practical purposes containment of product within the so-called 3-sigma limits is tantamount to meeting the requirements of a manufacturing or design specification. Even so, ordinary statistical theory shows that would correspond to allowing as many as 0.135 percent, or 135 per 100,000, to exceed the specification limit. Sometimes specifications are proposed that are so narrow relative to process capability that the output cannot be satisfactorily contained within the limits. In ordinary engineering and commercial practice, an agreement would be reached either to move the limit or redesign the part if no practical way to reduce process variation can be found. In fact, a determination would always be made of process capability before agreeing to specifications. In the case of mandatory requirements in FMVSS, however, the specifications are presumably premised on external and minimum criteria independent of production realities, and the fraction out-of-space, therefore, is not supposed to ever exceed zero.

Airbag Crash Test Results

In contrast to the quality control criteria and procedures described above is the situa-
tion prevailing with the FMVSS 208 airbag requirements and the outcome of a major “process capability” test program. Ford had 33 Mercury airbag cars crash tested in a round-robin series carried out at three different test laboratories.\(^1\) The test results were very variable, calling for just the kind of treatment in regard to limits as was described above. Despite the variation in individual test results, averages of Head Injury Criteria (HIC) and chest g of similar tests tended to be well within the proposed FMVSS 208 levels, as seen in table 1.

The data from the airbag test program resulted in an expected HIC at the driver position, in the 90-degree barrier tests, of 480; the expected chest g was 37-39.\(^2\) Because the average levels were quite low compared to the requirements, it would seem that demonstrating compliance from the test results should be easy. And perhaps it would if there were little concern for the chance that a compliance verification test sometime in the future might just happen to produce some unexpectedly deviant result. That possibility cannot be ignored because of the variation that was observed. While 480 HIC and 37-39 g were the central tendencies of the data, individual test results scattered quite a bit, most of it due to random influences in each test.

One way to look at the variation in HIC is to calculate the average difference between any two HIC measurements taken at random. The average difference between

<table>
<thead>
<tr>
<th>Company</th>
<th>Driver</th>
<th>Center</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIC:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calspan</td>
<td>480</td>
<td>165</td>
<td>450</td>
</tr>
<tr>
<td>Dynamic Science</td>
<td>480</td>
<td>345</td>
<td>360</td>
</tr>
<tr>
<td>Ford</td>
<td>480</td>
<td>335</td>
<td>510</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chest g:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Calspan</td>
<td>39</td>
<td>38</td>
<td>45</td>
</tr>
<tr>
<td>Dynamic Science</td>
<td>39</td>
<td>41</td>
<td>36</td>
</tr>
<tr>
<td>Ford</td>
<td>37</td>
<td>42</td>
<td>53</td>
</tr>
</tbody>
</table>

any two HIC values for the driver in the frontal test direction was estimated to be 125, a rather large figure compared to the expected HIC of 480. For chest g the average expected difference between any two values was 5 g, which might be compared with the expected values of 37-39 g. Another way of looking at variability in test results is to calculate, from the data scatter, a quantity known as the prediction limit for the next single test. Using the existing data to calculate, for example, the 99 percent prediction limit results in finding that the next test could result in an HIC exceeding 865 (for the driver position, in direct frontal tests, at Ford) as much as once in a hundred tests. While that seems very far away from the average value of 480 of the existing data, the amount of scatter in that data describes a mathematical distribution which predicts values of 865 or more occurring every so often. If a strict statistical approach were to be applied, a producer’s design limit would be calculated based on some allowable chance of producing test results indicating nonconformity to the requirements in the future.

Design Limits

On the average, crash test results seem to be well within the HIC = 1 000 and chest g = 60 requirements of the standard. But because of variation in individual test results, assurance that all future production will easily meet those requirements must be doubted. Assuming for the moment the mandatory requirement that 100 percent of


2 Note that the “expected” value refers to an average-like value calculated from a regression model of the experiment. Results relating to all the other variables are contained in the SAE report referenced above. As was stated in that SAE paper, revisions to the data were still being made at its writing as outliers and other suspicious data points were being re-evaluated. A number of data points were changed. The numerical changes in the summary results were small and thus did not affect any of the conclusions in the original paper. The figures quoted in this paper have been adjusted for those changes and thus will differ a little from those originally reported.
the test results shall fall within the limits, and treating 99.9 percent as tantamount to it, a design limit based on available observations would have to be placed at a level below the average value of the data! This would be an unprecedented requirement for any system where process capability is determined and taken into account in the setting of requirements. It is especially troubling when it happens with a specification that, while mandatory, is supposed to be a minimum requirement.

Figure 2 shows the nature of the compliance problem for the barrier crash test of airbag vehicles. It shows the smoothed distribution of HIC obtained in the round-robin airbag crash test series: note the expected value of 480 and the relation of the data to a design limit of 500, corresponding to the more modest expectations, with 75 percent confidence, that at least 99 percent of test results would indicate compliance.

Using the findings from the test series described above, one can proceed to the derivation of a set of possible producer’s design limits, limits set at some level within the mandated limit and intended to provide a margin of clearance to it.

Table 2 gives calculated values of design limits for HIC and chest g based on the test program described above. Since the average of a number of test readings is more stable than any single reading by itself, a limit predicated on the average of N repeated tests will of course be closer to the mandatory specification limit than any single test. Therefore, the tables include design limits not only for a single test but also for averages of 2, 4, 7, or 10 repeat tests. While so many repeat tests might never be run, the tables are of interest because they indicate the way precision changes as the number of tests is increased.

The table is headed by the minimum percentage of output expected to produce test results indicative of compliance. By the minimum percentage is meant that at least this many, hence possibly more, of the units are expected to produce such results. In the table for HIC it is seen that a 75 percent confidence that at least 99 percent of production will meet the specification would require a design limit of 550 for a single test. If two identical tests are going to be run by the same test agency, using the same test dummy each time, and the two HIC readings are to be averaged, then the design limits can be gradually raised, as seen in the table. When an unspecified dummy is selected at random, and a different one is used in each test, then the HIC design limit would always have to be of a somewhat lower value to protect the margin from dummy variation in HIC. The design limit shown in figure 2 was based on this random selection assumption. No significant differences among dummies were found for the chest g, so the two parts of that table have the same limit values.

The results in table 2 and the illustration in figure 2 show a rather difficult situation. A requirement that is supposed to be a minimum requirement turns out — if there is to be an adequate margin of protection against getting test results indicating non-conformance — to be more like a maximum specification. It should be recalled that all the results shown here derive from tests in full-size Mercury cars, and that any change from that to designs apt to give larger test readings will likely exacerbate the design limit problem.

Another important factor, not covered by the analysis thus far, is how to establish a
Table 2a. Producer's design limits for HIC to assure that test results will indicate FMVSS 208 compliance

<table>
<thead>
<tr>
<th>Confidence (percent)</th>
<th>N</th>
<th>Compliance using same dummy (percent)</th>
<th>Compliance using unselected dummy (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>50</td>
<td>1</td>
<td>875</td>
<td>780</td>
</tr>
<tr>
<td></td>
<td>2</td>
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<td></td>
<td>4</td>
<td>875</td>
<td>780</td>
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<td>875</td>
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<td></td>
<td>10</td>
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<tr>
<td>75</td>
<td>1</td>
<td>765</td>
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<td></td>
<td>2</td>
<td>795</td>
<td>705</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>820</td>
<td>725</td>
</tr>
<tr>
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</tr>
<tr>
<td></td>
<td>10</td>
<td>785</td>
<td>690</td>
</tr>
</tbody>
</table>

*aFor vehicles typified by 1972 Mercury cars, all tested under the same conditions at the same site. N is the number of identical tests whose results are averaged.

design limit that will not only protect the producer from infringement on the mandatory requirement, but also to protect against the additional uncertainty in expected outcome if a compliance verification test is run at some other laboratory. The different laboratories varied among themselves, even in the averages, as table 1 showed. Table 3 shows the results of calculations on the design limit for HIC when the single future test will be done at some unknown laboratory (but one producing the kinds of results as were obtained at Calspan, Dynamic Science, and Ford Motor Company in the round-robin test series). The adjustment for interlaboratory differences is complex. The differences depended on the seat position, the barrier angle, and the response variable. There was so little order in these variations they must be considered random rather than systematic. For example, there were no significant differences among laboratories for the driver in the 90-degree frontal tests. But there was for the right front position and table 3 shows that.

Getting a test result outside the requirement may not mean, however, that the product per se is outside the limit. It could be a consequence of test unrepeatability alone. Since product and test variations are additive, any deviant test result cannot clearly be ascribed either to product or test deviation alone. However, the evidence is that most of the variance is due to random influences on the tests, not so much that of product variation. Statistical analysis of the data from the round-robin test series failed to show any significant differences among
Table 2b. Producer's design limits for chest g to assure that test results will indicate FMVSS 208 compliance

<table>
<thead>
<tr>
<th>Confidence (percent)</th>
<th>N</th>
<th>Compliance using same dummy (percent)</th>
<th>Compliance using unselected dummy (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>50</td>
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<tr>
<td></td>
<td>10</td>
<td>49</td>
<td>45</td>
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</tbody>
</table>

The test cars, after adjusting for the main variables, in comparison to the residual variance.

BACKGROUND TO THE DETERMINATION OF DESIGN LIMITS

The Statistical Nature of Test Results

Almost all procedures for calculating appropriate test limits rely on the statistical nature and mathematical properties of data scatter. The familiar bell-shaped curve of data scatter implies that there is always some chance of getting a test result which is extremely deviant. Because the scatter of data thins out rapidly in the tails of the bell-shaped curve, engineers are ordinarily satisfied if the specification limit is placed at a point where the remaining area under the curve is very small, such as one per thousand.

To achieve an expected occurrence rate of zero beyond the specification limit would be impossible with the known statistical formulas. Generally, the Gaussian distribution, more often called the normal distribution, is the theoretical basis for calculations about the scatter of data. The mathematical description of the normal curve, as seen in figure 1, includes tails that extend to +

Table 3. Design limits for single tests (random dummy), for right front occupant [Percent]

<table>
<thead>
<tr>
<th>Confidence</th>
<th>Minimum compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75</td>
</tr>
<tr>
<td>One site:</td>
<td>90</td>
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<tr>
<td></td>
<td>95</td>
</tr>
<tr>
<td>Unpredictable site</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>95</td>
</tr>
</tbody>
</table>
SECTION 4: TECHNICAL SEMINARS

infinity. Nevertheless, there must be a physical limit someplace. Since there can be no test result below zero, the normal distribution can only be an approximation down at that end. At the high end, there is no possibility of an indefinitely high HIC or chest g for they will be limited due to the finite energy of a 30-mi/h crash test. The natural limitation for HIC and chest g is likely to be well out in the tail of the distribution and above the mandatory requirement, so that ordinary statistical theory based on the assumption of the normal curve is still appropriate. Therefore, the extension of the tail of the distribution into the region beyond the mandatory limit must be considered, even if it is truncated at some point beyond that.\(^3\)

To set a practical design limit within the specification, some estimate of test scatter must be made. This can only be determined after repeated testing. One can never be sure, after making a few tests, where the next test result will be; it might lie outside the range of the results already obtained. There is a steadily diminishing chance that a new test result will lie ever further away from those already obtained, but the chance is still there, especially if the amount of data already collected is small. Safety testing will often have to be sparse. When a fully instrumented crash test costs nearly $15,000, and when developmental testing must be done on expensive prototype models, there is not likely to be enough testing or enough data to satisfy all needs. So, it must be expected that future tests will sometimes produce results beyond the range of past data. As a result, the practical design limit, and hence the margin of clearance between it and the required specification, must be based on an evaluation of the chance of getting non-complying results in the future. Mandating a fixed requirement does not alter the fact of test variability and the chance that items which are essentially within compliance may occasionally test out of compliance.

\(^3\)A practical but artifactual limitation occurs because of instrumentation overload, but that does not affect the point being made here.

Airbag Crash Tests

Ford had 33 Mercury airbag cars crash tested in a round-robin series to evaluate crash test and dummy variability. It was found that all the Part 572 requirements could not be simultaneously met in any given dummy. It was also found that variations in these dummy calibration measurements were nevertheless not significantly reflected in subsequent crash test results; that is, the trend, if any, was not discernible amidst the variability in the data.

The 33 test cars were apportioned among Ford, Calspan in Buffalo, and Dynamic Science in Phoenix. Nine of the cars were used in side impact testing, and 24 in standard rigid barrier tests, at 30 mi/h. Those tests were run both in the 90-degree frontal direction and also into a 30-degree barrier wedge, as per FMVSS 208. Nine Hybrid II test dummies designed to meet the Federal Part 572 requirement were used. Three of the nine dummies were selected according to a rotational sequence and put in the front seat of each test car. The nine dummies were rotated among the three crash test laboratories. The airbag, without lap belt, was the only restraint. Since even 33 cars were not enough to allow for any exactly repeated tests a rather sophisticated statistical procedure, known as a partially balanced incomplete block experiment design was applied.

The test results were analyzed according to the test laboratory where the crashes were run, the barrier angle, the seated position, and the dummy identification. The effect of the variables on the resulting test data was determined. The contribution of random and uncontrolled factors affecting the test outcome was also determined. The test program, then, yielded an estimate of the amount of variability in test results due to: differences among the three laboratories doing the testing; differences between the two barrier angles; differences from one seated position to another; variability due to differences among the different dummies used in the experiments, and that due to repeated test runs, which we may call
chance or test variability. Table 1 shows some of the results.

**Method of Establishing Limit Values**

The purpose of this paper has been to show the nature of the problem rather than to go into technical detail. Therefore, the exposition of method will be limited to the following brief remarks about the calculations. A test limit can be derived, after establishing the process average and the variability, by further specifying two constants: first, the minimum fraction of production which must be in compliance; and second, the confidence level for that estimate. The design limit is based on the statistical tolerance limit.

**Upper Tolerance Limit (UTL)**

\[ UTL = \text{Design Limit} + h \times (\text{Standard Deviation}) \]

Solve for the design limit after setting \( UTL = 1000 \) (for HIC), and inserting \( h \) and the standard deviation. The factor \( h \) is a value derived from normal probability theory and available in tabulated form in statistical textbooks. Its value depends on the desired confidence level and on the minimum fraction of output that must be within the tolerance limit. It also depends on the number of tests and on the degrees of freedom of the standard deviation (that is, the amount of data on which it is based). The greater the number of tests, the more precise the information and hence the smaller the value of \( h \) would be. The factor \( h \) for several conditions is shown in table 4.

The data from the airbag crash test round-robin discussed earlier were analyzed after first converting the HIC readings to logarithms and chest \( g \) to its reciprocal. These transformations were required because the residual variation — that was left over after partitioning out the effects of the main variables and their interactions (using regression techniques because of the partially balanced incomplete blocks arrangement of the test condition) — was skewed. Hence, all calculations involving standard deviations and both prediction limits and tolerance limits (hence design limits) were carried out in the logarithmic and reciprocal forms. Then the results were inversely transformed so as to put the answers back into the original units.

The solutions for \( h \) were also obtained by this process of back and forth transformations. They also involved further complications. The standard deviation had been calculated on the basis of the available data, that from the round-robin test series, with some 45 degrees of freedom. Most tabulations of \( k \) assume that the tests involving variability, by further specifying two constants: first, the minimum fraction of production which must be in compliance; and second, the confidence level for that estimate. The design limit is based on the statistical tolerance limit.

![Table 4.—Values of \( k \), assuming 45 degrees of freedom in the estimate of variance](image)

<table>
<thead>
<tr>
<th>Number of tests averaged</th>
<th>( \gamma = 0.75 )</th>
<th>( \gamma = 0.95 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha = 95% )</td>
<td>2.354</td>
<td>2.928</td>
</tr>
<tr>
<td>99%</td>
<td>3.054</td>
<td>3.669</td>
</tr>
<tr>
<td>( \alpha = 95% )</td>
<td>3.410</td>
<td>4.141</td>
</tr>
<tr>
<td>99%</td>
<td>4.141</td>
<td>5.190</td>
</tr>
</tbody>
</table>

**NOTE.** \( \gamma \) = confidence; \( \alpha \) = minimum compliance level.

SUMMARY

In order to be assured that future test results will be in conformity to specifications, the producer must establish conservative design limits within which he will engineer and build the product. The design limit

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may be set by judgment or, if there are some data indicating the probable level of performance, the design limit can be established by statistical analysis. The results of a large round-robin airbag crash test program provided statistical estimates on which to base the calculation of possible design limits for HIC and chest g in FMVSS 208. Because of the considerable scatter in test results, design limits calculated by conventional means, of the kind that would be produced for industrial quality control purposes, turned out to be quite low relative to the actual range of performance. As a consequence, there would have to be a substantial further development of restraint designs to get the performance level well below the design limit, or a rather low confidence of obtaining future test results clearly within the requirements might have to be tolerated. The end effect is that the intended minimum requirement seems to work more like a maximum requirement, pushing on technical capability.

Development of Advanced Restraint Systems for Minicars RSV

CHARLES STROThER, MICHAEL U. FITZPATRICK, and TIMOTHY P. EGBeRT
Minicars, Inc. Engineering Staff

ABSTRACT

Design and development of the Research Safety Vehicle (RSV) restraint systems has provided a unique opportunity to integrate advanced restraint system concepts into a vehicle whose structure has been designed to be structurally superior in a crash environment. This combination has enabled Minicars to “tune” both structure and restraints to perform in a mutually complementary manner. Because of this integrated approach to system design, the restraint systems have shown in actual vehicle crashes to be capable of protecting vehicle occupants to velocities in excess of 50 mi/h. Although the restraints that perform this task are advanced systems incorporating the latest techniques in restraint design, such as dual bags, stroking airbag mounting surfaces, and so forth, the restraint components are simple and producible. This paper describes occupant restraint systems designed for the RSV.

INTRODUCTION

During Phase I of the RSV program, Minicars performed an analysis to determine the necessary characteristics of a safe, efficient, economical vehicle for the 1980’s time frame. As part of the study, a benefit/cost analysis was performed to identify that combination of safety features that would result in the highest safety payoff (benefits minus costs). Since the most important occupant protection is afforded by restraint systems, extensive analyses were performed to determine potential restraint systems which could be considered for the Research Safety Vehicle. Several candidate restraints were selected: standard 3-point belts; force-limited 3-point belts; preloaded, force-limited 3-point belts; force-limited airbelt systems; airbag restraints; and lap belts (for rear seat positions only). The results of these analyses (table 1) indicated the airbag restraint would provide the highest safety payoff for both the driver and right front seat passenger. Although lap belt restraints would provide the highest safety payoff for rear seat passengers, force-limited 3-point belts were nevertheless selected because it was felt that, in the context of a research program, a more advanced system was warranted, especially in view of the fact that its impact on the total restraint safety payoff was so slight.

Critical to the performance of any restraint system is the deceleration produced on the occupant compartment by the vehicle forestructure. The relatively long RSV front end is constructed from foam-filled sheet metal. This configuration produces mild compartment deceleration profiles (fig. 1) without creating significant compartment intrusion, even in severe frontal crashes.
Table 1. Ranking of restraint systems

<table>
<thead>
<tr>
<th>Driver</th>
<th>Right front passenger</th>
<th>Rear passenger</th>
<th>B/C ratio</th>
<th>Safety payoff (billion $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>AB</td>
<td>LAP</td>
<td>2.99</td>
<td>4.33</td>
</tr>
<tr>
<td>AB</td>
<td>AB</td>
<td>FL-3 PT</td>
<td>2.85</td>
<td>4.29</td>
</tr>
<tr>
<td>AB</td>
<td>AB</td>
<td>3 PT</td>
<td>2.88</td>
<td>4.28</td>
</tr>
<tr>
<td>AB</td>
<td>AB</td>
<td>FL-ABLTc</td>
<td>2.81</td>
<td>4.27</td>
</tr>
<tr>
<td>AB</td>
<td>FL-ABLT</td>
<td>3 PT</td>
<td>2.96</td>
<td>4.19</td>
</tr>
<tr>
<td>AB</td>
<td>FL-ABLT</td>
<td>FL-ABLT</td>
<td>2.88</td>
<td>4.17</td>
</tr>
</tbody>
</table>

aAssumes radar accident avoidance system with 1.2 g brakes.
bRSV choice.
cForce-limited air belt.

DRIVER RESTRAINT SYSTEM

The RSV driver restraint is comprised of an energy-absorbing steering column and mounting system, a steering wheel assembly that houses the airbag, and a knee restraint.

The steering column energy-absorbing (EA) unit (fig. 2) is a telescoping absorber in which the aft section, a 1 3/4-inch square tube, connects with the steering wheel assembly and the forward section, a 3-inch square tube, connects to the vehicle cowl.

Energy is absorbed during telescoping by a rollerless tape mechanism. A continuous length of steel tape is attached at its ends to the right and left side interior walls of the forward tube and at its middle to the forward end of the aft section of the column (fig. 3a). The tape forms two loops, each having a diameter approximately equal to one-half the difference of the forward and aft column section widths. As the column telescopes (fig. 3b), the tape loops roll off the sides of the forward section and onto the sides of the smaller aft section, producing a column collapse force given by

\[
F_c(x) = \frac{2 \sigma_y t^2 W(x)}{D}
\]

where \( x \) = column stroke (in)
\( \sigma_y \) = yield strength of the tape material (psi)
\( t \) = tape thickness (in)
\( W(x) \) = tape width at the loop as a function of column stroke
\( D \) = loop diameter (in)

The parameters above have been set to result in a theoretical stroking level of 1 750 pounds over the first 5 inches of its length. Thereafter the width of the bands increases to accommodate large adult drivers at the highest impact severity.

As with other steering columns, the RSV column is subjected to severe bending moments. The most severe of these is the counterclockwise\(^1\) bending moment associated with the upward force at the steering wheel rim end of the column. To counteract this moment without introducing excessive friction, a roller is provided at the aft upper end of the forward section of the column to bear on the top flat of the aft column section. A nylon slide pad is provided on the bottom forward end of the aft section to bear on the

---

\(^1\) As viewed from the driver side of the vehicle.

Figure 1. RSV compartment response in 50-mi/h barrier impacts.
lower interior surface of the forward column section, as shown in figure 4.

Significant lateral bending moments arise when the vehicle is involved in an angular or offset frontal collision and/or when the driver is not directly behind the column at impact. To counter these lateral bending moments, nylon pads are provided on the forward section of the column at its aft end on the interior vertical walls of the tube. These pads bear against the right and left sidewalls of the column aft section. Two shoulder bolts, inserted vertically through the forward section of the column, contain nylon rollers which bear on the side walls of the aft column section as shown in figure 5.

The steering shaft is a conventional (Ford) telescoping unit with a splined aft end. Bearings for this shaft are provided at the firewall at the point it enters the aft section of the column and where it connects to the steering wheel. Also, attached to the aft end of the column is a Ford turn indicator/ignition/column lock assembly.

The steering wheel assembly is comprised of a wheel rim, inflator, reaction plate/retaining ring assembly, airbag configuration, and a bag cover as shown in the exploded view of figure 6. The wheel rim is a General Motors Air Cushion Restraint System (GM ACRS) rim, a significantly more rugged rim than any other commercially available model. The wheel rim has four spokes, a diameter of 15 1/2 inches, and a depth of 4 inches. The inflator is a modification of a unit manufactured by Thiokol Corporation to meet GM ACRS specifications, the inflator propellant charge being increased by about 10 percent. The bag system is clamped to a large (9-3/4-inch diameter) reaction plate/retaining ring assembly.

The RSV driver bag system is a dual-bag configuration. Both the inner and outer bags are cylindrical in shape (fig. 7). The inner bag column is 1.0 cubic foot; the larger, outer bag has a volume of 1.7 cubic feet. The bags are constructed of low permeability, plain weave 840 denier nylon No. 6. Venting in both bags is accomplished solely by bag porosity. The airbag cover is vacuum-formed of 1/16-inch thick, low density polyethylene. Although this material is flexible, it holds its shape and is environmentally rugged. It is impervious to
all common solvents. The tear pattern, preslit in the aft face, is covered by decorative tape.

The lower body energy of the driver is absorbed by the foam knee restraint, attached to a sheet metal backing plate on the lower dashboard (fig. 8). As can be seen, the backing pan is attached to the cowl and the firewall, and is oriented at about a 45-degree angle. The knee restraint consists of about 10 inches of rigid foam faced with a protective and decorative elastic foam-backed cover material.

**System Operation**

Operation of the RSV driver restraint system is best described by relating the sequence of events which occur during the most severe frontal impact condition for which the system is designed a 50-mi/h barrier impact. A sequence of five sketches depicting critical moments in the frontal crash event is shown in figure 9. Sketch (a) shows the occupant, restraint, and vehicle at the moment of bumper contact with the barrier.

Sketch (b) shows the time of sensor switch closing that occurs in the bumper switches at about 9 milliseconds into the event. At this point, the driver has moved forward only a fraction of an inch.

About 30 milliseconds into the event the occupant begins to experience deceleration from his restraint system, as shown in (c). The small inner bag, which receives gas directly from the inflator, can respond very quickly.

At about 80 milliseconds into the 50-mi/h barrier impact (d), the force exerted by the airbag system on the driver’s chest exceeds the stroking force (about 1 750 pounds) of the steering column. Since the effective weight of the 50th-percentile upper body is about 60-65 pounds in this situation, the force-limiting nature of the collapsible steering column produces chest deceleration levels of about 30 g during column stroking. The larger cubic foot outer bag, inflated by the gas vented from the inner bag, captures and prevents the head from whipping forward.

Sketch (e) shows the end of column stroking. At about 100 milliseconds, the driver reaches maximum forward translation in the compartment. The steering column has stroked about 4 1/2 inches and the knees have penetrated the lower dash about 6 inches (e). At this instant the occupant begins a very mild rebound into the seat.

**Driver Restraint System Performance**

To date, 36 sled and three vehicle crash tests have been performed in Phase II of the
RSV effort to investigate various driver restraint system configurations. Because most of these tests were conducted to develop the system rather than evaluate system performance, it is not possible at this time to present a data package that completely defines the RSV driver restraint performance. Only developmental tests that demonstrate the performance of the final system configuration are included.

Sled Test Nos. 57, 58, 61, and 63 with vehicle crash Test Nos. 6.7 and 6.9 show the high-speed performance of the driver system with a range of driver somatotypes. In sled Test No. 57, the 50th-percentile male driver dummy was subjected to a simulated 45-mi/h perpendicular flat barrier impact. During this test, the column stroke was about 3 1/2 inches. Because peak femur loads were about 1800 pounds — somewhat higher than desired — the knee restraint was softened on subsequent tests. The results of this test are presented in figure 10.

In vehicle Test No. 6.7, an RSV structure with a 50th-percentile male dummy in the driver position was impacted into the flat barrier at 51.8 mi/h. Because at the time this test was run a somewhat stiffer vehicle front end was anticipated, the column collapse force was about 250 pounds higher than that used later in Test No. 57. The results of this test are presented in figure 11. Had the final configuration column been employed in this test, chest and head injury measures would have been somewhat lower because of the lower collapse force of the column. The recorded injury measures, however, are significantly below accepted injury criteria.

Essentially the same combination of vehicle structure and column design were tested in Test No. 6.9, in which the vehicle was tested in an offset barrier (right side engagement) at an impact speed of 45 mi/h. No column stroke resulted because of extremely low compartment deceleration levels experienced. Injury measures were below the accepted criteria, despite the lack of column stroking.

In sled Test No. 58, a 95th-percentile male driver dummy was subjected to a simulated 48-mi/h perpendicular, flat-barrier impact. In this test, a column stroke characteristic was made constant at 1750 pounds throughout 8
EXPERIMENTAL SAFETY VEHICLES

column stroked about 7 3/4 inches. The increase in stroking level was subsequently made more gradual. On the basis of these two sled tests, it is estimated that the 95th-percentile male driver will be protected to barrier equivalent impact speeds between 45 and 50 mi/h.

The RSV driver restraint system was tested to determine its effectiveness in protecting lightweight drivers. A representative plot of system performance in the perpendicular barrier impact mode when used by drivers represented by the 5th-percentile female dummy is shown in figure 14. The results are from Test No. 63, a simulated 45-mi/h impact. With such a lightweight driver, the column stroke was very small — only a fraction of an inch. Minimal stroking with lightweight drivers results because most of the occupant kinetic energy absorbed in the compartment is by virtue of bag penetration and lower dash crush.

Protection Capability — Summary

On the basis of the sled and vehicle crush tests conducted to date, it is estimated that the majority of RSV driver restraint system users will be protected in frontal impacts of a severity comparable to a 50-mi/h barrier impact. Protection levels for large drivers, represented by the 95th-percentile male dummy, are estimated to be slightly below this level — in the 45-50 mi/h range.

RIGHT FRONT PASSENGER RESTRAINT SYSTEM

Description

The restraint system selected for the RSV front passenger position, like the driver restraint, uses the dual airbag concept. Unlike the driver system, however, it was designed in accordance with two constraints not imposed on the design of the driver system. For the front seat passenger, it was necessary to develop a passive passenger restraint system that would not only meet the requirements
SECTION 4: TECHNICAL SEMINARS

Figure 10. Results of a simulated 45-mi/h barrier impact—50th-percentile male dummy driver (sled Test No. 57).

Figure 11. RSV development Test No. 6.7 driver dummy results.

for occupant protection, but would also maintain standard chest-to-dash distances so that ingress and egress and normal passenger movement in the compartment would not be hindered. It was also desirable that the system afford maximum protection for the out-of-position child in the front passenger seat and that the system be entirely mass-producible. Comprised of dual-chamber airbags, a Thiokol solid propellant gas generator, a stroking dash unit that houses the gas generator, and a knee pad, the system is linked to the vehicle structure via an energy-absorbing aluminum honeycomb that crushes at approximately 3700 pounds (fig. 15).

System Operation — Normally Seated Passengers

System operation commences approximately 9 milliseconds after bumper contact. The bumper sensor signals the gas generator to initiate gas flow into the relatively small (3.8 cubic foot) torso bag (see fig. 16 for inflation sequence). Because of the small bag size, the bag fills very quickly. Chest g's begin to increase approximately 25-30 milliseconds after bumper contact.

Airbag. As the torso penetrates the lower torso bag, torso g's and torso bag pressure begin to increase. This increased pressure
Figure 12. Results of a simulated 45-mi/h barrier impact—95th-percentile male dummy driver (sled Test No. 58).

Figure 13. Results of a simulated 50-mi/h barrier impact (tapered band)—95th-percentile male driver dummy (sled Test No. 61).
diverts a larger portion of the gas flow to a vent between the torso and head bags, causing the head bag to inflate. Approximately 50 milliseconds after bumper contact, the head bag is completely inflated. Since the head does not require support until after the torso has been somewhat retarded, the head bag need not deploy as rapidly as the torso bag. Thus, the dual-bag feature of the system enables the gas to be used twice — first to inflate the torso bag to slow the torso, and second to inflate the head bag to retard the head. Other advantages are inherent in the dual-bag system. For example, because the chest has a higher mass-to-area ratio than the head, it requires a higher bag pressure. This
requirement is ideally satisfied by the dual bag system since the volume and venting features of the two bags can be individually tailored to satisfy these differing head and chest requirements. Another very important advantage is that the inherently quick response time of the small torso bag and the tailoring characteristic cited combine to provide a very stroke-efficient airbag system.

The inflated RSV passenger bag is shown in figure 17. As can be seen, the membrane separating the two bags acts as a tension member to prevent the restraint bag from presenting a spherically-shaped bag front to the passenger at initial contact. With a membrane tensile force at the bag center, the bag front is nearly flat. This causes chest g’s to increase more rapidly early in the event (since the area of chest contact is increased) with a correspondingly higher percentage of passenger energy absorbed in the efficient “ride down” mode. The blunt profile also provides
more passenger stability — especially in oblique impacts — by preventing him from sliding off the bag to either side.

Dash Assembly. At approximately the same time the head bag becomes fully inflated, the knees contact the knee pad and apply force to the dash. When the combined force of the knees and the airbag become greater than the resisting force of the energy-absorbing honeycomb located in series with the dash, the dash begins to stroke. For 50-mi/h sled impacts, about 4 inches of dash stroke has been found to be ideal for bringing a 50th-percentile male dummy to rest in the compartment with minimum injury levels.

The stroking dash is preferred over a conventional airbag system for three reasons:

1. Very low chest amplification factors (ratio of torso g’s to crash pulse g’s) are obtained because the effective spring constant of the restraint can be reduced to near zero. Since the amplification factor can be shown to be proportional to this effective spring constant (which is quite high for a conventional airbag behaving like a pneumatic spring), it is important to reduce this spring constant to the lowest possible value. Because the honeycomb material is a constant force device, its spring rate is zero.

2. Increased distance with which to bring the passenger to rest is possible with the stroking dash because it moves forward from its conventional dash location (20 inches chest-to-dash with dash unstroked) during the crash. The additional stroke provided by the stroking dash further increases occupant stopping distance.

3. Lower rebound velocities are possible since a higher ratio of absorbed-to-stored energy is made possible by the crush efficient honeycomb energy absorber.

System Operation — Out-of-Position Child

A restraint system designed to protect the out-of-position child must incorporate features that prevent injuries due to inadvertent airbag deployment in noncrash and minor accidents. It must also ensure that design considerations for the out-of-position occupant will compromise or reduce the protection afforded by the system to the normally seated occupant.

These imposed constraints have been satisfied by incorporating several features into the RSV passenger restraint system, including a special bag-folding technique to reduce effective bag mass, low inflator mount and proper adjustment of inflator “down angles” for bag impact at the child’s center-of-gravity, and a recoil absorber.

Performance and Test Results

The results of recent sled and car crash tests are summarized in table 2. The results show good system performance. The full size range of vehicle passengers from 6-year-old through 95th-percentile male have been protected to injury levels below the allowable limits at 45 mi/h. In addition, in all vehicle crash tests conducted to date (Test Nos. 6.5, 6.7, and 6.9), the system has performed extremely well.

Crash Test 6.7. The first 50-mi/h barrier test (No. 6.7) was conducted on May 12, 1976, to verify the vehicle structure and restraint system performance at this crash severity. These systems had been successfully tested previously (Test 6.5) at 40 mi/h Banier Equivalent Velocity (BEV). A 50th-percentile male dummy was positioned in the passenger side of the compartment. Actual crash velocity was 51.1 mi/h. Test summary results are presented in table 3.

The overall passenger trajectory, based upon high-speed movies, was quite good. The only anomaly was the high femur loads, which resulted because the knees impacted the inflator mount. To prevent this, the bag was aimed a few degrees lower in Test 6.9. The airbag was then able to support a greater percentage of the total body load as well as provide cushioning between the knees and the inflator mount.

Crash Test 6.9. The first offset barrier crash was conducted on July 11, 1976, to evaluate restraint performance in an RSV structure in which intrusion was apt to be excessive (that
EXPERIMENTAL SAFETY VEHICLES

Table 2. Test results—right front passenger

<table>
<thead>
<tr>
<th>RSV test</th>
<th>Dummy</th>
<th>Velocity (mi/h)</th>
<th>Peak resistant chest (g)</th>
<th>HIC</th>
<th>Femur loads (lb)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
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<tr>
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<td>1 300</td>
<td>900</td>
</tr>
<tr>
<td>22</td>
<td>50th</td>
<td>43</td>
<td>44</td>
<td>374</td>
<td>1 050</td>
<td>1 050</td>
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<tr>
<td>23</td>
<td>50th</td>
<td>46</td>
<td>44</td>
<td>355</td>
<td>1 100</td>
<td>1 170</td>
</tr>
<tr>
<td>24</td>
<td>6-yr-old</td>
<td>46</td>
<td>38</td>
<td>441</td>
<td>a_n/a</td>
<td>a_n/a</td>
</tr>
<tr>
<td>25</td>
<td>95th</td>
<td>43</td>
<td>57</td>
<td>628</td>
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<td>60</td>
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</tr>
<tr>
<td>6.9b</td>
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<td>45</td>
<td>30</td>
<td>187</td>
<td>980</td>
<td>690</td>
</tr>
</tbody>
</table>

^a Not applicable.
^b Vehicle crash.

Table 3. Right front passenger restraint system—Test 6.7

<table>
<thead>
<tr>
<th>Item</th>
<th>Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIC</td>
<td>722</td>
</tr>
<tr>
<td>CSI</td>
<td>553</td>
</tr>
<tr>
<td>Peak resultant chest g's</td>
<td>46</td>
</tr>
<tr>
<td>Chest amplification factor</td>
<td>1.2</td>
</tr>
<tr>
<td>Femur loads (lb):</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>1 800</td>
</tr>
<tr>
<td>Right</td>
<td>3 200</td>
</tr>
</tbody>
</table>

is, only approximately half the frontal area of the car would be reacting the load. The barrier was offset toward the right front passenger side of the vehicle. A 50th-percentile male dummy was positioned in the passenger seat. Test speed was 45 mi/h. Results of the test are summarized in table 4. As can be seen, the passenger injury measures were extremely low for a vehicle of the subcompact class impacting the barrier at 45 mi/h.

Static Out-of-Position Child Tests. Combined sled test data and car crash results have shown the right front passenger system to function well in frontal crashes at impact speeds in excess of 45 mi/h for the anthropometric size range of passengers from 6-year-old child to 95th-percentile male. The restraint system has performed well in all recent tests. Injury measures have been substantially below the NHTSA injury criteria limits.

Specifically, the 6-year-old child experienced low injury measures for a 46-mi/h frontal sled test (see table 2—sled run No. 24).

Another series of tests is being conducted to demonstrate restraint performance for the 6-year-old seated in an out-of-position configuration. Previous programs conducted for NHTSA seem to show that it is conservative (higher injury levels are experienced) to statically conduct out-of-position tests where the airbag impacts the seated child dummy leaning against the undeployed airbag within a nonmoving vehicle.

To date fourteen such tests have been conducted. Results indicate that although the system works well — dummy torso levels and

Table 4. Right front passenger restraint system—Test 6.9

<table>
<thead>
<tr>
<th>Item</th>
<th>Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIC</td>
<td>189</td>
</tr>
<tr>
<td>CSI</td>
<td>261</td>
</tr>
<tr>
<td>Peak resultant chest g</td>
<td>30</td>
</tr>
<tr>
<td>Chest amplification factor</td>
<td>1.1</td>
</tr>
<tr>
<td>Femur loads (lb):</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>980</td>
</tr>
<tr>
<td>Right</td>
<td>690</td>
</tr>
</tbody>
</table>
velocities are well within criteria limits — head accelerations and consequently HIC values are very high when the dummy head contacts the seat back. Attempts have been made to reduce head accelerations and HIC values by increasing the seat back padding thickness, softening the comfort contour seat force limiters, and even lowering the inflator charge; however, HIC values at seat back impact remain in excess of 1,000.

Testing in this mode is continuing. In forthcoming tests it is planned to adjust the down angle of the inflator. This should reduce the velocity of the bag front in the horizontal rearward direction, thereby lowering the dummy velocity at the instant of seat back impact.

**RSV REAR PASSENGER RESTRAINT SYSTEM**

**System Description**

The rear passenger restraint system used in the Minicars RSV is a single-retractor, force-limited, 3-point lap and shoulder belt harness (fig. 18). The basic system consists of a reconfigured and slightly modified 1976 Chevette seatbelt system with force-limiters located at the anchor points. Although it looks and operates like the Chevette front seatbelt system, the RSV system more efficiently protects the occupant during a crash. Increased efficiency is attributed to three modifications made to the basic Chevette system: 1) the upper anchor point was relocated to provide a more advantageous angle through which to transfer forces from the vehicle to the occupant; 2) the standard nylon webbing was replaced with low-stretch polyester webbing; and 3) force-limiting devices were inserted at the three anchor points. The upper anchor was relocated and the webbing material replaced so that a significant restraining force could be applied to the occupant early in the crash event. Force-limiting softens the peak forces applied to the occupant and allows efficient use of the stroking space within the passenger compartment.

**Implementation and Packaging**

The RSV force-limited belt system is extremely simple to implement. Polyester seatbelt webbing, which looks and feels like the more common nylon, is presently being used in some production belt systems. No production tooling changes are introduced by changing to polyester belts.

Force-limiting is likewise easy to implement. The Minicars RSV system incorporates a small, lightweight, add-on mechanism at each anchor location of the production seatbelt hardware. The mechanism itself is a stamped metal piece with two ears pierced by a 0.25-inch diameter pin. A mild steel tape (0.90-inch thick) passes around the pin. Figure 19 shows the torso belt and retractor configuration with the force-limiter mechanism and figure 20 illustrates the lap belt force-limiting assembly.

**Dynamic Testing**

The RSV rear seat restraint was sled-tested using 50th-percentile male, 5th-percentile
It will be noted that the efficiency of the force-limited seatbelt was greater for the largest dummy than for the two smaller dummies. The restraint forces applied are the same for large and small occupants, because the system cannot distinguish occupant size. Higher accelerations with correspondingly higher injury measures are created for the smaller occupant mass.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Incoming velocity (mi/h)</th>
<th>HIC</th>
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<tbody>
<tr>
<td>28</td>
<td>37.2</td>
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<td>29</td>
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<td>30</td>
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<td>32</td>
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<td>40</td>
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<td>684</td>
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Table 5. 50th-percentile male dummy

<table>
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<th>Run No.</th>
<th>Incoming velocity (mi/h)</th>
<th>HIC</th>
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</thead>
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<td>39.5</td>
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<tr>
<td>42</td>
<td>34.3</td>
<td>806</td>
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<tr>
<td>43</td>
<td>35.5</td>
<td>1179</td>
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Table 6. 5th-percentile female dummy

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Incoming velocity (mi/h)</th>
<th>HIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>39.5</td>
<td>1588</td>
</tr>
<tr>
<td>42</td>
<td>34.3</td>
<td>823</td>
</tr>
<tr>
<td>43</td>
<td>35.5</td>
<td>1003</td>
</tr>
</tbody>
</table>

Table 7. 6-year-old child dummy retractor system

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Incoming velocity (mi/h)</th>
<th>HIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>41</td>
<td>39.5</td>
<td>1588</td>
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<tr>
<td>42</td>
<td>34.3</td>
<td>823</td>
</tr>
<tr>
<td>43</td>
<td>35.5</td>
<td>1003</td>
</tr>
</tbody>
</table>

One thing that seems evident based upon the development of the RSV rear seat restraint system is the ease with which present-day belt systems can be modified to give very much improved performance. Hardware is readily available that is excellent for this purpose, and only two minor changes—the use of polyester webbing and force-limiting anchors—are necessary to produce signif-
significantly more effective seatbelt restraint systems with greatly reduced injury levels.

SIDE IMPACT AND ROLLOVER PROTECTION

All RSV occupants are passively protected in lateral collisions and rollovers by the well-designed vehicle interior. Additionally, rear seat passengers are provided with an advanced seatbelt restraint system which when worn offers unquestioned benefit.

RSV side impact and rollover protection is afforded by the specially constructed gullwing door, which is the most significant feature of side impact and rollover restraint. The exterior structure of the RSV door works in conjunction with the interior padding to attenuate occupant lateral impacts. Crash-worthy door latches prevent occupant ejection during lateral and rollover collisions.

The RSV door interior is contoured as illustrated in figure 19. As can be seen, door padding is extensive in the shoulder and hip areas. The most critical area for padding is immediately adjacent to and just forward of the driver and front passenger seating positions. Substantial padding is required in this area of the door to provide adequate protection in side impacts. In this mode the occupant translates laterally with perhaps a slight forward component due to his vehicle's initial forward velocity and/or the less than perpendicular orientation of the vehicles at impact. These considerations result in contouring the center portion of the door as seen in figure 19. The center portion, about 15-20 inches wide, is angled to parallel the 22-degree seat back angle. A cross-sectional view of this portion of the door is presented in figure 20.

As can be seen, the shoulder and hip impact areas are provided with foam pads. The vinyl-covered ensolite vehicle skin provides damage protection during day-to-day use. Two vehicle-to-vehicle side impact tests (7.2 and 6.8) have been conducted to date using essentially this door padding configuration. Although the impact configuration and resulting dummy injury measures were comparable in the two tests, Test 6.8 is more significant and more interesting for several reasons:

1. The RSV side structure employed in this test is more representative of the final design,
2. Unbelted near and far side front seat occupants were positioned in the struck vehicle, and
3. The vehicle interior was extensively simulated to observe occupant contacts during the event.

In Test 6.8, the RSV driver side door was impacted by a Ford Pinto traveling at 34.7 mi/h. The Pinto, oriented 300 degrees to the RSV, contacted it at the A-pillar/door juncture. The two unbelted dummy occupants were 50th-percentile male surrogates seated in the front seat locations. The front seat area was provided with mock-ups of every conceivable contact surface in anticipation of impact from the far side (passenger) dummy. Included as mock-ups were a steering column assembly, right side dashboard, gear shift lever, and an item called a "I-G hip pad," suggested as a feature for the driver that would keep his lower body behind the wheel during severe vehicle maneuvers in the absence of lap belts.

The results of this test, tabulated in table 8, were viewed as very satisfactory. The far-side occupant certainly would not have sustained significant injury despite the absence of belt restraint. The near-side door pad produced very low driver accelerations and was penetrated only nominally (about 1 1/2 inches).

Side Glazing. Head impact energy is absorbed and ejection is prevented by using fixed side glazing. Side glazing constituents, dimensions, arrangement, and attachment to the door frame are presented in figure 21. The glazing consists of a membrane to which 100

<table>
<thead>
<tr>
<th>Item</th>
<th>Head HIC</th>
<th>Driver</th>
<th>Front passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest acceleration peaks (g):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-P</td>
<td>20</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>L-R</td>
<td>25</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>I-S</td>
<td>10</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Result</td>
<td>32</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>Pelvic left-right peaks (g)</td>
<td>22</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

\[ a^3 \text{ ms duration level } = 40 g. \]

\[ b^3 \text{ ms duration level } = 44 g. \]
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mil glass is autoclave-bonded. The glass functions only during normal vehicle operation. At impact, the glass breaks away from the membrane.

The membrane consists of Mylar (5 mils thick) and architectural vinyl (15 mils thick), the thicknesses of which were determined from the results of twenty-four head impact tests conducted on the Minicars VEAC I sled. In these tests, flat samples of side glazing were fixed in place and impacted at 20 mi/h by a 12.5-pound head form. Different combinations of Mylar and PVB thicknesses were evaluated. The results of some of these tests were presented in table 9. Note that the HIC measurements are about one-half that allowed in the FMVSS 208 injury criteria and that rebound velocities are about 40 percent of the impact velocity. The Mylar/PVB membrane is initially formed to have tabs about 3 1/2 inches long extending beyond the glass boundaries at its four sides. These tabs are folded back on themselves around a length of wire and heat-bonded to form a loop. These membrane loops fit inside the window frame channel as shown in figure 21. Spring steel clips are then inserted by special pliers into the frame channel to fix the glazing. Molding is then placed around the window to conceal the clips and provide a weather seal. To remove the window, the molding is stripped away and a screwdriver is used to extract the clips.

Side glazing can be removed in an emergency by pulling on a finger ring attached to a hidden wire imbedded in the membrane (not shown). The wire will cut the membrane on three sides, resulting in an exit opening.

SUMMARY

Protective features of the RSV compartment interior, and present performance results in simulated and/or actual vehicle impacts have been described. Impressive levels of frontal impact protection are provided front seat occupants by the use of advanced passive airbag restraints. Incorporated in both the driver and front passenger systems are two significant features which, with the specially configured vehicle front end, account for
Figure 23. RSV side glazing—sectional view of the lower attachment area.

Table 9. Glazing head impact results—20-mi/h impacts with 12.5-lb headform

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Impact speed (mi/h)</th>
<th>Recorded HIC</th>
<th>Head penetration (in)</th>
<th>Rebound velocity (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>20.4</td>
<td>458</td>
<td>5.0</td>
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<td>22</td>
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<tr>
<td>23</td>
<td>18.8</td>
<td>491</td>
<td>3.3</td>
<td>8.3</td>
</tr>
</tbody>
</table>
EXPERIMENTAL SAFETY VEHICLES

protection levels of approximately 50 mi/h. These features are (1) the dual-bag concept that achieves the fast response times required of systems capable of 50-mi/h protection, and (2) the force-limiting capability that enables occupant kinetic energy to be efficiently absorbed within the vehicle compartment, thus minimizing injury indices.

The dual bag concept is implemented in the driver restraint by two concentric (inner and outer) bags. The inner (torso) bag receives gas directly from the inflator and “vents” to the outer head bag. In the passenger restraint, a large partitioned bag is divided into an upper and a lower chamber. The lower chamber torso receives air directly from the gas inflator and “vents” to the upper head chamber.

Force-limiting in the driver system occurs in the telescoping of the steering column. In the front passenger restraint it occurs in the stroking of the right side dashboard. Force-limiting was also incorporated into the RSV rear seat 3-point restraint system to extend occupant protection capability approaching 45 mi/h with retractor. This capability exceeds that provided by conventional belt systems.

RSV occupants are protected in side impact and rollover accidents by the strong shut faces and secure door latches of the gullwing doors as well as the well-padded, roomy interior and the fixed side glazing. Vehicle-to-vehicle side impact test results indicate that RSV near- and far-side occupants would receive minimal injury in a 35-mi/h impact with a vehicle of the Pinto weight class.

Development of Lightweight Crashworthy Vehicle Structures

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Minicars, Inc., Engineering Staff

ABSTRACT

Over the past four years Minicars, Inc., has pioneered the development and application of lightweight but crashworthy vehicle structures. Outstanding results have been obtained by using light gage, foam-filled sheet metal sections. The feasibility of each structure for crashworthiness improvement was proven in the Subcompact Car Crashworthiness program for the National Highway Traffic Safety Administration (NHTSA). The practicality of such structures for production vehicles has been thoroughly investigated during the Research Safety Vehicle (RSV) program. The results of these studies indicate that lightweight crashworthy vehicle studies are a viable option of the 1985 time frame.

INTRODUCTION

Production automobile structures have historically been designed to support the vehicle under loads produced by normal operating conditions, such as road loads. These loads are induced by the vehicle mass as it traverses bumps and other road hazards. They are principally vertical loads distributed along the length of the vehicle with the distribution depending upon the lateral and longitudinal distribution of the vehicle mass. In most early vehicles — as well as some present-day models — the vehicle frame extends along the entire length of the vehicle to provide the primary structural support. On the other hand, most modern vehicles utilize a unibody construction in which compartment sheet metal behaves as structural members. Unibody construction is the latest development in the evolution of efficient, economical, lightweight structures for road load conditions.

The problem now facing the automobile industry is to design economical and lightweight structures which satisfy the current and proposed safety requirements as well as the standard road load conditions. The two loading conditions operate in different planes. Each condition requires different techniques, thus imposing an additional constraint on the new design. Road loads are designed using standard linear elastic design procedures in
which the structural components are kept well within the elastic region, whereas crash energy management structures operate in the plastic region. Plastic deformation of the structure over large deflections provides the most efficient energy-absorption capability. In high-speed frontal impacts it is frequently necessary for the front of the structure to crush almost to the firewall to provide adequate energy absorption. For instance, the kinetic energy of a 3 000-lb car hitting a barrier at 50 mi/h is 250 000 ft-lb. With an average crush load of 60 000 lb the crush distance must be at least four feet. For the lower speed front-to-side impacts the kinetic energy is much reduced but the force levels and the crush distances available in the side structure are also much less. A 40-mi/h classic “T” impact between two 3 000-lb cars represents a change in kinetic energy of about 81 000 ft-lb (based on conservation of momentum). For an average force level of 20 000 lb the total crush between the cars would be about four feet.

To decrease the crush distance the distance strength level must be increased. In all structural design tasks three primary considerations must be balanced: strength and flexibility of the structure, economy of producing the structure, and the weight of the structure. These are all interdependent so that a decrease in weight will generally either increase the cost or decrease the strength of the structures. Since the strength is of vital importance in supporting road loads and in absorbing crash loads, an increase in the cost of the structure is the most likely result of the decrease in weight.

To reduce weight in the vehicle structure it is essential either to reduce the quantity of material or to use lighter materials. Since lighter materials are more costly to use, weight savings are best obtained by reducing the quantity of steel in the structure. One alternative for using less steel is to change the configuration of the structure to a more efficient form. However, the most reasonable means of using less steel is to reduce the gage thickness of the metal part required in the structure. Thus, it is apparent that to produce lightweight cars the material thickness of the structural components must be reduced.

**BASIC CRASH MECHANICS**

A crashworthy vehicle structure is best defined as a structure which provides both survivable space and survivable accelerations for the occupant under prescribed crash conditions. Thus, crashworthiness becomes a matter of balancing the crash forces and crush distances to minimize the hazard. Present vehicles absorb energy by deformation of the sheet metal of the vehicle structure. The subframe provides the primary structure for carrying frontal impact loads from the bumper to the passenger compartment. A second load path develops when the radiator collapses against the engine and pushes it into the firewall. The firewall, by membrane action, develops a high force level. However, since deformation of the firewall is usually small, this load path is not a major energy-absorption mechanism. The frame collapse is the principal energy-absorption mechanism for frontal impacts.

The energy-absorption mechanism of the subframe is overall instability (column failure) of the frame component. A buckle occurs in the frame, initiating a bending moment due to the axial load. A plastic hinge develops in the frame at the buckle with subsequent collapse occurring by rotation of the hinge. In some automobiles the low-speed energy absorber accentuates the problem of placing an eccentric load on the frames. As shown in figure 1, the plastic hinge is a poor energy-

Figure 1. Predicted behavior of typical plastic hinge.

![Graph](image-url)
EXPERIMENTAL SAFETY VEHICLES

absorption mechanism. Once the plastic hinge is formed, the load drops significantly as the eccentricity of the buckle increases. As can be seen by the low-energy absorption represented by the area under the force-deflection curve, these devices are not as efficient as a constant load mechanism. It is also important to note that prior to the formation of the hinge a high elastic spike may occur that causes a high acceleration level.

Figure 2 presents the crush data of an 8 inch X 8 inch closed box section tested in compression. It can be seen from this curve that a high elastic buckling load is obtained. This drops very rapidly to approximately half the value. For the remainder of the crush the load oscillates around one-half the elastic value as successive buckles are formed. Energy absorption of the sheet metal box is as inefficient as the plastic hinge.

For side impact conditions the height mismatch between the bumper and the rocker panels mandates that door crush and “A” post deflection provide the energy-absorption mechanism. Because these structures are fairly soft, as shown by the crush data of figure 3, significant energy would be absorbed during a front-to-side impact only if a major intrusion occurred.

The membrane action of the door structure provides the energy storage mechanism. The load builds slowly since membrane action does not develop until significant deformation has occurred. The energy-absorption capacity of such a force deflection curve is relatively low. Side structures with these deformation characteristics will exhibit large intrusion under crash conditions.

The problem for both front and side crashworthiness is to improve the energy-absorption capability of the vehicle with little or no increase in the weight of the vehicle. Minicars has developed stabilized vehicle structures using foam-filled sheet

Figure 2. Comparison of static crush data for foamed and nonfoamed samples.

Figure 3. Static crush data for side structures of various vehicles.
metal sections which appear to satisfy these criteria. Structures of this type offer additional advantages by providing distributed support for the no-damage bumper and allowing the use of replaceable front modules damaged in moderate velocity accidents. The technical aspects of these structures have been verified by testing under NHTSA contracts with outstanding results.

**FOAM-FILLED SHEET METAL STRUCTURE**

Three major benefits are derived from using foam-filled sheet metal structures:

1. Energy absorption efficiency is improved because the post-elastic load fall-off is reduced, that is, more energy is absorbed per pound of structure.
2. Elastic buckling load is increased for large panels by the stabilizing effect of the foam.
3. Crash behavior of the structure is more predictable and controllable with foamed sheet metal sections.

The effect of foam filling on the post buckling load is shown in figure 3. The crush loads of two identical sheet metal boxes, one empty and one foam-filled, are contrasted. In the filled box it is seen that the post-crush load is higher than that of the unfilled box. A comparison of absorbed energies for a given structure shape shows an approximate 20-percent increase in energy absorption per pound of structure.

The second benefit is an increase in stability of the sheet metal itself. Adhesion between the foam and sheet metal prevents the formation of buckles at the normal buckling load. This increase in stability allows lighter gage sheet metal sections to be used that have a buckling load equivalent to that of current production cars. The Minicars RSV structure, for instance, employs 0.030-inch (22 gage) thick steel sections extensively and provides crashworthiness to 50-mi/h impacts. Lighter gage sections could possibly satisfy vehicle strength requirements, although stiffening beads might be required to prevent elastic buckling in large panels.

The improved predictability of foam-filled sheet metal structures during crash loads is a great benefit to restraints design. An efficient restraint system design requires a unique and well-defined crash pulse. This is extremely difficult to analyze and design into a vehicle. The combination of sheet metal and foam provides two variables that can be modified to develop the desired crash pulse. With foam-filled sheet metal sections it is possible either to alter the density of the foam or to change the thickness of the sheet metal sections, thereby changing the overall crush behavior of the vehicle. This increased capability design modification will allow tailoring of the car structures to restraint system requirements without unnecessary cost or weight increases.

The crash pulse for the RSV as originally proposed for 50-mi/h frontal barrier impacts is presented in figure 4. Superimposed are the results of the first RSV design iteration. These curves correspond well within a reasonable tolerance band. Since this initial design, the crash pulse of the RSV has been modified to maximize the vehicle crush to improve compatibility with conventional car side structures. Modifications to the RSV design pulse have been achieved simply by changing the densities of foam (that is, a decrease from 4 lb/ft$^3$ to 2 lb/ft$^3$) in the structure and by modifying the sheet metal geometry of the main structural components. The final RSV pulse shape is shown in figure 5.

The ultimate result of using foam-filled sheet metal sections is a lighter weight vehicle with more energy absorbed per pound of structure. While it is true that a given crash pulse can be obtained without using foam-filled sheet metal structures, a significant weight penalty is imposed in the design.

**PRODUCIBILITY EFFECTS**

In general, production problems fall into two categories: those that are technically impossible to solve and those that require implementation of economical techniques. Since Minicars has produced and tested foam-filled RSV structures, all the RSV production problems fall into the second category. Foam-filled sheet metal structures have been
shown to be technically feasible but they may require specialized production techniques. The problem is then to develop the most efficient production techniques to achieve maximum economy and still satisfy anticipated 1985 safety requirements.

Six areas of concern associated with foam-filled vehicle structures are:

- Fabrication of closed sheet metal boxes
- Production handling of thin gage sections
- Production foaming techniques
- Durability of the structure
- Flammability during impacts
- Disposability of the structure after completion of the life cycle

Fabrication of large closed sheet metal sections is difficult since joints must be accessible to allow for production spot-welding techniques. This requires external flanges and fence lines that could affect the external appearance of the structures. In the RSV the external forces are not a problem because the body-in-white is covered with a stylish, flexible body glove.

The second concern is associated with production forming and consultants believe the automotive industry will be capable of forming and handling sheet metal as thin as 26 gage (0.018 in) by 1985. Primary structural members, however, should be at least 22 gage (0.030 in) with an 18-gage (0.050 in) frame section to facilitate vehicle assembly in the production line.

The most significant concern in production by far is the actual foaming of the vehicle. Since the foam is susceptible to decomposition due to the heat applied during the welding process, foaming must be done in one of the last stages of production operation. Foam should be injected in the vehicle structure when the body-in-white is near completion. Minicars is now using a Model K500-2P Admiral foaming machine, considered by the plastics industry to be a production machine. Since this machine was not designed specifically for automotive production, it would have to be modified. Much research is required to determine the correct rise-time, number of foaming heads, positioning of foaming heads, and so forth. For instance, it may be necessary to use multiple heads to

Figure 4. Comparison of original actual and predicted force deflection characteristics for RSV front structure—bumper stroke not included.
speed the foaming operation. The rise-time of the foam — the time it takes for the original liquid to become a solid foam — is also an important variable. It is possible to have rise-times ranging from a near explosive 50 ms, to a very slow 10-second rise. Such considerations are concerned with economical production problems since the basic foaming operation has been shown to be technically feasible.

The remaining three areas of concern listed are associated with the long-term use of the vehicle. The durability, flammability, and disposability of the polyurethane foam are problems that occur during the life cycle of the vehicle. Durability will be a problem if the normal road load deformation, temperature cycles, and so forth cause disintegration of the foam cell structures. This question can be reliably answered only after vehicles have undergone service exposures for long duration and extreme conditions.

The flammability of the foam is a special concern in a crash environment since out-gassing may pose a serious threat. The extent of the flammability problem will be studied by Minicars during the course of the RSV contract. A precrashed RSV structure will be burned to study the flammability of the structure.

The disposability of urethane foam is the final problem associated with foam-filled structures. After the useful life of the car, the foam must be extracted from the sheet metal to allow recycling of the steel. Polyurethane is a highly stable compound and does not decompose naturally. Consequently, an economical and safe method for disposing of, or preferably recycling, the foam chemicals must be demonstrated.

Although the questions described are significant, Minicars believes the advantages of using foam-filled sheet metal for improving crashworthiness far outweigh the problems. Production problems have been shown to be problems of economy rather than problems of technology. The problems associated with the life cycle of the vehicle are more in the nature of concern than a truly established problem.

There is no evidence that durability, flammability, or disposability are problems. Much investigation is required to first ascer-
tain whether these are problems and, if so, how these problems can be resolved. Small, lightweight cars would appear to be the way to the future. They are economical to operate and provide significant energy conservation. It behooves the automotive community to place particular attention on development of light automotive structures.

From Experimental to Production Safety Vehicles

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AB Volvo, Sweden

INTRODUCTION

Volvo’s presentation to this year’s International Technical Conference on Experimental Safety Vehicles (ESV) is not based on a contractual participation in the current Research Safety Vehicle (RSV) program. Our voluntary participation continues, however, and we would like to report that our own RSV work is now providing much technical information for further development by using the hardware of our present production vehicle. We believe, therefore, that an outline of the development, design, and crash test results of this vehicle may be of general interest within the scope of the 1976 conference.

It is our opinion that Volvo’s present production vehicle of the 2400-series in many aspects represents a vehicle very close to RSV’s long-term goals of safety and produci-

bility for a size and weight class of increasing importance [1], that is, the 3 000-pound car (fig. 1).

Producibility is obvious and the background for the safety aspects consists of our own test results, supported in part by the findings of the National Highway Traffic Safety Administration’s (NHTSA’s) research on the crashworthiness of full-size and subcompact automobiles by investigating their frontal stiffness [2].

The general framework for the industrial development of automobile safety can be very different, however, from those criteria that could be and often are applied to a specific research project. In the present case, nevertheless, the resulting hardware could meet the
criteria from industry and research. We shall explain why and how Volvo arrived at the present design of the vehicle.

We have chosen to limit this presentation to frontal crash conditions, since another Volvo paper under preparation is intended to cover other crash situations.

**BACKGROUND**

Let us take a short look at the safety of highway vehicles some years ago. At the end of the sixties, Volvo had a reasonably safe passenger car on the market. Multidisciplinary accident investigations provided feedback from the real world and showed that the choice of design criteria for the rolling model had been appropriate. Also, Volvo's efforts to increase seatbelt usage through the introduction of retractors on the 3-point, slip joint belts proved to be another occupant safety improvement.

Volvo's activities and results have been reported with the ESV program on earlier occasions [3, 4]. We shall now report how the findings from such data influenced the choice of mechanical parameters for the frontal-crash characteristics of the new Volvos.

We shall also mention some other factors which influenced the design specification with regard to safety. At the time, the newly organized ESV program and the NHTSA Program Plan published in 1970 and 1971 forecast further development of the safety requirements of future motor vehicles. Also, the standard for passive restraint systems soon appeared, the FMVSS 208, and became an important criterium for body crashworthiness engineering of the new production vehicle, together with the substance of the then existing body of Federal Motor Vehicle Safety Standards (FMVSS).

We had, therefore,

- Volvo's multidisciplinary accident investigations
- the ESV program
- the NHTSA Program Plan
- the FMVSS

...to build upon.

The following gives the development from this general background into established, quantified goals for safety system performance under specific frontal-crash conditions. The prerequisites taken into the decision-making process are listed.

**THE NEW CRASHWORTHINESS GOALS**

It is proper to start with some accident facts. The rolling model rate of occupant fatalities in Swedish traffic for the 1400-series amounted to about 12 per 100 000 registered vehicles per year during the early seventies. By comparison, the U.S. rate in the same period for all passenger cars in use was 35 occupant fatalities per 100 000 registered vehicles per year [5]. We were certain, therefore, that Volvo's accident statistics gave reference to a high level of safety.

If one were referring to accident statistics, with many fatal occupant injuries per given number of registered vehicles per year, the conclusions in terms of the relative merits of various crashworthiness goals would probably be different. Under a high fatality rate condition, one would probably expect that even "small" improvements in safety, such as an energy-absorbing steering wheel designed to protect up to, say, 20 mi/h BEV would be very beneficial. Under relatively safe conditions, however, the task to pinpoint beneficial changes for further improvements is much harder. Still, this was a top-ranking item in the design specification for the new vehicle, and through the analysis of accident data some priorities could be set. For instance, studies on the relative merits of 40- or 50-mi/h BEV crashworthiness levels showed 50 mi/h BEV to be a level of secondary importance [4]. The crashes with fatal injuries and extensive deformations of the occupant compartment did not correlate with the barrier equivalent impacts. The ESV proposal for 50-mi/h BEV crashworthiness, therefore, was not considered a realistic goal for near-term production vehicles.

Hence, the total energy-absorbing capability of the front part of the vehicle was not a problem of concern regarding occupant protection. Instead, a reduction of the frontal crash deformation force level was considered.
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From this, smaller interior impact velocities from unrestrained occupants could be expected, with lower force and associated deceleration levels during impacts at a given velocity against undeformable objects. Consequently, lower injury probabilities could be expected. Summarizing so far, strong arguments pointed to a low force level, long-deformability, energy-absorbing front part of the vehicle, instead of a high force level, short-deformability system to absorb the kinetic energy of crashes at given BEV's. The difficulty of achieving passive protection of occupants even in moderate crash velocities with a high force design was demonstrated by Fiat at the 1973 ESV conference [6].

The expression “high force level” may be given a more precise description. The force level is considered “high” by our standards, if, in a 30-mi/h barrier crash, the dynamic stopping distance is down towards 0.5 meter, or the average g-level is up towards 20 g. Conversely, the force level is considered low if the average deceleration level is down towards 10 g during the entire crash time under the same 30-mi/h barrier impact condition, or if the dynamic stopping distance amounts to 1.0 meter.

Indirectly, the head injury criteria requirement in a 30-mi/h barrier impact test also sets a limit to the crash force level. The reason is that the HIC number can be kept below the 1000 limit only if the belt-restrained passenger dummy head is not allowed to impact the upper part of the instrument panel. This is a result of the definition of the HIC number [7]. Contacts with vehicle interior parts, other than the seatbelt, governed the HIC calculations, even if the contact forces did not dominate the forces acting on the head. Many times the forces acting along the neck alone would give a HIC number above the limit. The overall result was, however, that with the interior displacement distance given, the dynamic stopping distance during the 30-mi/h barrier impact had to be above 0.6 meter. This would ensure that the deceleration of the dummy head took place without impact when the dummy was restrained by Volvo's retractor belt system.

What other legal requirements or proposals were essential? As mentioned earlier, the proposed FMVSS 208 requiring passive occupant protection was judged very important. Not only was it decided that the 30-mi/h barrier crashworthiness requirement was a must, it was also considered that the impact velocities would be upgraded to the 40-mi/h level.

Briefly concluding the above general system performance requirements, a dynamic deformation distance of around 0.7 meter or 28 inches during a 30-mi/h barrier crash was selected to be a reasonable first approach to ensure fulfillment of a possible HIC requirement for the near future. Should 40-mi/h passive protection be required, 1.0 meter or 39 inches of deformation distance during the barrier crash was estimated to be a reasonable condition for successful crash protection at this velocity. It was also essential that the deformation distances given above were used in an efficient way and that large distances were not lost at low force levels much below, say, a 10-g level of occupant compartment deceleration. After these first stages of analysis, the engineering of the sheet metal hardware of the vehicle front could start.

THE CRASHWORTHINESS ENGINEERING METHODOLOGY

Volvo's approach to the design of a vehicle with a given crashworthiness is basically empirical [8]. In addition to this, simple calculations are performed on various sheet metal configurations to judge, on a primary level, the elastic behavior of the structures. For extensive plastic deformation, as in a crash, we have not been able to use such technology as the finite element methods with any great success. This difficulty arises mainly because of the general lack of useful modeling theories applicable to plastic deformation.

Another difficulty originates from the variation in sheet metal thickness produced during the stamping operations. This variation will cause plastic crash deformations to occur at random in detailed parts of the structure. Empirically, however, the average as well as the overall deformation forces and distances tend to remain within rather narrow limits of
the order of ±5 percent. There are other factors besides sheet metal thickness and sheet metal geometric configurations to be considered, such factors as the ultimate strength of the sheet metal, the quality of spot-weldings, the design of localized reinforcements, and a few others.

The general design approach, therefore, is to start with the construction of prototype vehicles using previous experience and brief calculations. After an initial elastic analysis of the proposed layout in simulated normal use, the crash testing of the vehicles can begin. The weak areas have to be found and rebuilt to obtain desired behavior during the specified crash test. Through careful analysis of high-speed movies taken from above and below the vehicle during the crash, supplemented with acceleration and dynamic deformation measurements of "hidden" points in the forward part of the vehicle, the energy-absorbing process can be understood and modified in order to reach specified goals.

In principle, this is a very simple and straightforward approach, but it is not entirely without difficulties. As said before, the energy-absorbing process is a complex matter that is governed by many factors. Apart from those mentioned earlier, we observed that the average force level required to buckle the sheet metal structures in the vehicle changed with the deformation velocity. Since the influence of the deformation velocity was judged to be highly significant, the choice of the impact velocities for the early prototypes had to be made carefully.

We knew that, at the start of production, the vehicle had to comply with safety standards based mainly on a 30-mi/h barrier impact. From that point of view, a safe approach would have been to start with those crash tests and proceed on to higher impact velocities. The first prototype, however, was crashed at 40 mi/h. As expected, a rather low g-level was obtained and the primary locations for reinforcements were found. After additional crash testing at 40 and 30 mi/h, we reached the overall goal expressed above. We later managed to reduce the number of reinforcements to two, localized inside the front subframe structure, one on each side.

Further details of this development will be published elsewhere.

CRASH TEST RESULTS

The rest of this paper is a brief presentation of the crash characteristics of the new Volvo. A number of different crash tests have been performed with the vehicle, but again we will limit this review to frontal impacts. We have crash test results available from a most severe 75-mi/h impact performed by NHTSA in the research project conducted by Calspan, down to 5-mi/h bumper tests. To cover all these impacts is, however, beyond the scope of this paper. The results of the 75-mi/h car-to-car closing velocity crash and the 45-mi/h barrier crash performed at Calspan will be omitted here because the results are published elsewhere [2].

This review will concentrate on results from frontal crash tests normally used for compliance testing and from similar crashes often discussed as alternatives in conjunction with future safety requirements for passenger cars. Furthermore, only 30- and 40-mi/h impact velocities will be considered because these seem to be the only probable test parameters for production vehicles in the near future. Therefore, it also seems logical to start with an analysis of crash data from the most common test used today, the flat barrier perpendicular impact.

PERPENDICULAR BARRIER IMPACT RESULTS

Summarized crash test results will be presented for the vehicle and for two front-seat occupants restrained by air bags or 3-point seatbelts. Only impact velocities of 30 and 40 mi/h will be considered.

Let us start with the vehicle data. The dynamic deformation of the vehicle recorded at 30-mi/h impacts has been around 0.75 meter or 30 inches. A typical impact velocity change curve is shown in figure 2. The velocity change per unit time is fairly constant over the first 60 milliseconds, and the corresponding g-level during this interval is close to 12 g.
After this first crash phase, consuming roughly 0.6 meter or 24 inches of the vehicle front in deformation, the velocity change becomes faster. As a rough average for the rest of the deformation, a $g$-level around 22 $g$ is recorded. This increase in the $g$-level is considered to be caused mainly by forces transmitted from the barrier into the vehicle body over the engine, drivetrain, and rear axle [8]. At the beginning of this second phase, the engine, as such, has essentially lost its forward momentum through direct interaction with the barrier. Consequently, the moving mass of the vehicle decreases rapidly while the restrained occupants will add forward-acting momentum to the vehicle body. After maximum deformation, the momentum of the dummies will govern the final and rebound phase of the crash.

The occupant compartment deformations in these crashes are negligible and the interior space can be fully utilized to reduce occupant velocity. Injury criteria for the occupants will depend on the restraint system used and will differ slightly between driver and passenger. Typical results obtained using an air bag as well as 3-point belt restraints are given in table 1. Both systems are capable of holding injury criteria well below anticipated limits for human tolerance and further discussion of this will be left to other Volvo papers.

Next, we will examine the 40-mi/h crash data with the new Volvo vehicle. The overall dynamic deformation distances have been around 1.0 meter or 39 inches. At this impact velocity, the occupant compartment deformations recorded are small (fig. 3) and located mainly in the footwell and firewall areas. After most of the crashes, it has been possible to open all doors without tools and an example of this will be shown in a movie of such a crash. Also, sun roofs and side windows were operable and offered exit possibilities to the occupants after such crashes. The velocity change of the vehicle during such a test is shown in figure 4. Now, the initial plateau level is about 14 $g$ and lasts...
SECTION 4: TECHNICAL SEMINARS

Figure 3. 40-mi/h perpendicular barrier impact.

Figure 4. 40-mi/h perpendicular barrier impact.
for about 45 milliseconds. After this, the engine and drivetrain forces increase the deceleration for about 15 milliseconds up to 35-40 g average. Then, the remaining forward velocity will be lost during the next 40 milliseconds at an average deceleration level of 17 g. After 100 milliseconds, the occupant compartment forward velocity is zero and the total average is thus slightly over 18 g. In the figure, the vehicle rebound velocity is surprisingly small and due to forward loading by restrained occupants. For comparison, a velocity change curve for Volvo's former model, the 1400, is also shown. The occupant compartment integrity in this case was also good, but the deceleration level was, on the average, 25 percent higher. It can be seen that, in this case, the velocity is reduced to zero after 75 milliseconds and the rebound velocity is greater.

Let us, however, return to the occupant test results for the 40-mi/h barrier impact with the present Volvo. Crashes have been performed with dummies restrained by air bags as well as with the standard Volvo 3-point seatbelt system. In table 2, comparative injury criteria recordings are shown for the different systems and for drivers as well as passengers. With the 3-point belt system, the chest severity index is well below the 1000 level, but the head injury criteria exceed this limit. As stated above, however, the forces acting on the head during these impacts come over the neck as well as the forehead.

It has been said many times that no scientifically founded tolerance limits have been established under such load conditions and probably even these higher numbers may be tolerable. Our combined experience from field accidents and simulated crash conditions points to this conclusion [9].

The 40-mi/h data from the dummies restrained by the air bag systems, which we have under field evaluation, show occupant protection criteria well below the tolerance limit of 1000 for the passenger dummy. For the driver dummy, the chest injury criteria are a borderline case and for the driver head, the limit is somewhat exceeded. Possibly, the same HIC comments given above will apply to a certain extent, if not as pronounced, to the belted dummies. It should also be mentioned that for experimental purposes more powerful and larger air bag systems on the driver side have been tested with head injury criteria results below the 1000 limit. The crash dynamics of air bag-restrained dummies in the 40-mi/h crash will be shown in the movie at the end of this presentation.

<table>
<thead>
<tr>
<th>Item</th>
<th>Driver HIC</th>
<th>Driver SI</th>
<th>Passenger HIC</th>
<th>Passenger SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seatbelt</td>
<td>1250</td>
<td>680</td>
<td>1660</td>
<td>550</td>
</tr>
<tr>
<td>Air bag</td>
<td>1280</td>
<td>980</td>
<td>570</td>
<td>690</td>
</tr>
</tbody>
</table>

ANGLED AND OFFSET BARRIER IMPACT RESULTS

In an attempt to expand our knowledge of various crash behaviors, we have also performed crashes of other types, therefore, we will also report some data from such crashes with the new Volvo. Apart from the perpendicular barrier crash, the most often applied frontal crash type appears to be the impact against the 30-degree angled barrier. We have experienced that very different behavior may evolve during such crashes with cars of different design. The new Volvo's behavior, however, is not very different from that obtained during the frontal 30-mi/h barrier impact. The deformation of the front end of the car is extremely small on the “late” barrier impact side and amounts to a few inches. On the side that first impacts the barrier, the deformation amounts to about 1 meter (39 inches). The overall deformation picture can be seen in figure 5. In figure 6, the complex deformation pattern of the front is seen from below the car. The deformation of the occupant compartment is clearly negligible. The analysis of velocity change curves, from this type of nonsymmetrical impact, is more complex due to the translational as well as rotational movement of the vehicle body. During the essential part of the impact, however, when restrained
dummies move forward inside the car and up to the time when they have rebounded back into their seats, the angle of rotation and the lateral movement of the vehicle were very small with the new Volvo. To simplify, we have summarized the severity of the 30-mi/h, 30-degree angled barrier impact by considering it to be on a 10-g average deceleration level. The origin for this approximation is the forward velocity change curve recorded under the driver front seat and shown in figure 7.

The dummy occupant injury criteria recorded in these crashes, with air bag as well as with 3-point belt restraints, are far below the 1,000 limit. Examples of our results are shown in table 3.

The last crash test from which we have chosen to report results is another nonsymmetrical impact at 30 mi/h. It is an offset impact into "half a barrier," which actually means that, with regard to the width of the vehicle, one-half is in direct interaction with the impacted flat barrier. So far, only limited data have been generated for this type of crash. Still, we have found the vehicle behavior and dummy-recorded data to be of interest. Contrary to expectations, the rotation of the vehicle developed very gradually and was 8 degrees at the end of the crash. A top view of the vehicle and the barrier immediately after the crash is shown in figure 8. The deformation distance of the vehicle on the impact side was 0.87 meter or 35 inches and on the nonimpact side, zero. Therefore the deformation of the occupant compartment did not affect occupant protection. The average or effective g-level was 13 g, calculated from the velocity change curve measured below the impact side seat and shown in figure 9. The recorded injury criteria was 370 for the head of the driver dummy and 290 for the passenger dummy head. It was not possi-

Table 3. Injury criteria for a 30-mi/h, 30-degree angled barrier impact

<table>
<thead>
<tr>
<th>Item</th>
<th>Driver</th>
<th>Passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HIC</td>
<td>SI</td>
</tr>
<tr>
<td>Seatbelt</td>
<td>180</td>
<td>120</td>
</tr>
<tr>
<td>Air bag</td>
<td>300</td>
<td>180</td>
</tr>
</tbody>
</table>
Figure 8. 30-mi/h half barrier impact.

Figure 9. 30-mi/h half barrier impact (Injury Criteria, see text).
ble to calculate the severity index for the driver dummy chest, since a channel was lost, but it read 160 for the passenger dummy. The restraint system used here was the current Volvo 3-point belt.

CONCLUSIONS

Because the main objective of this paper was to report crash injury protection philosophies and data to compare with other RSV work, we think that today we have open-end conditions, particularly regarding future occupant restraint systems, be they advanced seatbelt configurations, vectored, contoured, reinflatable air bags, or developed combinations. Of highest importance is the selection of appropriate crash test types and crash test velocities. When more crash data and more injury data have been investigated, however, Volvo will be ready for the important discussions on future regulatory work with a direct impact upon future production vehicles.

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SEMINAR TWO
ACCIDENT ANALYSIS

Accident Investigations of the Federal Road Research Institute

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ABSTRACT

Several research projects will be used to describe the activities of the Federal Road Research Institute (Bundesanstalt für Straßenwesen, BASt) in the field of accident investigations.

INTRODUCTION

In the Federal Republic of Germany, accident investigations have been carried out for many years. State and private industry, universities and associations—they all analyse road traffic related accidents, using different approaches and methods.

In this report it is impossible to provide a systematic summary of all these activities, which are rather voluminous. Instead, this contribution is limited to render an account of a few scientific investigations initiated by the BASt in this field in recent years and carried out on its behalf.

As pointed out in the governmental status report at the beginning of this conference, a central agency for accident research in the Federal Republic of Germany was established in 1972 in the BASt, which is an institution for science and technology under the Federal Department of Transport. This central agency was set up upon an initiative of the German parliament (Bundestag) and is responsible for coordinating the activities in the area of accident research, evaluating the results of scientific studies, and examining the influence of measures to improve traffic safety for efficiency.

Meeting these manifold tasks requires a precise knowledge of what exactly happens in an accident. This is an absolute precondition. Therefore, the BASt has had a number of research projects carried out on accidents [1].

GENERAL PREFACE

Official data on highway traffic accidents as well as other quantities relevant to safety research—such as registration of motor vehicles, total circulation of vehicles, and traffic offenses (criminal or otherwise)—are usually based on full surveys. But in the majority of studies related to what happens in accidents, the volume of totals concerned makes it generally very difficult if not impossible to collect and investigate all units, so partial surveys have to be carried out.

When assessing such studies, some examples of which will be given later in this report, it is now the question of representative sampling that assumes special importance. Such sampling can only be done on the basis of a sound knowledge of the basic totals in question. The selection of appropriate basic totals depends, and this must be emphasised at this point, on the actual angle or approach, with the conceptually exact formulation of these total quantities deserving particular attention.

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Close to these problems of representative sampling is the question of comparing and linking different surveys. In principle, comparing the results of different studies requires that there be equality in the representation, collection, precision of observation, and documentation of the various data concerned. Controlling these requirements is a very difficult task and can only be achieved by experts from the fields involved and statisticians working together with necessary care.

RESEARCH WORK BY MEANS OF OFFICIAL STATISTICS

Under the act for implementing road traffic accident statistics, Federal statistics are maintained and updated in the Federal Republic of Germany, on accidents where fatalities, injuries, or damage to property are caused as a result of public highway traffic [2]. The results of these official statistics provide the basis for an evaluation of accidents.

Underlying these statistics are all accidents (as defined above) that the police are notified of. Again, this is not a total survey of all accidents. I shall come back later to the problem of the percentage of unnoticed or undetected accidents.

Without further describing the results of the routine evaluations carried out at regular intervals [3], we should give a brief account of some research studies where these official statistics are used to investigate specific questions. In one project, additional characteristics of belt use are registered in nine select cities of the Federal Republic of Germany, under an agreement with competent police departments. The evaluation of this volume of data, which goes further than the official statistics, is aimed, in particular, at investigating the effect of belt use on personal injuries.

Apart from such extensions of official statistics, several investigations proceed by combining statistical surveys of their own with the official statistics. Two far-reaching studies are worth mentioning here:

- The more-than-average increase in traffic accidents in 1970 raised the question: In what direction is the general trend of these accidents moving? In addition to the data of the official accident statistics, as well as statistics on traffic-related crimes, this extensive study also included data on the development of motor vehicle traffic (also especially on mileage rates). It became apparent that the trend lines of traffic accident events — with measures for improving safety remaining the same in terms of kind and direction — are moving towards a point of culmination or, at least, rising less steeply. The tendency of an increase in relative safety — related to traffic services — requires reinforcing by extraordinary measures if there is to be, in the near future, a constant, absolute decline in the statistics of injuries and deaths [4].

- Furthermore, on behalf of the BASt, the effects of a 100-km/h speed limit on secondary (country) roads were investigated in an extensive research programme from 1970 to 1974. Again, this project combined field investigations with in-depth evaluations of serious road accidents registered by the police, in order to detect and analyse changes in patterns of accidents. These investigations were accompanied by studies of changes in the flow of traffic as well as the attitudes and opinions of the motoring population. Generally, a marked drop emerged in accidents with injuries to persons [5].

LOCAL ACCIDENT INVESTIGATIONS

Since 1972, local accident studies have been performed on behalf of the BASt. After these investigations first started in Heidelberg, they were followed by surveys in Hanover and West Berlin. The investigative methods used ("accident registration by a team of physicians and engineers") are similar to those used by other European and American on-the-spot surveys so that there is no need to describe them. So far, a total of about 1 800 accidents have been collected.

In numerous studies, especially from the Institute of Automotive Engineering in Berlin (Professor Appel), results on individual complexes of subjects have been published based on the data collected. These studies have
attached special importance to the issues of lateral collision and pedestrian accidents. Currently, all accidents registered by each of the three teams are being combined into a centralised evaluation, using one standard form. In addition, the data collected provide the basic material for an international Biomechanics programme of cooperation, where select accidents are reproduced.

FURTHER DATA COLLECTIONS

In addition to the evaluation of official accident statistics and the data collections of local accident studies, the BASf has made the attempt, in conjunction with other agencies that register data on accidents, to expand the data basis for accident research. For example, there was a retrospective investigation of the frequency of accidents where seatbelts had not helped mitigate the consequences of the accident. In that study, accident records were compiled from hospitals, medico-legal institutes, pathological anatomy, and car manufacturers, using records that had been created before January 1, 1976 (the date when belt use became legally binding in the Federal Republic of Germany). Eighty-five accidents involving 106 injuries were reconstructed. In less than 1 percent of all injuries, the consequences of the accident were presumed to be more serious than would have been the case if the person injured, in the same accident, had used no seatbelt [6].

RESEARCH PROJECTS ON METHODOLOGICAL ISSUES

In addition to the projects described above, the BASf has allocated research projects on methodological questions of accident statistics.

In a newly established administrative district with a population of 264,546, a pilot study is being undertaken on the subject of "registration and analysis of the percentage of hidden accidents." Over a period of 8 months, accident data will be collected, irrespective of personal names, by the following agencies:

- Police
- Hospitals
- Garages
- Liability insurance companies
- Select large companies (off-premises accidents)
- Emergency service
- Federal post office (accidents at work)
- Federal rails (accidents at work)

Using the following criteria: place of accident, time of accident, consequences of accident (injuries/seriousness of damage to property), and nature of participation in traffic, the accidents are assigned to the several files of the collecting agencies. Based on this assignment, it is then possible to assess the percentage of accidents (such as, from the "hospitals" unit of survey) that do not return in police records. The results that emerge include:

- Only about 50 percent of all injured persons treated in hospitals because of road accidents are known to the police.
- The probability of collection depends on the following factors: severity of accident, type of accident, place of accident, driving experience, involvement in criminal proceedings, and those of insurance compensation.

In another project, an attempt is made to improve the significance of the official statistics by using advanced statistical methods. Specifically, the following statistical techniques are applied, using biennial data from a federal state:

1. By means of binary-coded causes of accidents, a hierarchical cluster analysis was carried out. The clusters obtained were used to define a new classification variable, "type of cause," which found entrance in the methods described below.

2. According to the techniques devised by L.A. Goodman (see Technometrics, 13, 1971), criteria that were supplied in classes were used to create contingency tables. In a first step, elementary as well as non-elementary hypotheses (such as, interactions of second order) were tested,
reducing the hypothetical range to be tested by meaningful definitions. In the second step, models were determined (in analogy with multiple regression) in accident groups as homogeneous as possible; to allow objective simple interpretation.

3. Also as part of this work, Kullback's information analysis (John Wiley, Information Theory and Statistics, N.Y., 1959) was applied to nominally scaled criteria, establishing the type of damage (fatalities, injuries, property) as dependent variable and, by way of predictors, such as type of accident, type of cause.

4. In applying the contrast group analysis and extending the method of Morgan and Sonquist (JASA, 58, 1963), a multi-dimensional metrical variable was formulated as a dependent criterion (number of deaths, number of injured, amount of damage to property), with nominally scaled independent variables.

The investigations and calculations of the above project are still going on.

In a third statistical and methodical project, the subject of regional sampling units in highway traffic safety research was investigated. The objective was to find out whether it is possible to construct a basic sampling that can be used to carry out investigations irrespective of specific angles or issues. Also, it should be ascertained what kind of information is needed for constructing such basic sampling. The method of multiple-stage representative sampling with a selection of counties or districts as primary units has been proposed as a possible solution. Further, for specific studies, a selection is to be made from these primary units according to criteria to be established. Systematic data collection in these units is necessary [7].

DOCUMENTATION OF ACCIDENT INVESTIGATIONS

On behalf of the BASt as well as the Automotive Engineering Research Association of the Confederation of Car Industry, the Institute of Automotive Engineering at Berlin Technical University compiled, in 1976, a comprehensive documentation of institutions involved in the field of accident research in Europe. According to the objectives of this study, those research establishments dealing with the following were considered more closely:

- Collect data on road accidents themselves
- Register at least the crash and postcrash phases of accidents
- Focus their research activities on the area of accident prevention or mitigation of consequences of accidents by motor vehicles

The research programmes of these institutions were examined for the following criteria:

- Nature and scope of the data collected
- Procedure and technical aids in data collection
- Team composition
- Personal and material cost
- Objectives of evaluation and use of results

In this documentary study, which gives an excellent quick summary, the research teams and the results obtained are coded in relation to specific complexes of problems [8].

OUTLOOK

This description of different activities of the Federal Road Research Institute (BASt) in the field of accident research is to be concluded here with suggestions for further improvement in data collection. In view of the large number of accidents, it seems neither technically nor financially feasible to collect all data on all accidents in a comprehensive data bank system. Instead, future efforts will be aimed at coordinating, in a systematic manner, the existing or planned investigations of events and patterns of accidents. To pursue these objectives, the following approaches would seem most promising:

- Combination of current surveys. Accidents with serious personal injuries are on record both (mainly technically) with the police
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...and (medically) with the hospitals concerned. The BASt will endeavour to combine these two collection systems in a suitable manner in order to achieve new findings especially in the field of biomechanics.

- Uniform data collection. Coordinating the numerous scientific accident investigations requires a large measure of uniform data collection. The BASt is working on these tasks especially in the international bodies of the European Experimental Vehicles Committee (EEVC) and the International Organisation for Standardisation (ISO). In a study group of the Organisation for Economic Cooperation and Development (OECD), a proposal for a selection of so-called basic data has been submitted, to be uniformly collected in a maximum number of investigations [9].

- Mean accident data model. Another topic of current thinking is related to using collection systems on a representative basis in collecting accident data. This approach should fill the existing gap between the official collection of data by the police and scientific accident research on-the-spot, with a problem-oriented variable depth of evaluation. The targets pointed out in the research report of the Highway Safety Research Institute on “A National Accident Sampling System” [10] would seem to be largely consistent with our own thinking. However, it would be premature to go into this aspect here.

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Accident Studies Related to Vehicle Safety

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ABSTRACT

This paper reviews the present state of knowledge in the areas of both primary and secondary safety. It then describes current projects in the United Kingdom that will provide an up-to-date picture of injury patterns and mechanisms of injury to car occupants and the more vulnerable road users. Finally, future research needs are considered: proposals include combined at-the-scene and injury studies concentrating on crash reconstruction, and intermediate level studies on a nationwide basis to assess risks of injury in relation to changes in vehicle design.

INTRODUCTION

Investigations of accidents in depth have been extended in scope in the United Kingdom in recent years to increase the understanding of accident and injury causation, and to explore the potential for remedial action in the area of both primary and secondary safety [1]. This paper summarizes recent work at the Transport and Road Research Laboratory relevant to vehicle safety, review the needs for future research, and outlines proposals to meet the needs.

RECENT RESEARCH

Primary Safety

The circumstances leading up to the occurrence of accidents are so complex that a reliable assessment of accident causation can only be made with detailed knowledge of the many aspects of road environment and vehicle and road users that may have contributed to the accident. To this end, a four-year, multi-disciplinary study, involving attendance at the scene of accidents reported in one locality, was completed in 1974. It established the relative importance of different factors as main contributors to the occurrence of accidents, and the interactions between them. The main conclusions are reported elsewhere [2] and detailed analyses of different aspects are also available.

In the context of vehicle safety, the study puts in perspective the importance of vehicle defects in contributing to accidents [2], [3] and the role of loss of control associated with or without braking [4]. Vehicle defects played a major part in eight per cent of all accidents.

Overall, defective tyres and brakes are featured most frequently, making up one-third each of the contributory defects (see table 1). These defects are of the kind that can develop in a relatively short space of time and arise because of lack of regular maintenance by the owner of the vehicle. An annual check such as required by vehicle regulations clearly provides no guarantee that defects will be detected and remedied as soon as they should be. Only studies made more frequently, possible at weekly intervals, can do this. These conclusions largely relate to cars and light vans, since the numbers of other types of vehicle in the sample are small. Nevertheless, a check on the representativeness of the sample selection in relation to the national accident data bank, suggests that these findings give a valid nationwide perspective of the car safety problem in terms of primary safety.

In the same survey a study was made of loss of control of cars in relation to whether or not braking occurred. There were 2 747 cars involved in 1 832 accidents, made up of:

- Loss of control when braking -- 140 cars in 137 accidents (8 percent)
- Loss of control without braking -- 429 cars in 396 accidents (22 percent)
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Table 1. Vehicle defects and their contribution to accidents in a survey of 2,130 accidents

<table>
<thead>
<tr>
<th>Type of defect</th>
<th>Number</th>
<th>Percent (relative to 2,130 accidents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflation before impact</td>
<td>27</td>
<td>67 2.7</td>
</tr>
<tr>
<td>Illegal tread or combination</td>
<td>18</td>
<td>67 2.7</td>
</tr>
<tr>
<td>Wrong pressure</td>
<td>22</td>
<td>67 2.7</td>
</tr>
<tr>
<td>Brake defects</td>
<td>65</td>
<td>2.7</td>
</tr>
<tr>
<td>Steering defects</td>
<td>7</td>
<td>0.3</td>
</tr>
<tr>
<td>Lights:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defects</td>
<td>4</td>
<td>10 0.4</td>
</tr>
<tr>
<td>Inadequate</td>
<td>6</td>
<td>10 0.4</td>
</tr>
<tr>
<td>Mechanical failure</td>
<td>22</td>
<td>0.9</td>
</tr>
<tr>
<td>Electrical failure</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td>Load defective</td>
<td>10</td>
<td>0.4</td>
</tr>
<tr>
<td>Windscreen defective</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td>Poor visibility</td>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td>Overall poor condition</td>
<td>5</td>
<td>0.2</td>
</tr>
<tr>
<td>Total defects</td>
<td>198</td>
<td></td>
</tr>
<tr>
<td>Total accidents in which defects were main factors</td>
<td>173</td>
<td>8.0</td>
</tr>
</tbody>
</table>

- Braking without loss of control — 1,262 cars in 1,134 accidents (62 percent)

The circumstances under which loss of control occurred were examined. For example, drivers under 25 years had a high involvement in both types of loss of control situation: loss of control when braking was particularly associated with wet roads, and loss of control without braking with single vehicle accidents. Particular examination of loss of control with braking showed that this results almost equally in spinning and drifting (that is, side slipping). Braking was generally well balanced although load and deceleration sensing might be used more to increase the range of stable braking. The use of front and rear anti-locking brakes might be expected to halve the incidence of braking loss of control in cars.

These depth investigations and other studies [5] have also identified the main problems associated with two-wheeled vehicles. The greatest potential for accident reduction lies in the use of anti-locking brakes on motorcycles and improving the conspicuity of all two-wheeled vehicles.

Secondary Safety

Over the decade leading up to 1974, the Transport and Road Research Laboratory traffic medicine team carried out a series of studies of patterns of injuries to vehicle occupants and pedestrians, and mechanisms of injury related to different aspects of vehicle design and use [6, 7]. In total, nearly 3,000 persons were interviewed and examined in hospital. These studies were invaluable in identifying some of the major problem areas, and led to recommendations for changes in vehicle design to alleviate injury severity. They also provided a basis for experimental work on limits of human tolerance from examination of case studies. Selection of injuries for study was not, however, sufficiently controlled to enable extrapolation of patterns and severities of injury to give a national representation of the problem.

To extend the scope of this work, a 2-year project was launched in July 1974 to provide a larger and more representative sample. It has covered injuries to all road traffic accident casualties seen at one hospital (whether detained or not), backed by follow-up studies through police reports, vehicle examinations, and questionnaires of all other persons and vehicles involved in the accidents concerned. The study, which covered over 1,100 accidents involving vehicle occupant casualties and a further 1,700 accidents involving injuries to unprotected road users, will provide an up-to-date picture of injury patterns related to vehicle features. Specific analyses of patterns and severity of injury, and mechanisms by which they occur will be addressed to:

- Restrained and unrestrained vehicle occupants
- Types of seatbelt and types of windscreen (for restrained occupants)
- Type of impact (frontal or side)
- Intrusion
- Vulnerability of unprotected road users (non-vehicle-occupants)

In particular, it is hoped to gain a more comprehensive assessment of injuries to restrained vehicle occupants than has been
possible in earlier years when samples studied were considerably smaller and seatbelt use much lower than it is today. Further, the inclusion of non-injured vehicle occupants in the survey will enable a better assessment to be made of the effectiveness of belts in reducing the severity and occurrence of injury. Some preliminary analyses of the safety of unprotected road users have already been reported [8, 9].

Because the selection of the sample has been closely controlled, it will be possible, by suitable weighting of data, to extrapolate to an overall perspective view of the relative importance of different factors in terms of secondary safety.

FUTURE NEEDS

It is widely recognised that the priority needs for future research lie in the area of secondary safety, with the particular aim of furthering knowledge on human tolerance levels. To this end it is necessary to relate crash severity to the nature and severity of injury, an essential preliminary to which is the development of satisfactory measures for both crash severity and injury severity. The Abbreviated Injury Scale (AIS) [10] provides a suitable basis for the latter, but the former is still open to dispute and uncertainty.

A second requirement of high priority is the ability to assess injury risks in relation to changes in vehicle design and usage as vehicle safety features and legislation are introduced. On the one hand, national accident data collected on a routine basis do not contain adequate detail, either of vehicle damage or injury, for this purpose. On the other, depth investigations have hitherto been on too small a scale numerically to provide statistically significant results. There is need to develop a methodology that will provide sufficient detail in sufficient numbers to enable risk assessment to be made.

Primary safety should not be overlooked in consideration of future research needs, but the priorities lie in studies of vehicle use — driver impairment and fitness to drive — rather than vehicle design.

PROPOSALS FOR RESEARCH

To meet future needs for vehicle safety research, the Transport and Road Research Laboratory is proposing two major accident investigation projects: a combined at-the-scene and injury study concentrating on crash reconstruction and driver impairment; and an intermediate level crash-injury study on a nationwide basis to assess risks of injury in relation to changes in vehicle design and use.

At-the-Scene Investigations

A two-year project starting in late 1976 will be based on accidents reported to the police at the time of the accident over an area of about 300 km² in southeast England (in the vicinity of the Transport and Road Research Laboratory). It will involve attendance at the scene by TRRL investigators to observe the circumstances of the accident, follow-up examination of vehicle damage, interviews with persons involved, and medical assessment of injuries incurred. At the scene, effort will be concentrated on details necessary for crash reconstructions, particularly with application of the Calspan CRASH programme to estimate impact velocity and Δv in mind. Observations will also include body contact points, positions of detached major components (such as screen frames) and seatbelt use. Past experience has shown that interviews will provide valuable information on the pre-crash phase — for example, maneuvers prior to the accident, driver impairment, skill, and experience. Medical examinations and reports will give detailed assessment of the nature and severity of injury to the AIS scale. Thus the combination of attendance at the scene and the subsequent follow-up procedures provides an opportunity to gain a comprehensive appraisal of accidents throughout the pre-crash, crash, and post-crash phases. It is anticipated that the study will cover about 1 000 accidents in the 2 years.

Crash-Injury Studies: Intermediate Level Investigations (CISILI)

The aim of CISILI is to acquire vehicle-injury related statistics in sufficient quantity to provide answers over short (3-month) periods on the effects of changes in legisla-
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tion, design, driving habits, and component types toward increased secondary safety. By coordinating data on a nationwide basis it will be possible to concentrate data on specific problems related to whatever is the current topic of interest, for example, a particular type or model of vehicle, type of impact, or design feature.

The project proposal aims to achieve 5,000 detailed accident reports per year, covering at least five different areas of the country. As preliminary to setting up this system, a pilot study will be carried out in one area to establish methodology. It is proposed to make use of the expertise of local police and government vehicle engineers to provide information on the circumstances of each accident and features of each vehicle, that will then be matched through appropriate medical authorities with hospital records of injuries. Data collected will be based on procedures used in past crash-injury studies, though the amount of detail will not be as great. The function of the TRRL team will be to act as coordinators and analyse aggregated data.

ACKNOWLEDGMENTS

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.

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SECTION 4: TECHNICAL SEMINARS


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The National Crash Severity Study

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ABSTRACT

The Office of Statistics and Analysis (OSA), National Highway Traffic Safety Administration (NHTSA), has embarked on a 2-year National Crash Severity Study (NCSS). NCSS is the bridge between the Restraint Systems Evaluation Project, conducted by OSA during 1974-75, and the National Accident Sampling System, scheduled for full implementation in 1980.

The primary objective of NCSS is to provide a nationally representative data base to determine statistical relationships between crash conditions and injury severity and to estimate the distribution of crash conditions among the nation’s automobile towaway accidents. Special attention will be devoted to estimating the distribution of delta-V (ΔV, velocity change during impact) and the extent to which ΔV can be used to predict injury severity. NCSS will also describe, for each injury with an Abbreviated Injury Scale (AIS) rating equal to or greater than 2 (AIS ≥ 2 includes moderate or more severe injuries), the details of the specific injury, the contact point causing it, the medical treatment required, and the days of disability and workdays lost. These data will be used to support major new analyses on injury causation and injury costs and consequences.

The NCSS data are “nationally representative” in the sense that they are collected in a purposive sample of eight areas. The NCSS areas have almost the same distribution of central city, suburban, small-town, and rural population as the nation, and there is at least one NCSS area in each of the nation’s four demographic regions. Within each NCSS area, accidents are chosen for investigation by strict adherence to a stratified probability sampling scheme. The NCSS sample will eventually contain 25,000 occupants, including approximately 600 fatalities and 1,500 severe (AIS-3,4,5) injuries. This sample will be representative of approximately 100,000 occupants of automobiles towed from accidents in the eight areas.

The NCSS data are collected by seven multidisciplinary accident investigation teams. In each accident, they will obtain only those data elements needed for NCSS analyses. These include measurements of damage and post-crash trajectory required for calculation of ΔV by computer reconstruction of the accident.

A quality control contractor will be responsible for checking that all teams interpret data elements in a consistent manner, that teams adhere strictly to the sampling protocol, and that data completeness and accuracy are maximized.

INTRODUCTION

A primary objective of NCSS is to collect representative accident data that will contribute to the evaluation of various proposed measures of accident severity and their relationship to injury. As used in this study, collision severity refers to the forces applied to a vehicle in a crash. Examples of proposed measures of severity are velocity change during the collision phase (ΔV), relative collis-
sion velocity (velocity of vehicle relative to
the object struck at time of impact), and
absorbed energy (energy absorbed by the
work of crushing the vehicle structure). It is
anticipated that the analytical result of this
objective will be expressed by cumulative
distribution functions of crash severity and
curves showing injury risk as a function of

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MOTIVATION FOR NCSS

The reader, at this point, may be asking
himself what motivated the NHTSA to
choose as particular analytic objectives for
NCSS the determination of (1) the cumula-
tive distribution of accident severity (princi-
pally $\Delta V$)\(^1\) and its relationship to injury
severity, (2) specific interior contact points
and other crash conditions besides $\Delta V$ that
influence injury, and (3) the immediate,
delayed, and long-term losses and conse-
quences resulting from crash injury.

The motivation can be better understood
if, first, one reviews the motor vehicles
safety standard evaluation process practiced
in the United States and, later, the body of
recent research that suggests ways of
improving this process. Evaluation of stand-
ards requires the evaluation of countermea-
ures designed to satisfy the standard. There
are two types of countermeasures to be
evaluated, existing countermeasures and pro-
posed ones.

Evaluation of existing crashworthiness
countermeasures by means of statistical anal-
ysis of accident data consists of collecting
samples of crashes involving occupants pro-
tected and unprotected by the countermea-
ure. If both samples are “alike” in all
respects except for the countermeasure, and
if the samples are nationally representative,
the effectiveness of the countermeasure is
estimated by the simple difference of the
injury rates of the samples. If the samples
are not “alike” or “nationally representa-
tive,” it is nevertheless often possible to
adjust the results (that is, poststratification
of the cases with differential weighting) so
that they do become alike and nationally
representative. The evaluation process in the
United States most often employs the vector

\(^1\) A discussion of $\Delta V$ and its use as a measure of

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variable $\Delta V$ (the scalar magnitude of $\Delta V$ and the direction or Principal Direction of Force) as the variable for testing whether the samples are “alike” and for “adjusting” them if they are not.

The technique that is applied to proposed crashworthiness standards is more complicated. The technique may be unique in some ways to each particular application; nevertheless, each utilizes to a greater or lesser degree, the combination of laboratory and field data listed below:

- $\Delta V$ and Principal Direction of Force (PDOF) and their joint distribution on the nation’s roadways
- The AIS
- The barrier test collision
- Anthropomorphic dummies that ride in the test crash vehicles, with deceleration levels measured on various parts of the dummy during the crash
- A correspondence of deceleration levels to AIS, based on crash tests with cadavers
- A correspondence of AIS to societal cost

The procedure consists of designing a prototype device, running barrier crash tests at appropriate values of $\Delta V$ and PDOF using dummies protected by the device, and identical tests with unprotected dummies, taking the appropriate deceleration readings and translating them into AIS. At this point, one has predicted AIS as a function of $\Delta V$ and PDOF for protected and unprotected occupants (one has determined “detailed countermeasure effectiveness” and the “relationship of accident severity to injury severity”). Then, for each value of PDOF and $\Delta V$, the predicted AIS is multiplied by the number of crashes occurring nationally at that PDOF and $\Delta V$ and the sum (integral) is taken over all values of PDOF and $\Delta V$. Thus, one estimates the total number of injuries, at each level of AIS, that would occur nationally in the course of a year, if all occupants were protected by the device and if they were not protected. The reduction in the number of injuries, at each AIS level provided by the device, is multiplied by the average societal cost of that AIS, and the sum is taken over all AIS levels, thereby estimating the total societal benefit.

Two factors are of great importance in this technique. First, it is necessary to determine the equivalent barrier test speed for any crash occurring in the field. Second, for the technique to be meaningful in the context of the nationwide highway environment, the nationwide distribution of equivalent barrier test speeds must be known.

Elaborate use of a technique similar to that described above was made by Minicars in their systems-analytic model supporting their Research Safety Vehicle Project [3], and by the John Z. DeLorean Corporation in their air bag evaluation [4]. In the latter two studies, severity was measured by a $\Delta V$ obtained from collision mechanics rather than an equivalent barrier test speed.

In all of these studies, however, the national joint distribution of PDOF and $\Delta V$ was estimated from the Multidisciplinary Accident Investigation data file. This file, collected primarily before the 55-mi/h speed limit was imposed, is lacking in sample size, and is believed to be biased due to convenience sampling and the lack of a well-defined sampling frame. It is little wonder, then, that the accident research community is interested in obtaining more suitable data for estimating the national joint distribution of PDOF and $\Delta V$, the “distribution of accident severity.”

The strength of the procedure hinges on several key assumptions:

- A barrier test crash of a given PDOF and speed can be equated to all highway crashes of the same PDOF and equivalent $\Delta V$ in the sense that both result in the same occupant deceleration levels.
- Injury severity (AIS) is a reasonably simple monotone-increasing function of the occupant deceleration level and depends rather little on other variables, such as occupant characteristics or the specific contact point/injury mechanism.
- The deceleration levels producing cadaver

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2Frontal crashes for a countermeasure concerned with protection in frontal impact.

3Head deceleration for a countermeasure designed to protect the head.
injuries are about the same as those for live occupants.

- The mean cost of these injuries of a given AIS level prevented by the standard roughly equals the mean cost of all injuries of that AIS level.

In recent years, a body of literature has developed that questions the foregoing assumptions. The literature falls into two categories: studies based primarily on field data, and clinical analyses of laboratory data.

An important field data analysis [5] that questioned assumption (1) was presented by the West Germans at the 1974 ESV conference. It clearly showed that the preponderant majority of highway crashes do not outwardly resemble barrier crashes (that is, highway crashes usually produce triangular damage located near the corners). The study did not prove that the lack of outward resemblance led to differences in deceleration levels, countermeasure effectiveness, and so forth; nevertheless, it surely stimulated more detailed research. At the same ESV Conference [6] and in a subsequent study [7], the French presented evidence that highway crashes tended to produce lower vehicle deceleration and less severe occupant injury than flat barrier crashes of the same PDOF and $\Delta V$.

Another approach based on field data consisted of determining the overall effectiveness of a device in highway accidents and comparing the result to predictions based on laboratory data. A significant discrepancy would indicate the existence of errors in one or more of the assumptions or in the PDOF-$\Delta V$ distributions used but, unfortunately, it would not pinpoint the source of error. A good example of this genre was NHTSA's Restraint Systems Evaluation Project [8], which suggested that 3-point belt effectiveness in reduction of significant injury (moderate or greater) was 50-60 percent—that is, significantly higher than had been predicted from laboratory data. It also appeared to suggest that belt effectiveness was rather invariant over a wide range of accident severity, whereas the laboratory studies always found that effectiveness decreased as severity increased. Several studies of the Energy Absorbing Column (EAC) [9, 10] suggested that its effectiveness was significantly lower than had been predicted from laboratory data.

The clinical analyses of laboratory data generally attacked assumptions (2) and (3). They presented individual case histories of cadavers and live occupants whose experience was clearly inconsistent with those assumptions. The shortcoming of the clinical approach is that it rarely permits statistical inference to the general population: the assumptions may fail in individual cases but may still, on the average, do a good job of characterizing the population. A clear example of this genre was the study [11] of a single person who dives into a bathtub. Thanks to his robust constitution, preimpact muscle tension, and the nature of the contact point, he sustains an incredible deceleration level without injury. Two studies [12, 13], comparing 3-point belted cadavers in sled tests to 3-point belted live occupants in highway crashes of the same PDOF and $\Delta V$, not only claimed that the AIS of the live occupants was lower than the cadavers but also that the contact point/injury mechanisms were different: the cadavers suffered chest and abdominal injury from contacting the belt whereas the live occupants' most severe injury was often a fracture of an extremity due to slapping the instrument panel.

Such research has stimulated interest in gaining better understanding of crash phenomena through statistical analysis of field accident data. The National Crash Severity Study will try to collect a large nationally representative sample (the lack of which was a handicap in the clinical case studies) containing the appropriate data elements: a consistent estimate of $\Delta V$ based on computerized accident reconstruction and an assessment of the individual contact point/injury mechanisms (the lack of which was a handicap in the field data studies mentioned above). The base-line relationship of AIS to $\Delta V$ and PDOF for unrestrained occupants will be obtained directly from NCSS field data, rather than from roundabout methods such as cadaver tests or inference from the Multidisciplinary file. Moreover, it
will be possible to assess by statistical means the strength of the relationship and compare it to the strength of crash conditions other than $\Delta V$ and PDOF that influence injury severity. Those crash conditions may eventually be simulated by laboratory tests. By classifying the specific contact point/injury mechanisms on the NCSS sample, one will obtain the data base for making generalizations that could not be made from the clinical case studies. The data base will be useful for refining the choice of measurements to be made on dummies in various crash modes.

The last NCSS objective (analyzing consequences of crash injury) was motivated by doubts about assumption (4) (namely, the mean cost of injuries of a given AIS prevented by the standard equals the mean cost of all injuries of that AIS). The task force planning the RSEP [2, p. 328] noted the wide variance of costs within each AIS level (for example, momentary unconsciousness and retinal detachment are both AIS 2) and expressed concern that assumption (4) would lead to an overstatement of societal benefits if the device tended to mitigate an injury such as momentary unconsciousness without affecting one such as retinal detachment. The RSEP task force, therefore, directed an analysis of this subject [8], which, unfortunately, was not successful because the data were unsuitable: only the specific injury type was collected by RSEP investigators; the assignment of a cost to each occupant was made after-the-fact by collecting insurance data for various injury types.

NCSS will improve on RSEP by collecting the occupant’s actual injury consequences of each occupant. Injury consequence data collection is also motivated by recent NHTSA thinking that many aspects of injury consequences, particularly long-term disability, are inadequately documented in existing data files.

**ANALYSES BASED ON NCSS DATA**

A primary objective of NCSS is to determine the cumulative distribution function of $\Delta V$ for towaway-involved occupants and the injury rate (that is, the proportion of occupants having injury greater than or equal to a specified AIS level) as a function of $\Delta V$. Both functions, it is believed, have S-shaped graphs, as shown in figure 1.

The reader is, no doubt, familiar with the S-shaped curves. The reason that the cumulative distribution curves are S-shaped is that the events rarely occur below some minimal speed. Crashes of extreme severity are also rare. There is a middle range where most events occur. As a result the cumulative distribution climbs steeply within that range.

The reason that the $\Delta V$-AIS curves are S-shaped is somewhat more complicated. Suppose that one could run the same collision over and over again with all factor identical each time except $\Delta V$ (in the laboratory this can actually be done—for example, flat barrier crashes with identical vehicles and dummies). Under these ideal conditions one would find a specific value of $\Delta V$, say $\Delta V_o$, below which none of the occupants are injured and above which all are injured. For this family of collisions, the $\Delta V$-AIS curve would be a step function: equal to 0 below $\Delta V_o$ and to 100 percent above. In any real-world family of collisions, however, there are inevitably some factors other than $\Delta V$ that vary from case to case—some of the occupants may have been a little more robust than average and thus remained uninjured at speeds slightly above $\Delta V_o$, while others were more delicate and were injured below $\Delta V_o$. Thus the injury rate is non-zero to the left of $\Delta V_o$ and less than one to the right. The closer one gets to $\Delta V_o$, the further the injury rates deviate from the ideal ones. These phenomena produce an S-shape of the curve. One can see that the shape of the curve says something important about the strength of the relationship between $\Delta V$ and injury: the steeper the curve (that is, closer to a step function) the weaker the influence of confounding factors and the stronger the validity of $\Delta V$ as a predictor of injury.

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4 Even under these conditions it might not be true—for example, rollovers, in which a car landing on its top and injuring the occupant could, with more speed, have rolled once more and landed on its wheels, possibly not injuring the occupant.
One can also see that two parameters are especially crucial in describing the ΔV-AIS curves: (1) How steep is the curve? That is, how strong is the relationship of ΔV and injury? and (2) At what ΔV is the steep part of the curve centered? That is, what would ΔV₀ be if one could remove the confounding factors? These parameters will be discussed further.

For a large sample of data (for example, the entire NCSS file of about 24 000 occupants), the plotting of the cumulative distribution curve is an entirely straightforward process: the data points may be plotted directly and the curve connecting them will appear smooth to the naked eye. The plotting of the ΔV-injury curve is also easy: the ΔV axis is subdivided into enough class intervals to yield a curve that appears to be smooth. This technique is illustrated in figure 2.

The objective, however, is not merely to produce the curves for the entire towaway

\[ \text{Cumulative distribution function of } \Delta V \]

\[ \text{Injury severity as a function of } \Delta V \]

Figure 1. The graphs are to be interpreted as follows: Point \((X_1, Y_1)\) on the first curve implies that \(Y_1\) percent of all towaway crashes have \(\Delta V \leq X_1\). Point \((X_2, Y_2)\) on the second curve implies that of all the occupants involved in crashes with \(\Delta V = X_2\), \(Y_2\) percent of them had AIS \(\geq 2\).
population but also for numerous subsets. Cumulative distributions and ΔV-AIS curves are needed for various values of

- AIS
- Crash mode
- Principal direction of force
- Region of car impacted
- Belt use
- Vehicle size
- Occupant seat position
- Occupant age
- Specific injury type or body region
- Specific contact point/injury mechanism

Unfortunately, directly plotted cumulative distribution and ΔV-AIS curves for rather small subsets of the population would not appear smooth to the naked eye. Indeed, ΔV-AIS curves obtained by finding the injury rates in each class interval would not even be monotone, due to sampling error. A smoothing technique, whose precision can be quantified by statistical means, is needed. Because the curves are known to be S-shaped rather than straight lines, ordinary linear regression is unacceptable for this purpose. A number of nonlinear regression models, however, appear to be more suitable [14; 15, pp. 357-371]. The logit model may be especially useful: it always produces S-shaped curves and has often been used to predict the probability of an outcome (such as the percentage of occupants having AIS ≥2) as a function of another parameter (such as ΔV). In particular, the logit model has been used in medical research to describe the reaction of victims (that is, the percentage of persons killed) as a function of the dosage of a poison. It would be quite consistent, in this context, to regard ΔV as a "poison" that can be administered in various "dosages."

The logit model, being a form of nonlinear regression, leads to the determination of two coefficients that define the S-shaped curve best fitting the data. The first coefficient determines the steepness of the curve and the second, the location of the center of the steep part of the curve. Thus, the regression coefficients of the logit model express mathematically the parameters that had been mentioned in the intuitive discussion of the ΔV-AIS relationship.

The objectives of NCSS, however, are not merely to plot the curves for a few large subsets of the data, but rather for many small subsets based on multiple combinations of the variables listed above, such as what is the relationship of ΔV to AIS for unrestrained, 16- to 25-year-old drivers of subcompact cars struck in the left door with 9:00 direction of force? This involves the determination of a probability (of injury) as a function of several variables, some of which are continuous (ΔV) and others discrete (seat position, restraint use, and crash mode). The logit model has been extended to cover precisely such situations (that is, multiple independent variables, mixed discrete, and continuous) and may be satisfactory.

There are some additional complexities involved with the NCSS data that will likely require modifications in the regression model:

1. The key independent variable, ΔV, is not measured exactly but is only an estimate based on computer reconstruction. Thus, the strength of the relationship between AIS and the estimated ΔV actually understates the one that would have been observed if true ΔV had been available. It is known that a correction factor for the independent variable can be used in ordinary linear regression, but can a similar factor be introduced here?

2. The ordinary logit model operates with data based on a simple random sample. The NCSS data, on the other hand, will be selected by stratified random sampling. Thus, the regression must be carried out with differential case weighting.

3. The ordinary logit model produces a skew-symmetric curve—that is, the upper tail has the same shape as the lower tail. In NCSS, this would mean that the injury rate at high ΔV approaches 100

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5 See "The Sampling Plan."
percent at the same rate that it approaches 0 percent at low ΔV. There is no intuitive reason why this should be true. Thus, it may be necessary to modify the model so as to allow the tails to be of different shapes.

(4) Confidence bounds for the curves are needed. Unless such confidence bounds are presented, it is impossible to assess the risk of error in any statistical inferences (such as cost/benefit assessments) based on the curves.

The authors would like to challenge the statistical research community to find the appropriate mathematical model and its concomitant software to operate with the NCSS data to produce the desired curves.

The second major objective of NCSS is to study crash conditions other than ΔV and Principal Direction of Planar Force (PDOF) that influence injury severity. Ideally, one would like to predict the injury rate as a function (F) of ΔV, PDOF and other crash conditions:

\[ AIS = F(ΔV, PDOF, X_1, \ldots, X_n) \]

F is a rather complicated function, since ΔV, PDOF and X_1, \ldots, X_n interact with one another and with AIS—for example, the ΔV needed to produce a fatality when PDOF = 6:00 (rear-end impact) is significantly higher than the ΔV needed when PDOF = 9:00 (left-side impact).

The methodology described above ("Motivation for NCSS") essentially suggests that no X_1, \ldots, X_n need be considered—that is, AIS = F(ΔV, PDOF) yields reasonably accurate predictions. The statistical and clinical literature discussed in that section, though, mentions a number of other crash conditions X_1, \ldots, X_n that may interact significantly with ΔV, PDOF, and AIS and, in that case, would need to be added to the model F:

- The specific contact point/injury mechanism couple. This couple is of vital importance, since some couples may produce significant injury at lower ΔV than others.
- The role of intrusion in producing injury. "Intrusion" refers not only to external objects that enter the passenger compartment but also to injury-producing reduction of the passenger compartment. In particular, there is some evidence that intrusion may occur at fairly low ΔV in frontal crashes with substantial offset.
- The role of ejection in producing injury and the likelihood of ejection as a function of other crash conditions. In particular, it is thought that the likelihood of ejection has a relatively weak relationship to ΔV.
- Variation in g-forces for a fixed ΔV. In particular, offset frontal collisions, which are especially common on the highway, have lower g-forces than fixed barrier crashes of the same ΔV. This may result in a lower injury, especially for restrained occupants.
- The role of vertical forces in nonrollover collisions, especially insofar as they affect contact point/injury mechanism couples. (These are especially important in the case of the energy-absorbing steering column and the airbag because they may cause the driver to strike the device from an angle other than the one for which it was designed.) Vertical forces are insignificant in flat barrier tests but quite common on the highway: in vehicle-to-vehicle collisions they can result from differential bumper height, especially when there was preimpact braking; in single-vehicle collisions they can result from off-road excursions on uneven surfaces.
- The role of vehicle rotation yawing in nonrollover impact, especially insofar as it affects contact point/injury mechanism couples. The vehicle interior spins while the occupant moves straight ahead, resulting in different contact points from a collision without rotation but with the same direction of force. Rotation is likely to occur in offset collisions, which are common on the highway.
- The specific part of the car struck. This factor may be more important than the direction of force. For instance, a 9:00 impact into the driver's door with ΔV = 30 is much more severe than a similar impact into the left-rear quarter panel.
- The nature of the object struck. This factor
may influence g-forces, rotation, intrusion, and ejection.

- Variations of occupant tolerance to impact. These variations may substantially weaken the \( \Delta V \)-AIS relationship. Occupant age has a strong relationship with tolerance.

- Occupant preimpact actions. Such actions as bracing or change of posture may affect both contact points and tolerance to impact. This factor was singled out in the clinical studies comparing cadaver and live occupant injury.

Ideally, one would like to consider the 10 conditions mentioned above as \( X_1, \ldots, X_{10} \), employ a statistical technique to find an \( F \) that predicts AIS from \( \Delta V \), PDOF, and \( X_1, \ldots, X_{10} \), and then simplify \( F \) by eliminating independent variables that do not significantly improve the prediction. From such a procedure one would also learn what portion of the variance in AIS is explained by \( \Delta V \) and PDOF, what portion by the other variables, and what portion is yet to be explained.

In fact, there is little hope that such modeling could be carried out. The list of independent variables is a potpourri of continuous, ordinal, and categorical variables with highly nonlinear relationships to one another. This, alone, would make the statistical analysis difficult. A second problem is the extremely high degree of interaction among the variables. For instance, high \( \Delta V \) is associated with high g-forces; PDOF between 8:00 and 10:00 is associated with left-side impacts, and so forth. Moreover, some of the variables stand in an intuitively clear cause-and-effect relationship to one another: rotation and vertical forces cause changes in contact points; specific parts of the car struck lead to ejection and intrusion. Thus, any statistical technique would have to estimate the strength of the interactions as well as the main effects. Under such circumstances, it becomes a matter of philosophy to separate the effects of one variable from another. A third, more serious problem is that many of the variables have not been rigorously defined or have so many categories that they are unsuitable for multivariate analysis.

It seems more realistic, then, to attempt to relate by statistical means AIS to \( \Delta V \), PDOF, and just a few of the other variables. This would permit at least a partial assessment of the strength of the relationship between \( \Delta V \) and AIS.

For many of the other variables, it will only be possible to give simple tables of their joint distribution with AIS and \( \Delta V \) and a listing of individual case histories. Even if no more were to be accomplished, NCSS would still represent substantial progress. For instance, NCSS would be the first nationally representative file of contact point/injury mechanism couples and would thereby make it possible to identify, for the first time with such inference, the relative importance of various interior components in causing injury. Special attention will be devoted to isolating the injury-producing factors in cases of low \( \Delta V \) and high AIS, and the relative incidence of such cases will be determined.

The reader may ask what techniques will be used to obtain some of the variables listed above. \( \Delta V \) will be obtained by computer reconstruction of the accident, as will be discussed ("Types of Data Needed"). The specific contact point/injury mechanism couple (including sources of intrusion or routes of ejection) will be determined, for AIS \( \geq 2 \) injuries, by the vehicle inspection and occupant injury. By "injury mechanism" is meant the method by which the contact produces the injury, for example, bruising by direct impact, crushing by compartment reduction, laceration by flying glass, and neck fracture by hyperextension resulting from chest contact.

A rough estimate for average g-forces (or pulse width) and extent of rotation can perhaps be developed from the same computer program that calculates \( \Delta V \), since that program computes speed and direction at impact, speed and direction at separation, and crush distance.

Vertical forces will probably be described only in gross terms. A Society of Automot-
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tive Engineers (SAE) subcommittee, charged with improving the Collision Deformation Classification (CDC), is currently developing codes to describe vertical forces by using the first two columns of the CDC.

Data on occupant tolerance to impact will be limited to determination of occupant age, sex, height, and weight. The occupant interview will contain questions on such pre-impact actions as bracing.

The third major objective of NCSS is to study the consequences of injury. There are several techniques for describing these. The societal cost approach attempts to take various different losses due to injury and assign a money value to each, thereby obtaining a single dollar figure to express the severity of the injury. "Societal cost" is generally considered to include direct hospital and medical costs, lost wages, cost of rehabilitation, legal costs, and insurance administration. The societal cost approach has been criticized, on the one hand, because some of the items (lost wages) need not constitute a genuine loss to society and, on the other, because it excludes some losses that cannot easily be assessed a money value (social disabilities not involving financial loss, increased susceptibility to other diseases due to crash trauma). The objective of NCSS is not to resolve these philosophical disagreements, but rather to collect better data on the items that can be measured. They are:

- Number of days in the hospital
- Number of outpatient doctor visits
- Work days lost
- Days of bed rest
- Days of social activity restriction

The data elements will be obtained from occupant interviews and hospital records.

Similar data have been collected for some years by the National Center for Health Statistics in their home interview surveys. NCSS data will be unique, however, in that they are based on a representative file of automobile accidents taken from a well-defined sampling frame. (The difficulty with data files not collected by NHTSA is that the accident thresholds used therein are not directly comparable to the ones used by NHTSA. Thus, it is misleading to use, say, the "average" injury cost developed from those files to describe the "average" injury as defined by NHTSA.) Furthermore, the NCSS data will give the details of the accident that produced the injury consequences, as well as just the injury consequences themselves. The NCSS data will make possible the tabulation of injury consequences as a function of crash mode, $\Delta V$, and so forth. The "middleman" of AIS is thereby eliminated—rather than obtaining AIS as a function of $\Delta V$ and hospital days as a function of AIS, one would obtain hospital days directly as a function of $\Delta V$.

The NCSS data will make possible the examination of potential biases in the NHTSA technique of assigning a "mean cost" to each AIS level (see "Motivation for NCSS"). The five direct consequences measured in NCSS will be crosstabulated against overall occupant AIS, thereby obtaining the mean and variance of injury consequences at each AIS level. Specific types of injuries whose consequences fall either far above or far below the mean of their AIS category will be singled out and considered for reclassification in a higher or lower AIS category, respectively. The correlation of injury consequences with occupant age and sex, for specific injury types, will be determined. But the analysis that will shed the most light on potential bias in the NHTSA technique is the effectiveness of belts in reducing "societal cost" of nonfatal injury, which will first be found by the traditional technique (find effectiveness at each AIS level and multiply by the mean cost of each AIS and frequency of each AIS). Then, the effectiveness of belts will be found by looking at the actual reduction in hospital days, doctor visits, and so forth, for belt users. A significant difference would probably indicate a bias created by using the traditional technique.

The NCSS field data, as currently envisioned, would be collected within a month of the occurrence of the accident. Unfortunately, this does not permit time for collecting data on some injury consequences about which the least is known: rehabilitation, delayed symptoms and disabilities, increased susceptibility to other diseases, and the long-term effect on social and family...
life. Therefore, NHTSA is contemplating a reinterview program for a sample of NCSS occupants who had sustained significant injuries. The interviews would be conducted 1 year after the accident and would be concerned with some of the consequences mentioned above.

THE NCSS SAMPLING PLAN

The NCSS data will be nationally representative in that they will be a purposive sample of the nation’s automobile towaway accidents. By “purposive” we mean that the areas in which NCSS investigators will sample accidents comprise a variety of geographic locales and degrees of urbanization similar to the United States. “Purposive” also means that the areas were selected by the NCSS staff on the basis of their judgment that the composite area would be nationally representative and that data collection contractors could readily be hired in those areas; the areas, however, were not picked by a probability (random) sampling scheme. The NCSS area sample thus represents an intermediate point between the Restraint Systems Evaluation Project, conducted in 1974-75, which was largely a convenience area sample with some purposive aspects, and the National Accident Sampling System, which will begin data collection in 1977 and will be a probability sample of the nation’s accidents.

NCSS will be conducted in the eight areas shown in table 1. The areas had, in 1970, a composite population of roughly 3,500,000 or 1/60 of the nation’s population [16]. About 700,000 resided in central cities of Standard Metropolitan Statistical Areas (SMSA’s) containing more than 1,000,000 persons6 (Areas 4 and 8). Another 700,000 resided in suburbs of SMSA’s containing more than 1,000,000 (Area 1), and 700,000 resided in SMSA’s containing more than 250,000 and fewer than 1,000,000 persons (Area 6). The remaining 1,400,000 lived in non-SMSA areas or in SMSA’s containing fewer than 250,000 persons (Areas 2, 3, 5, and 7). About half of this last group lived in rural areas.

Thus, the urbanization distribution of the NCSS sample is close to the urbanization distribution of the United States in 1970. Because crash severity (the most important data element in NCSS) is thought to have high negative correlation with population density, it is important that the NCSS areas be representative of urbanization.

About 700,000 of the residents of the NCSS areas resided in the Northeastern States (Area 1); about 900,000 in the North Central States (Areas 2 and 3); about 1,500,000 in the Southern States (Areas 4-7); and about 400,000 in the Western States (Area 8). Thus, the geographical distribution of NCSS is also moderately close to the national distribution. It is not clear, though, whether this will enhance national representativeness, except in a cosmetic fashion.

In contrast to the selection of the NCSS areas, which was done by purposive sampling, the selection of individual accidents from the sampling frame within each area will be done by strict probability sampling.

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6That is, the entire SMSA (central city + suburbs) was larger than 1,000,000 in the 1970 census.

<table>
<thead>
<tr>
<th>Areas</th>
<th>Contractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Niagara and Erie Cos. (less Buffalo), New York</td>
<td>Calspan Corp.</td>
</tr>
<tr>
<td>2. Washtenaw and Lenawee Cos., Michigan</td>
<td>Highway Safety Research Institute</td>
</tr>
<tr>
<td>3. Southwest Indiana (16 cos.)</td>
<td>University of Indiana</td>
</tr>
<tr>
<td>4. Miami, Florida</td>
<td>University of Miami</td>
</tr>
<tr>
<td>5. Lexington, Kentucky and environs (7 cos.)</td>
<td>University of Kentucky</td>
</tr>
<tr>
<td>6. Bexar and Guadalupe Cos., San Antonio, Texas</td>
<td>Southwest Research Institute</td>
</tr>
<tr>
<td>7. Rural South Texas (13 cos.)</td>
<td>Southwest Research Institute</td>
</tr>
<tr>
<td>8. Central Los Angeles, California</td>
<td>Ultrasystems</td>
</tr>
</tbody>
</table>
Probability sampling within areas has already been conducted successfully by five of the seven NCSS contractors during the Restraint Systems Evaluation Project [2] and there is good reason to expect it will succeed in NCSS. Furthermore, NHTSA has found in its past studies that whenever non-probability (convenience, purposive, or quota) sampling techniques were advised for individual accidents, the investigators gravitated toward selecting accidents that were “more interesting” or the data that were “more easily obtained.” Needless to say, the more severe accidents were usually more interesting and provided larger quantities of less perishable data. Thus, files based on nonprobability sampling techniques have tended to be seriously biased toward higher crash severity. Nothing could be more disastrous than this for a study attempting to find the national distribution of crash severity!

The sampling frame for NCSS will be all police-reported accidents occurring in the nine areas between October 1, 1976, and December 31, 1977, in which at least one passenger car was towed from the scene due to accident damage. Any passenger car involved in such an accident and towed from the scene is a case vehicle. (Cars involved but not towed are not case vehicles, nor are trucks, even when towed; however, these vehicles must be inspected for damage to be used in the CRASH program.) Any occupant of a case vehicle is a case occupant. Most of the statistics—that is, the ΔV-AIS curves—will be based on case occupants.

NCSS will collect a stratified sample of accidents within each area, as was done successfully in the Restraint Systems Evaluation Project [2]. There will be three strata, with different sampling fractions. Stratum 1 includes all accidents in which at least one case occupant died within 30 days as a result of the accident or was hospitalized overnight immediately following the accident. Every accident in Stratum 1 will be investigated by NCSS (even uninjured case occupants will be in the NCSS sample with certainty if the accident in which they were involved was in Stratum 1). Stratum 2 will consist of all accidents not falling in Stratum 1, but in which at least one case occupant was transported from the scene to a treatment facility. A 25-percent sample will be drawn from Stratum 2. Stratum 3, of course, consists of all other accidents and will be sampled at 10 percent. The fairly high oversampling of fatal and hospitalization accidents is due to the exceptional interest in finding the cumulative distribution function of ΔV in fatal and in AIS 3 accidents. On the other hand, the extreme oversampling may result in some loss of precision in calculating ΔV-AIS curves, especially at the higher range of ΔV, because there will be fewer noninjury cases for the purpose of calculating injury rates. Thus, sampling fractions may need to be revised if a significant loss of precision is detected.

A systematic sampling technique will be used for selecting the accidents in Strata 2 and 3. A day is chosen at random; all accidents in Stratum 2 that occurred on the chosen day within a certain police jurisdiction are in the sample; all accidents in Stratum 2 occurring 4, 8, 12, and 16 days after the chosen day within that jurisdiction are also in the sample. This type of systematic random sampling should be efficient and easy for the data collectors to observe and it is also fairly easy to discover if there were infringements of the sampling plan (such as accidents sampled on the wrong day).

There will be a quality control contractor who, among other things, will be responsible for seeing that the probability sampling plan is meticulously observed in the field and that missing data are kept as low as possible (see “Quality Control”).

The expected yield of accidents in the NCSS areas and the number of cases that will actually be investigated in NCSS are shown in table 2. The sample size for NCSS (10 000 accidents) is based on budgetary considerations.

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7 Since each case is weighted by the inverse of its sampling fraction when statistics are calculated from the file, no bias is introduced by the disproportionate stratified sampling [17].
Table 2. Expected number of events nationally, NCSS areas, and within NCSS sample

<table>
<thead>
<tr>
<th>Event type</th>
<th>Number of events</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>United States 1 year</td>
<td>NCSS area 18 mos.</td>
<td>NCSS sample</td>
</tr>
<tr>
<td>Accidents with at least 1 towed car</td>
<td>1 600 000</td>
<td>40 000</td>
<td>10 000</td>
</tr>
<tr>
<td>Towed cars</td>
<td>2 100 000</td>
<td>53 000</td>
<td>13 300</td>
</tr>
<tr>
<td>Towaway-involved occupants</td>
<td>3 800 000</td>
<td>95 000</td>
<td>24 000</td>
</tr>
<tr>
<td>Towaway-involved occupants with AIS-2</td>
<td>300 000</td>
<td>7 500</td>
<td>4 000</td>
</tr>
<tr>
<td>Towaway-involved occupants with AIS-3, 4, 5</td>
<td>70 000</td>
<td>1 750</td>
<td>1 600</td>
</tr>
<tr>
<td>Towaway-involved occupants killed</td>
<td>27 000</td>
<td>675</td>
<td>675</td>
</tr>
</tbody>
</table>

In summary, the NCSS sample design will provide estimates of the distribution of crash severity and of injury rates as a function of crash severity that differ from the true distributions in the NCSS areas by no more than a small, statistically measurable confidence interval (± 10 percent for the ΔV cumulative distribution function for frontal fatalities). Based on the manner in which the NCSS areas were selected, these results can be considered nationally representative with reasonable heuristic confidence.

TYPES OF DATA NEEDED

The field methodology to be utilized in the study is referred to as a level 2 study at NHTSA. Such a methodology uses technicians and junior engineering or science personnel in the field to collect a limited range of data elements. The data elements are usually limited in depth and scope. The limited scope of the investigation is best illustrated by noting that it is essentially confined to the crash phase of an accident, with very little attention devoted to the precrash and postcrash phases. The limited depth of the investigation is illustrated by the use of an algorithm such as CRASH, which is based on momentum principles, to achieve the reconstruction of the dynamics of the collision. An in-depth investigation of the crash phase of an accident would ordinarily use the SMAC computer code to estimate the crash dynamics. The SMAC code is based on integration of the equation of motion.

An important aspect of this mode of data collection is the compromise it attempts to strike between the collection of data on a large body of accidents and achievement of a low missing data rate. NHTSA places a high premium on the elimination of missing data. Clearly, some missing data are unavoidable, yet in a large study universe they can easily escalate to 30 percent of the important variables if care is not maintained. One of the features to be utilized in this study is to augment the regular review of police records with a police-generated notification of fatal and serious injury accidents. This varies according to the local circumstances, but it is intended to initiate early response to many accidents. Otherwise, frequent visits to the police records are the sustaining action that initiates the investigation. These visits take place on 1- to 3-day intervals according to the frequency of accidents. The 2- and 3-day cycles occur in sparsely populated rural areas and over holidays and weekends when the records are not readily available.

Another important action is to augment the telephone interview of occupants with mail and house visits to complete the interview when the telephone approach fails. The incidence of such failure is always large in areas and instances when driver telephone
numbers are not recorded on the police report. In each case involving vehicle inspection, driver interview, and occupant injury, the method utilized to obtain the data will be encoded. At the conclusion of the study, it is then possible to speculate on the outcome of the missing cases using the attributes associated with the different methods and sources of data.

The complete set of data collected in an NCSS investigation can be categorized according to accident or environmental factors, vehicle factors, and occupant factor. A complete list of the variables is noted in appendix A. Herein we consider only some of the important variables and the methodology exercised in their evaluation. Perhaps of greatest interest is the determination of velocity change ($\Delta V$) during the crash phase. It must be kept in mind that this applies only to collisions that are planar in nature. Those collisions such as rollovers and other off-road accidents that involve significant nonhorizontal forces are not included in the computation of $\Delta V$. A special protocol for single-vehicle nonplanar accidents will be used. It will be modeled after an extensive study [18] of single-vehicle crashes by the accident research team at the University of Miami. From analysis of these special single-vehicle crashes, it is hoped that measures of severity can be quantified for rollovers, and so forth. Here it is noted that only in the case of planar accidents is severity to be determined.

The CRASH computer code [19] includes two algorithms for computing $\Delta V$. One algorithm is based solely on damage to the involved vehicles. The second algorithm is based on the knowledge of post-impact trajectories. In the damage-only algorithm the required data include the dimensions, masses, and orientation of the vehicles at impact, the principal direction of force (which is assumed to coincide with the direction of $\Delta V$), and the profile of damage to the vehicles. This damage profile is used to compute the energy absorbed by the vehicles in crush work, and is based on a limited body of data expressing the force-deflection characteristics of vehicles. NHTSA is currently improving this database, yet it remains at this time one that expresses only roughly the differences in vehicle size and structure that exist. Fortunately, the calculation of $\Delta V$ is proportional to the square root of the energy absorbed and thus any error in this term is not transmitted linearly. (The reader should be cautioned that $\Delta V$ depends on other variables than absorbed energy and is not a simple expression of barrier equivalent speed that is sometimes associated with absorbed energy.) Assuming it is accurate, the power of this algorithm can be appreciated, for it requires only an inspection of the damaged vehicles by a trained technician to gather the required data.

NHTSA was concerned that so little data exist to adequately test the damage-only algorithm. Furthermore it was desirable to determine impact speeds. For these reasons, it was decided that another approach would be followed on as many accidents as possible. In this second approach the $\Delta V$ is computed by a knowledge of the vehicle orientations at impact and their departure velocities at the end of the impact. The pre-impact orientation and the vehicle masses are estimated by vehicle inspection. The departure velocities are determined from an analysis of the post-collision trajectories. These trajectories must be established from an inspection of the scene and include the path, the surface friction coefficient, and that portion of the path in which the vehicle was skidding, rolling, and spinning.

It is recognized that in many accidents of low severity no significant trajectory data are available. Clearly in these cases the damage-only algorithm must suffice. Even in those cases where a substantial and significant amount of scene data are present immediately following the accident, the ephemeral nature of this evidence makes it elusive. For this reason, the data collection teams are instigating rapid response techniques with local police to learn as soon as possible of high severity accidents. In this manner it is hoped that a scene inspection will be achieved within 12 hours of most high severity accidents. Thus, these cases will
have two methods of computation of $\Delta V$. The use of two methods will provide increased reliability over the damage-only algorithm, which as noted above is not exhaustively tested. Over the life of this study, it is expected that the limitations and accuracy of the damage-only method will be better understood. The use of the trajectory analysis is intended to contribute to this understanding. As noted above, the collection of trajectory data allows for the calculation of impact speed as well as velocity change. Having the impact speeds will then provide the necessary data to compute the relative collision velocity at impact, which has been used in the past as a measure of severity [20].

Another important group of data elements is related to the passenger compartment, both interior and exterior. From the interior of the passenger compartment, the occupant contact points associated with moderate or greater injury can be determined and identified with the injury. It is recognized that many contact points are elusive and difficult to determine, particularly in the case of minor injury. Such contact points are often observed and understood only after extensive examination of the vehicle and injury evidence. It is believed that the large number of cases of injury that will be collected for the evaluation of occupant contact points will reduce much of the uncertainty introduced by this level 2 methodology.

A second data element associated with the vehicle interior is one associated with interior intrusion. The intruding component will be identified, that is, steering column, A-pillar, instrument panel, side-door panel, and so forth. The amount of intrusion will be quantified, although it is recognized that such measures are only accurate to approximately $\pm 1$ inch.

An interesting variable grouping relating to the passenger compartment exterior is one associated with side structure performance. The position and amount of maximum crush will be located relative to the overall length of the passenger compartment. This information will be collected for vehicles with and without side-door beams and B-pillar supports. Through analysis it is believed an assessment can be made of the efficiency of side structural components in accidents.

Some interesting and possibly useful information on the societal costs of injuries will be collected. NHTSA desires to know the impact of injuries on lost work time and restricted activity as well as the surgical and direct hospital costs. Cost data will not be collected, as these will be taken from regional and national norms for various injuries. Through the use of lost work time and restricted activity, it is believed that a better distinction can be made between certain injuries that to date have been related chiefly to a "threat-to-life" scale, rather than to one of societal cost.

**QUALITY CONTROL**

The quality control efforts are directed toward achievement of two objectives—first, that the data collection teams adhere to consistent definitions and thus react substantially the same to similar field circumstances, and second, that the process of transferring the data from source records to a data processing file be accomplished with the minimum of coding errors. The most important step in achieving these objectives is the establishment of a quality control center operated by the quality control contractor. The quality control center is the focal point of efforts to insure that the seven field teams are maintaining a uniform data collection effort. The first important task involving the quality control center has been the determination of data elements and their definition. These have been determined through a joint effort of the quality control contractor and the NHTSA. The NHTSA has established the study objectives and estimated the field data needs and methodology to accomplish these objectives. In many cases, data elements themselves are specified using past experience as a guide. The quality control contractor has taken this embryonic beginning and developed definitions and data forms to be used in the field effort. With the exception of the use of the CRASH
The final step directed to these quality control objectives is to pass all of the cases submitted through a rigorous edit and consistency check using a computer. The edit checks are straightforward, simply ascertaining that a variable was encoded and that the value was within the possible field of values as determined by the variable definitions. The consistency checks are more involved. Each of the important variables including vehicle damage and occupant injury are subjected to consistency checks. For example, if the vehicle sustains damage requiring the code of F, for general area of damage, in the third character of the Collision Deformation Classification (CDC), the principal direction of force coded in the first two characters of the CDC must be 09, 10, 11, 12, 01, 02, or 03 0'clock. In addition to checks between variables, checks are made to insure an occupant record is submitted for each occupant, that a record is submitted for each vehicle, and so forth. A detailed report is obtained on each team’s monthly submission. The report is generated by the computer edit software and is forwarded to the quality control center as well as the submitting team. Errors discovered must be corrected, and a significant number of errors is cause for rejection and review of the entire batch.

SUMMARY

The collection and analysis of accident field data to support motor vehicle and highway safety countermeasure evaluation and research is an evolving process that builds upon and is strengthened by the past experience. In the National Crash Severity Study, the NHTSA is taking a step forward that will expand our data base in crash severity phenomena and in accident data collection. Upon completion of the NCSS, a data base will exist that is large in numbers and nationally representative in character. The product should be of great aid to the research community in measuring the relative importance of many aspects in the crash spectrum. Finally, the NCSS represents an important step in field data collection, it being the first purposive sample of nationwide data of this character. In this respect it
represents the first operational step toward a standing nationwide network of accident data collection.

REFERENCES


**APPENDIX A: MEASURES OF COLLISION SEVERITY**

A much needed development for highway traffic safety research is to define and utilize an accurate measure of the forces exerted upon a vehicle during a collision. Herein such a measure is referred to as one of collision severity. The major reason for seeking a collision severity measure is to provide a means of quantifying the diversity and variations of the characteristics and factors involved in the collision phase of motor vehicle accidents. For example: impact speeds span a broad range from near zero to approximately top vehicle speed; directions of impact encompass the 360 degrees horizontal plane and often involve vertical components; contacted surface areas vary from a small area to a full side or length of the vehicle; vehicle sizes and shapes are legion; protective devices and mechanisms are numerous. Each of these plus many more factors generate different accident conditions and lead to a wide variety in the consequences resulting from the collision event. A meaningful collision severity measurement would provide a common basis for comparison across many of the variables. The consequences of collisions, ranging from minor property damage through physical injury to fatalities, are nearly as variable as the impact conditions. However, there are measures advocated for quantifying results or consequences of accidents such as frequency of occurrence, dollars of cost to repair damage, and frequency and severity of injuries. It would be desirable to define similarly concise measures of collision severity.

The goal of highway traffic safety programs is to minimize the costs and other undesirable outcomes of accidents. As a contribution to this end, a collision severity measure would serve as a predictor of collision results, that is, establish a parametric relationship between accident severity and societal costs and/or resulting injuries. With such a relationship it would be possible to infer the “average” cost and injuries associated with a given accident without experiencing the actual collision with its resulting financial losses or injuries. This would then allow for improvements in comparisons of real life accidents with laboratory conducted experiments. Under controlled laboratory conditions one could better study such things as injury mechanisms, differences in vehicle design, and vehicle safety features.

Other benefits would be derived from a realistic, reproducible, and quantified collision severity rating. It would provide a means of relating speed to accident damage and injury. Intuitively and statistically, there is a relationship between accident consequences and speed. However, it is probable that the relationship is nonlinear and complex. A quantitative measure of collision severity would provide additional insight into the relationship and possibly allow explanation and realistic evaluation of observations such as the decrease in fatalities resulting from the nationwide 55-mi/h speed limit. It would be a mechanism for evaluating the differences in injury severity that result from impacts at various angles. Are injuries more severe from frontal impacts or
side impacts for the same collision severity? Where should emphasis on vehicle structural strength be placed? It would provide guidelines for selecting the types of collision events for which a given expenditure of funds would provide the greatest payoff in benefits. Which accidents are most severe? What magnitude of collision severity becomes unreasonable to eliminate at realistic costs?

Criteria

There are numerous considerations involved in the selection of a measure of collision severity. Some of the more obvious ones are:

- The measure should portray a theoretically correct picture of the forces involved in the collision.
- The measure should be consistent and uniform so that the severity ratings may be used on all accidents.
- The measure should be easy to apply, calculate, or obtain, and be quantitative in nature.
- The measure should be understandable and have meaning to nontechnical people.
- The measure should be suitable for all types of vehicular mishaps; collisions between vehicles, collisions of a vehicle with a fixed object, rollovers, underride, override, and others. It is recognized that an “ideal” measure will probably never be developed and that the above considerations will not be entirely satisfied. Therefore, the objective is to define the “best” measure of collision severity for meeting the requirements for research.

A major objective of the NCSS study is to obtain a relationship between crash severity and injury severity. In order to meet this objective, it has been necessary to define the measure of crash severity to be used. Because available data for choosing the “best” measure are limited, the approach has been to select the measure that theoretically and intuitively “best” suits the needs and then to supplement the data with other advocated measures. This approach led to adopting the change in velocity during impact (delta velocity or $\Delta V$) for primary consideration as a collision severity measure in NCSS. Supplemental severity measures will include dissipated kinetic energy and relative speed at impact. The intention of NCSS is to document the crash phase of the accident event thoroughly so that any new proposed measures of severity can be evaluated from the data collected.

Technical Discussion

Traffic accidents may be classified in numerous ways. One consideration useful in reconstructing accidents is whether the collisions can be treated as, or approximated by, a two-dimensional or planar event. In a planar accident the vehicles can be considered to have only three degrees of freedom—translation in the x- and y-directions and yaw rotation which takes place in the x-y plane. Thus all forces acting on the vehicle can be expressed in x- and y-components. Three-dimensional or nonplanar accidents would require the consideration of six degrees of freedom; x-, y-, and z-translation and rotation about all three axes.

In nonplanar cases, resultant forces acting on the vehicle have a z-direction (or vertical) component that has to be considered as well as two additional axes of rotation. Nonplanar accidents would include events in which the vehicle:

(a) Vaults into the air and is subjected to vertical forces upon landing. A typical example would be a vehicle running off of the roadway, over a steep downward side slope at a high speed, leaving the ground surface, and actually becoming a projectile. Upon landing, the vehicle may be subjected to impact forces containing considerable vertical components.

(b) Is subjected to sudden changes in grade, either on or off the roadway, and the vehicle’s suspension system “bottoms out” so that large vertical accelerations are imparted to the vehicle and its occupants.

(c) Rolls over (either laterally or longitudinally) with possible forces applied to the vehicle from all three directional axes.

(d) Overrides or underrides another vehicle’s structure as a consequence of structural
differences (such as a truck and car) or panic braking, and so forth. At the present, efforts are being directed to obtaining a measure of crash severity for only planar accidents. Additional development is required prior to applying known techniques to the analysis of the nonplanar events. With existing techniques, extensive reconstruction cost and effort are required to determine any reasonable quantitative measure of crash severity for nonplanar events. The number of events for which data could be obtained is, therefore, limited.

It is hypothesized herein that appropriate measures of accident severity are those that quantify the forces acting in the collision. Thus the acceleration, which is the net force per unit mass, is a measure of severity. Of primary interest is the acceleration of the vehicle center of mass. Accelerations of other points on the vehicle structure may consist of a substantial transient vibration of high frequency acceleration in addition to the fundamental acceleration of the center of mass. A typical acceleration-time history for the center of gravity of a vehicle involved in a collision is shown in figure A1. It is obvious that the function $a(t)$ is complicated and would be difficult to quantify and use. At the present time, acceleration traces of the type shown can be obtained from accidents by two methods, crash recorders and accident reconstruction simulation programs such as SMAC. Neither of these two methods is practical for large numbers of accidents with present technology. Crash recorders are not installed in a representative number or selection of vehicles; and the SMAC program is an expensive tool to apply to large numbers of accidents. As a consequence, alternative methods have been sought that are less expensive even at the sacrifice of some information.

The approach to the problem was to select some characteristics of the acceleration trace as a measure of collision severity. Among the characteristics of the function $a(t)$ are: velocity change $\Delta V$; pulse width $\tau$; peak acceleration $a_{\text{max}}$; average acceleration $a$; onset rate $r$; and pulse shape factor $t^*$. Each of these characteristics is identified in the acceleration-time trace in figure A1 and is discussed in detail below. It must be remembered that force and acceleration are vectors, that is, they possess the properties of magnitude and direction. For this reason, it is convenient to express them in two coordinate directions, $x$ and $y$, measured in the reference frame of the vehicle. Hereafter, each of the quantities is implied to be in $x$ and $y$ components.

The velocity change, $\Delta V$, is one of the more frequently used measures of collision severity. It is the area under the acceleration-time curve and it is computed by taking the integral of the acceleration over the pulse width, such as:

$$\Delta V = \int_0^\tau a(t) \, dt$$

$\Delta V$ may also be defined as the vehicle’s velocity change during the actual collision phase of the accident. Thus the equations of collision mechanics can be used to evaluate $\Delta V$ without actually integrating $a(t)$. This is accomplished by the momentum-impulse relationship. For a body of constant mass, Newton’s Second Law

$$F = m \frac{\partial V}{\partial t}$$
is integrated to yield
\[ \int_0^\tau F(t) \, dt = m \int_{V_i}^{V_f} dV \]
where \( \int_0^\tau F(t) \, dt \) is the total impulse and \( m \int_{V_i}^{V_f} dV \) is the change in momentum. The impulse imparted to one body must be equal and opposite to that of the body with which it collides. If other forces such as tire friction\(^1\) are neglected during the impact, the momentum lost by one body is gained by the other; that is, the momentum within the system is conserved. If the subscripts a and b denote two colliding vehicles, it then follows that
\[ m_a(V_{af} - V_{ai}) = -m_b(V_{bf} - V_{bi}) \]
or
\[ m_a \Delta V = -m_b \Delta V \]
where
\[ \Delta V = V_f - V_i \]

It is instructive to look closely at the impulse and understand its relation to the collision. Obviously the total impulse represents the sum of all of the elementary impulses. It can be expressed by defining an average force, \( F \).
\[ \int_0^\tau F(t) \, dt = \bar{F} \tau \]

In other words the total impulse is related to the average force \( F \) over the collision period. It should also be noted that \( F(t) \) is an average in space of all of the elementary contact forces acting at the collision interface.
\[ F(t) = \int_A F(x,y,t) \, dA \]

where \( F(x,y,t) \) is the instantaneous interfacial contact force per unit area. Thus the total impulse is an average in space over the collision interface and an average in time over the pulse width. Because it is related to the average force, the total impulse, the momentum change, and the velocity change \( \Delta V \) are coincident in direction with the Principal Direction of Force (PDOF). The PDOF is estimated by accident investigators in determining the Collision Deformation Classification (SAE J224A) and is defined as the direction of the resultant force that caused the vehicle deformation.

**Pulse Width** \( (\tau) \). The pulse width is the duration of time over which the collision forces exist and is usually expressed in milliseconds. Obviously the same \( \Delta V \) extended over a greater time interval is indicative of a less severe accident, as the forces applied to the vehicle have a lower magnitude. Such differences in pulse width are observed when comparing acceleration traces between collisions involving a fixed object versus those involving a yielding object (another vehicle). An interesting and meaningful comparison is offered by figure A2 in which the velocity change is approximately the same for three collisions. Clearly, the typical offset vehicle-to-vehicle circumstance, in which the pulse width is markedly greater, is the least severe, resulting in a smaller peak deceleration as well as a smaller average deceleration.

**Average Acceleration** \( (\bar{a}) \). The average acceleration is
\[ \bar{a} = \frac{1}{\tau} \int_0^\tau adt = \frac{\Delta V}{\tau} \]

The three characteristics, pulse width, average acceleration, and velocity change are related as noted above. If any two are known, the third is also known. Thus, for a given \( \Delta V \) lower values of \( \bar{a} \) indicate greater pulse widths, lower magnitudes of collision forces, and a less severe impact.

**Maximum Acceleration** \( (a_{\text{max}}) \). The maximum acceleration has a weaker relationship to the severity of the accident than does average acceleration. If all collision pulses were of the same duration and shape, maximum acceleration would be directly related

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\(^1\)Tire forces seldom exceed approximately 1 g compared to the 10-40 g's developed from the collision forces. Therefore, the error introduced by neglecting tire forces is small.
to average acceleration and hence to $\Delta V$. In practice, there are limitless combinations of pulse shapes and duration that can make maximum acceleration a misleading measure. Maximum acceleration peaks usually occur when major structural or engine components are encountered during deformation of the vehicle. These accelerations are of relatively short duration in comparison to the overall pulse width. From a practical consideration, maximum acceleration is also varied by the filtering and response characteristics of accelerometers and recording equipment and may not represent a true value. For these reasons less significance is attached to maximum acceleration than to average acceleration for an overall measure of severity.

Pulse Shape Factor ($t^*$). The distance ($d$) traveled by the vehicle's center of mass during the collision pulse can be expressed as

$$d = V_1\tau + \Delta V \cdot t^*$$

where $t^*$ is the time between the centroid of the pulse and the end of the pulse. The term $V_1\tau$ represents the distance traveled by an unrestrained occupant during the period $\tau$ if there is no contact with an interior component. The difference, $d-V_1\tau$ (or $\Delta V \cdot t^*$), is a hypothetical relative distance traversed by an unrestrained occupant with respect to the vehicle's center of gravity during the collision pulse. (This assumes that the occupant's velocity is sustained at $V$, a condition that is accurate until interior contact is made.)

From the above relation it is apparent that for a given $\Delta V$, larger values of $t^*$ result in increased relative motion between the occupant and the vehicle. Because there is a comparatively small distance available for relative movement, large values of $\Delta V \cdot t^*$ suggest that unrestrained occupants will contact the vehicle interior. To what extent does this contact influence severity? If occupant contact with the interior occurs, such contact may aggravate or mitigate injury according to the interior component contacted. If the interior contact point is associated with a designed safety feature such as a collapsing steering column, laminated and nonlacerating windshield, or collapsing instrument panel the contact can be beneficial to an unbelted occupant. Proper design of these components will limit occupant acceleration onset rate and peak acceleration. By achieving contact before the pulse ends the occupant strikes the interior with less relative velocity and is subjected to lower accelerations and is less susceptible to injury if the interior component is designed to "accept" occupant contact. This phenomenon is known as "ride-down." The optimum design of interior components from this point of view is the air bag system.
SECTION 4: TECHNICAL SEMINARS

This noncollision event definitely has different results than a 30-mi/h \( \Delta V \) collision into a rigid barrier where the pulse width would be in the range of 0.10 to 0.12 second, average acceleration \( (\bar{a}) \) equal to 12-15 \( g \)'s and peak acceleration \( (a_{\text{max}}) \) approximately 30 \( g \)'s. This property of \( \Delta V \) indicates that it cannot be indiscriminately applied to all events. For \( \Delta V \) measures to be useful and comparable certain restrictions or precautions are necessary.

The measurement must be restricted to actual impacts of a specified time duration—say less than 200 milliseconds. Any \( \Delta V \) obtained from a situation lasting longer than this time period should be treated as suspect and very cautiously compared with those from shorter time period impacts.

Care should be taken in comparing \( \Delta V \)'s from collisions involving vehicles colliding with objects of different rigidity; that is, the time-acceleration trace of a vehicle impacting a rigid barrier has a shorter pulse width and a greater maximum acceleration than that of the same vehicle striking another vehicle and sustaining the same \( \Delta V \).

Another question on the proposed use of \( \Delta V \) is whether it can be obtained from damage measurements of the involved vehicles. Experience has revealed that in numerous accidents it is impossible to obtain accurate measurements of impact locations, final resting points, trajectory paths, coefficient of friction, and so forth, which are necessary for a complete reconstruction of the accident event. However, in a large percentage of these cases, it is possible to inspect the involved vehicles and obtain measurements of the damage inflicted upon the vehicles. For these cases it is proposed to estimate \( \Delta V \) from damage only, using the CRASH algorithm [19]. In the investigated accidents, it is anticipated that the least reliable trajectory data will relate to certain central impact situations and low damage accidents. Total reliance for \( \Delta V \) has to be placed on damage measurements in such cases. In non-central impacts, the vehicles will rotate and more often generate trajectories, thus more data will generally be available and \( \Delta V \) calculations from trajectories will be possible, as well as results from damage.
SUMMARY

$\Delta V$ has been selected for primary consideration as a measure of collision severity because it meets many of the criteria established previously:

(a) Is relatively easy and inexpensive to obtain through reconstruction of accident events and therefore can be used on large numbers of accidents. Estimates can be obtained from vehicle damage as well as from the complete data collected at the accident site.

(b) Is a meaningful quantitative characteristic of the acceleration trace during the collision phase. $\Delta V$ is a vector thus having a direction as well as magnitude.

(c) Has a meaning that can be understood by users.

Certain limitations in the use of $\Delta V$ are noted:

(a) Requires further development prior to use in accident types such as rollovers, underride, vaulting, and so forth.

(b) Can be applied uniformly only to collisions of relatively short duration—say less than approximately 200 milliseconds.

Car/Vehicle Side Impacts — A Study of Accident Characteristics and Occupant Injuries

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ABSTRACT

In recent years, the analysis of real-life accidents and the development of vehicle safety have been concerned above all with the problems of frontal and rear-end collisions. Substantial reductions in the injury risk involved were proved possible.

This focal point of the research work has, however, tended to overshadow the problem of automobile side collisions. So far, very few standardised side collision tests have been conducted, and these have shown minor conformity with the course of real-life collisions. The analysis of real-life accidents has yielded little data on accident characteristics in side collisions and their consequences.

On the basis of representative material in this report, the accident characteristics of car/vehicle collisions are being analysed with particular attention to the change in collision frequency with increasing severity of the injuries to occupants. The mass ratio between frontal- and side-impacted vehicles, the damage to a vehicle from a side impact, and the resultant injuries to occupants, are analysed in detail. The data furnish clear pointers on the measures necessary to improve occupant protection in side collisions. This report is also intended as a contribution towards standardising the definitions of side collisions, which today still differ to a great extent, and establishing a basis for the creation of real-life-related car collision tests.

THE SIGNIFICANCE OF SIDE COLLISIONS

Frontal/side collisions, which make up 39 per cent of collision statistics, are the most frequent type of car collision involving occupant injuries [1,2]. The frequency of severe injuries to occupants in a side-impacted vehicle is twice as high as for the occupants of the vehicle with frontal impact [3].

Because of the fact that, in frontal/side collisions, one vehicle suffers frontal and the other side damage, the frequency of cases with main deformation in the area of the side surfaces is reduced to 12.8 per cent [4]. As a consequence of the high degree of injuries, however, 28 per cent of all fatally injured, 20 per cent of all seriously injured (as from AIS 3), and 27 per cent of all injured (as from AIS 1) occupants in car/vehicle accidents are to be found in cars with a side impact [3].
Corresponding percentages of fatally injured occupants in side collisions are revealed by other accident statistics in Europe and the United States. [5-7].

A total of 6,616 car occupants were fatally injured and 69,599 seriously injured in the Federal Republic of Germany in 1974. Further optimisation of the side structure could, therefore, influence the degree of injury to 1,850 of the fatally injured and 13,800 of the seriously injured car occupants, proving that the focal aspect “side structure” is absolutely essential for achieving an overall reduction in occupant injuries in cars.

In car side collisions, collisions with other cars predominate (65 per cent). Approximately 5-7 per cent are collisions with lorries. Of the remainder, almost 30 per cent are car/object collisions, in which serious injuries to occupants occur with above-average frequency.

This report deals exclusively with car/car and car/lorry collisions; an analysis of car/object collisions will follow in a later report.

THE INVESTIGATION MATERIAL

Within the scope of their accident research, German automobile insurers have, since 1969, evaluated almost 150,000 car accidents involving injuries to occupants, of which some 50,000 cases provided sufficiently precise data for a scientific analysis. These investigations [1, 2, 3, 8] are carried out retrospectively on the basis of insurance files by a team of engineers supported by medical experts. This accident material is evaluated in a multiphase analysis (fig. 1). From the Evaluation Phase 2, comprehensive analyses on the origin and consequences of the accident are conducted with pictorial documentation supported by a police report, an expert on the vehicle damage, a reconstruction of the accident with site sketch, and a medical report on the severity of the injuries and the progress of treatment. Additional information is obtained by questioning or contacting the parties involved by the accident analysis team.

For the purpose of these investigations, details of all car accidents with injuries to occupants are forwarded to the respective insurance company, the accident survey thus covers the entire Federal Republic of Germany and reflects a fully representative picture of accident circumstances in car/vehicle collisions. The injuries (table 1) and the distribution of accident types (table 2) conform closely to the relative figures of the official statistics [9].

This report covers 1,009 car/vehicle side-collision accidents in which an occupant suffered injuries of the severity degree AIS 1 and upwards in one of the vehicles involved. The report deals exclusively with accidents of Evaluation Phase 2 (fig. 1) emanating from the year 1974.

Applied Definitions

One of the main problems in an international comparison of results of side collisions is the lack of standardised definitions. To
Table 1. Comparison of the injury severity: HUK-Accident Investigation “Safety of Automobiles 1974” with the official statistics in the FRG [8]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Per cent</td>
</tr>
<tr>
<td>Cars in accidents with occupant injury</td>
<td>15 000</td>
<td>219 635</td>
</tr>
<tr>
<td>Car occupants</td>
<td>27 275</td>
<td>100</td>
</tr>
<tr>
<td>Killed car occupants</td>
<td>443</td>
<td>1.6</td>
</tr>
<tr>
<td>Seriously injured car occupants</td>
<td>4 336</td>
<td>15.9</td>
</tr>
<tr>
<td>Car occupants with minor injuries</td>
<td>16 592</td>
<td>60.8</td>
</tr>
<tr>
<td>Uninjured car occupants</td>
<td>5 904</td>
<td>21.7</td>
</tr>
<tr>
<td>Total number of injured car occupants</td>
<td>21 371</td>
<td>78.3</td>
</tr>
</tbody>
</table>

Note. Average passenger per car: \( i = 1.7 \)
All car accidents except: car-pedestrian, car-bicycle, and car-motorcycle.

Table 2. Frequency distribution of collision types according to the federal statistics and the HUK-Investigation “Safety of Automobiles 1974”

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Per cent</td>
</tr>
<tr>
<td>Rear-end accident</td>
<td>49 816</td>
<td>18.8</td>
</tr>
<tr>
<td>Oncoming traffic accident</td>
<td>138 644</td>
<td>52.4</td>
</tr>
<tr>
<td>Accident at crossing</td>
<td>4 725</td>
<td>31.5</td>
</tr>
<tr>
<td>Collision with rigid objects</td>
<td>76 119</td>
<td>28.8</td>
</tr>
<tr>
<td>Total</td>
<td>264 579</td>
<td>100</td>
</tr>
</tbody>
</table>

Note. All car accidents with occupant injury in 1974 except car/pedestrian accidents, other vehicle/pedestrian accidents, and accidents on roads passing rails.

Impact Area. The categorisation dimension in side collisions can only be the area of main deformation, which embraces the area of maximum intrusion in a lateral direction and the entire area of substantial deformation of structural bearing parts. The transmission area of the collision impulse is thus defined, through which the direction of motion of the car with side impact is changed and the movement of the occupants relative to the vehicle is initiated. Examples of typical main deformation in collision areas I, II and III are summarised in figure 3.

Intrusion. Intrusion is defined as a static impression of the occupant compartment between the A and C posts following a collision. The intrusion indicated whether and to what depth a reduction in the dimensions of the vehicle inner compartment has resulted. The intrusion, as such, does not represent a measurement of the collision severity, as it is dependent on external collision factors (speed, mass ratio, collision type) and on the rigidity of the vehicle impact area and the contour aggressiveness. Thus, the same degree of intrusion can result from completely differing degrees of accident severity and occupant stress load.

The risk of injury by intrusion depends on the form, depth, and position of the intrusion relative to the seat position of the occupant.
**Figure 2. Definition of side collisions: classification of impact areas and direction of impact.**

**Direction of Impact.** The direction of impact is the direction of the change in impulse to which the vehicle is subjected during the collision phase. This change in impulse corresponds to the time integral factor $Pdt$ and indicates the mean direction of the collision forces through which the change in speed of the vehicles is caused.

The degree and direction of this impact impulse change depends on the initial and post crash speed of the vehicles involved, their mass ratio, and the type of collision. The direction of the relative speed of the vehicles, on the other hand, takes into account only the speed of the vehicles immediately prior to the collision and is, therefore, not useful for specifying the direction of impact. A description of the direction of impact based on the position of the longitudinal axis of the vehicles is not possible, as neither the mass nor the velocity factors of the collisions are taken into account. The directional motion (occupant trajectory) of the belted occupant during the collision is almost opposite the direction of impact. The nonbelted occupant, on the other hand, represents an unrestrained mass whose trajectory ensues from a vectorial addition of the velocity of the occupant prior to the collision and the change in speed of the vehicle during the collision, with the rotational and transitional energy quotas thereby taken into account. The trajectory of the opposite-side occupant can, therefore, deviate considerably from the direction of impact. But in the case of the impact-side occupant, a trajectory opposing the direction of impact can be assumed with fair proximity.

As the impact on the vehicle is the initial factor governing the trajectory of the occupant, a categorisation of occupant injuries based on the direction of impact should be made. In addition to this, even accident investigations conducted on the spot often cannot determine the trajectories of the occupants with certainty, as damage marks are seldom ascertainable, and even these may
Figure 3. Examples of car side damage corresponding to impact areas I, II, and III.
have occurred in the primary collision phase or during a subsequent secondary collision.

**Impact Speed.** The problem of speed specification in side collision has not yet been satisfactorily solved.

The actual collision speeds and their vectorial addition to the relative speed merely indicate an initial situation, which can result in varying degrees of accident severity according to the respective collision type, mass ratio, and impulse transmission during the collision.

In side collisions, the Equivalent Test Speed (ETS) often cannot be determined with sufficient accuracy, as the actual deformation rarely corresponds to the damage sustained in crash tests. The procedure for determining the speed variation \( \Delta V \) [10-12] also depends on an estimation of the ETS, the mathematical determination of the change in speed being based on the theory of central impact, which occurs rather seldom in side collisions.

A categorisation of occupant injuries can be made by determination of the ETS or speed variation \( \Delta V \), or by specification of the actual relative collision speed. The impact speed in a crash test with a stationary vehicle struck from the side that would correspond to these factors will have to be investigated in detail and further studies in this field are necessary.

In the present work, only the sectors of the collision speeds of both vehicles immediately prior to the collision are specified, thereby enabling an estimation to be made of the maximum possible speed ratios. In view of the aforementioned reservations, however, it should be understood that the actual collision consequences will, in the majority of cases, be well below these maximum stress load limits.

**Classification of the Overall Vehicle Damage.** This classification is made on the basis of the HUK Overall Damage Index in five categories [1], in which the extent and depth of the main deformation and, above all, the limitation of the protective function of the occupant compartment are taken into account. The system applied here is generally comparable to the VDI [13].

**Injuries to Occupants.** These are specified by the AIS Classification, with the Overall Severity Index and individual injuries also being reflected [14].

**RESULTS**

**The Injury Risk in Side Collisions**

In table 3, a comparison is made between the 1 009 side collisions with lateral direction of impact (on which this report is based) and 744 car/vehicle side collisions involving a longitudinal direction of impact.

Side collisions with injuries to occupants are apportioned in a ratio of about 57 to 43 between collisions with the lateral and collisions with longitudinal direction of impact. By virtue of the differing collision phase sequence, the vehicle damage and occupant injuries OSI 1/5 in longitudinal side collisions are less severe than those in collisions with lateral direction of impact. Accidents resulting in fatal injuries are, however, just as frequent, for in side collisions with a longitudinal direction of impact, the vehicles are frequently entangled in the area of the front axle, which results in severe deformation of the occupant compartment in a frontal/side direction. Examples of this are given in figure 4. The motive mechanism leading to this type of damage is fundamentally different from that in the side collisions with lateral direction of impact that are under review here and must accordingly be dealt with separately.

**Collisions Areas and Injuries to Occupants**

Table 4 shows the frequency of collision areas and resultant injuries in the 1 009 case studies of side collisions with lateral direction of impact. With 53.5 per cent, main deformation in the occupant compartment is very frequent in relation to collisions up to the level of the front axle (39.9 per cent). The most severe injuries occur in cases where the main deformation extends beyond Collision Area II. The more severe the injuries resulting from the accident become, the greater the significance of Collision Areas II
Table 3. Comparison of accident and injury severity in car vehicle side collisions with lateral and longitudinal direction of impact

<table>
<thead>
<tr>
<th>Injury severity</th>
<th>Lateral 08/09/10/02/03/04a</th>
<th>Longitudinal 01/11/12/05/06/07a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cases</td>
<td>1 009</td>
<td>744</td>
</tr>
<tr>
<td>Number of accidents severe/extreme car damage</td>
<td>90</td>
<td>33</td>
</tr>
<tr>
<td>Average HUK—classification car overall damage index</td>
<td>2.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Number of occupants:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatal (AIS 6)</td>
<td>23</td>
<td>15</td>
</tr>
<tr>
<td>Severe/critical (AIS 3-5)</td>
<td>83</td>
<td>25</td>
</tr>
<tr>
<td>Moderate (AIS 2)</td>
<td>169</td>
<td>88</td>
</tr>
<tr>
<td>Minor (AIS 1)</td>
<td>1 161</td>
<td>824</td>
</tr>
<tr>
<td>Number of uninjured occupants</td>
<td>317</td>
<td>232</td>
</tr>
</tbody>
</table>

aAs defined in figure 2a.

and III, whilst the frequency of collisions in the Front/Side Area I continuously decreases (table 5).

The frequency of the directions of impact in the various collision areas is shown in table 6. The frontal/side directions of impact 02/10 predominate with around 60 per cent, whereby typical differences exist between the Collision Areas I, II, and III. If only accidents with severe occupant injuries as from AIS 3 upwards (table 7) are considered, the maximum of the side directions of impact 03/09 shifts to Collision Area III. The rear side impacts that occur relatively often in Areas III and V point to the risk of injury through the B post.

In summarising, it can be said that 45.9 per cent of all side collisions (fig. 2) and 59.6 per cent of all side collisions with severe occupant injuries show the main deformation to be in Collision Areas II and III, with the direction of impact in 90 per cent of the cases being in the region of an angle of 60-80 degrees to the longitudinal axis of the vehicle.

Mass Ratios in Side Collisions

In figure 5, a comparison is drawn between the distribution of mass in vehicles with side impact in collisions and the corresponding vehicle registration figures in the Federal Republic of Germany. The proportion of vehicles in the categories 700 to 900 kg and 900 to 1 200 kg involved in side collisions corresponds to their proportionate share of the market. Lighter vehicles of less than 700 kg are slightly over-represented; heavy vehicles of 1 200 kg or more are under-represented. If the 237 cases with injuries to occupants of severity degree AIS 2 in the car with side impact are taken as the sole basis, this trend clearly intensifies.

The greater risk of injury to the occupants of light vehicles and the possibility of improved occupant protection, even in vehicles of the 700- to 900-kg category, are obvious.

The mass ratios of the vehicles involved in all 1 009 side collisions were determined and set out in the relation

\[
M = \frac{m_2}{m_1} = \frac{\text{Frontal colliding vehicle (striking vehicle)}}{\text{Car suffering side impact (struck car)}}
\]

From this it ensues that, as the mass ratio M increases, the relation factor for the struck car becomes less favourable.

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Figure 4. Examples of severe damage to cars in side impacts with longitudinal direction of impact.
Table 4. Collision frequency and injuries in 1 009 car side collisions with lateral direction of impact

<table>
<thead>
<tr>
<th>Item</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cases</td>
<td>403</td>
<td>134</td>
<td>329</td>
<td>72</td>
<td>66</td>
<td>5</td>
<td>1 009</td>
</tr>
<tr>
<td>Uninjured occupants OSI 0</td>
<td>38.8</td>
<td>12.3</td>
<td>34.1</td>
<td>6.9</td>
<td>7.6</td>
<td>0.3</td>
<td>100</td>
</tr>
<tr>
<td>Injured occupants OSI 0</td>
<td>16.6</td>
<td>16.3</td>
<td>20.4</td>
<td>18.2</td>
<td>21.6</td>
<td>9.1</td>
<td>100</td>
</tr>
<tr>
<td>Uninjured occupants OSI 1</td>
<td>44.4</td>
<td>12.9</td>
<td>28.0</td>
<td>7.1</td>
<td>6.8</td>
<td>8</td>
<td>100</td>
</tr>
<tr>
<td>Injured occupants OSI 1</td>
<td>69.6</td>
<td>62.8</td>
<td>61.3</td>
<td>68.6</td>
<td>71.2</td>
<td>72.7</td>
<td>66.2</td>
</tr>
<tr>
<td>OSI 2</td>
<td>40.2</td>
<td>14.2</td>
<td>63</td>
<td>11</td>
<td>1.8</td>
<td>9.1</td>
<td>100</td>
</tr>
<tr>
<td>OSI 3-5</td>
<td>9.2</td>
<td>10.0</td>
<td>11.9</td>
<td>9.1</td>
<td>9.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OSI 6</td>
<td>34.9</td>
<td>19.3</td>
<td>33.8</td>
<td>4.8</td>
<td>6.0</td>
<td>1.2</td>
<td>100</td>
</tr>
<tr>
<td>Total number of occupants</td>
<td>741</td>
<td>239</td>
<td>530</td>
<td>121</td>
<td>111</td>
<td>11</td>
<td>1 753</td>
</tr>
</tbody>
</table>

These mass ratios are shown in cumulative presentation relative to the injury severity in the struck car (fig. 6). In 50 per cent of all collisions, the striking vehicle is only 10 to 20 per cent heavier than the struck car. The 90 per cent sector — due to car/truck collisions — increases, however, in side collisions of all degrees of severity to M = 1.75, and particularly in collisions with severe injuries as from category AIS 3 to M = 2.4. In the percent frequency distribution shown in figure 7, 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.

Despite the fact that the vehicle masses in side collisions are able to assert themselves only proportionally, the mass aggressiveness — intensified by the contour aggressiveness — presents a basic problem in car/car side collisions.

The main difficulties, however, lie not so much in the charge in maximum collision frequency, as in the increase of the 90 per cent point in collisions with severe injuries over category AIS 3.

The collision frequency of vehicles in the various mass categories, specified for all side collisions and for all collisions resulting in injuries such as AIS 3 in the struck car, is furnished in tables 8 and 9.

The maximum collision frequency is found in the 750- to 900-kg range. The quota of light vehicles under 750 kg involved in side collisions as the side struck car, increases from 13.3 per cent, for all collisions, to 24.5 per cent for collisions with severe injuries as from AIS 3. Whereas 10.3 per cent of all occupants of light vehicles involved in side collisions suffered severe injuries (severity degree AIS 3), this figure drops to only 3.5 per cent in the case
Table 5. Frequency distribution of impact area versus accidents with different occupant injury

<table>
<thead>
<tr>
<th>Number of:</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cases</td>
<td>403</td>
<td>134</td>
<td>329</td>
<td>72</td>
<td>66</td>
<td>5</td>
<td>1009</td>
</tr>
<tr>
<td>Cases with occupant injury OSI $\geq$ 2</td>
<td>85</td>
<td>40</td>
<td>88</td>
<td>15</td>
<td>8</td>
<td>1</td>
<td>237</td>
</tr>
<tr>
<td>Cases with occupant injury OSI $\geq$ 3</td>
<td>26</td>
<td>22</td>
<td>34</td>
<td>5</td>
<td>6</td>
<td>1</td>
<td>94</td>
</tr>
</tbody>
</table>

Injured occupants:

| OSI $\geq$ 1                                     | 618| 200| 422 | 99 | 87 | 10 | 1436  |
|--------|------------------|----|-----|-----|----|----|-----|-------|
|        | 43.0             | 13.9| 29.4| 6.9 | 6.1| 0.7| 100  |
| OSI $\geq$ 2                                    | 102| 50  | 97  | 16 | 8  | 2  | 275   |
|        | 37.1             | 18.2| 35.3| 5.8 | 2.9| 0.7| 100  |
| OSI $\geq$ 3                                    | 34 | 26  | 34  | 5  | 6  | 1  | 106   |
|        | 32.1             | 24.5| 32.1| 4.7 | 5.7| 0.9| 100  |

Table 6. Direction of impact and impact area in all car side collisions with occupant injury

<table>
<thead>
<tr>
<th>Direction of impact</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>44.3</td>
<td>14.4</td>
<td>28.5</td>
<td>7.1</td>
<td>5.4</td>
<td>0.3</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>268</td>
<td>88</td>
<td>173</td>
<td>43</td>
<td>33</td>
<td>2</td>
<td>607</td>
</tr>
<tr>
<td></td>
<td>35.4</td>
<td>12.0</td>
<td>40.3</td>
<td>5.8</td>
<td>5.5</td>
<td>1.0</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>109</td>
<td>37</td>
<td>124</td>
<td>18</td>
<td>17</td>
<td>3</td>
<td>308</td>
</tr>
<tr>
<td></td>
<td>27.0</td>
<td>27.6</td>
<td>37.7</td>
<td>23.4</td>
<td>25.7</td>
<td>60.0</td>
<td>30.5</td>
</tr>
<tr>
<td></td>
<td>27.7</td>
<td>9.6</td>
<td>34.0</td>
<td>11.7</td>
<td>17.0</td>
<td>-</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>9</td>
<td>32</td>
<td>11</td>
<td>16</td>
<td>-</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td>6.7</td>
<td>9.7</td>
<td>20.8</td>
<td>24.3</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>39.9</td>
<td>13.3</td>
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</table>
Table 7. Direction of impact and impact area in accidents with severe occupant injury (AIS ≥ 3) in side-struck car

<table>
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<th>Direction of impact</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>Total</th>
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<td>1.7</td>
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<td>1</td>
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</tr>
<tr>
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<td>7.1</td>
<td>10.7</td>
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<td>100</td>
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<tr>
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<td>34</td>
<td>5</td>
<td>6</td>
<td>1</td>
<td>94</td>
</tr>
</tbody>
</table>

Figure 5. Involvement of cars with different mass ratios in side collisions compared with the car registration in the FRG in 1974.

of heavy vehicles exceeding 1 100 kg. A notable feature is that this risk factor already diminishes sharply in mass category 750-950 kg.

An important factor in determining test conditions is the fact that, in some 70 per cent of all collisions and in 65 per cent of all serious collisions, the mass of the striking vehicle was in the range up to 1 100 kg. The share reflected by the mass category 1 100 to 1 800 kg, namely 22.1 per cent and 23.4 per cent, is at all events also quite high.

Collision Speeds

For the reasons given, the collision speed of the striking vehicle is coordinated in figure 8 to the speed of the struck car at the moment of collision.

A significant result ensues from the fact that, in real-life accidents, a vehicle that is stationary or moving only very slowly, is almost always struck from the side at speeds below 45 km/h. The accident situation obviously has an influence on the collision speeds — the faster the struck car is travelling, the higher the collision speed of the striking vehicle. The characteristics of energy dissipation therefore normally differ in low- and high-speed side impacts.
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Figure 6. Mass ratio in side collisions depending on the injury severity in the side-struck car.

Figure 7. Collision frequency and mass ratio in car/car and car/truck side collisions.
### Table 8. Vehicle mass categories and collision frequency in all car/vehicle side collisions

<table>
<thead>
<tr>
<th>Striking vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side struck car</td>
</tr>
<tr>
<td>&lt;=750</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>751 - 950</td>
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<tr>
<td></td>
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<tr>
<td>951 - 1100</td>
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<tr>
<td></td>
</tr>
<tr>
<td>1101 - 1800</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

*Occupants OSI > 3

Number of occupants

Some 75 per cent of all vehicles involved in side collisions were impacted at a speed of less than 45 km/h, and 95 per cent 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 [15] only 40 to 45 per cent of the kinetic initial energy is transformed into deformation energy, the remainder being consumed in post-crash movement. 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 per cent of all real-life collisions.

The Location of Damage in The Occupant Compartment (Collision Areas II/III)

In connection with the significant Collision Areas II/III, a detailed analysis was conducted to determine the typical types of damage occurring in the occupant compartment between the A and C posts and to thus establish indicative pointers on specific countermeasures for reducing the risk of injury in side collisions.

In about 45 per cent of the 463 side collisions in Area II/III, the area of main deformation embraced almost the entire occupant compartment (fig. 9). The area between the A and B post suffers the maximum damage twice as frequently as the area behind the B post. The significance of the B post in preventing compartment intrusion is clearly demonstrated in figure 9.

Differentiation can be made between two typical forms of intrusion, namely:

- **The rectangular form:** The typical characteristic here is intrusion over a broad area, with the A and B posts absorbing the deformation energy equally in most cases.
Table 9. Vehicle mass categories and collision frequency in accidents with severe occupant injury (OSI $> 3$)

<table>
<thead>
<tr>
<th>Striking vehicle</th>
<th>$&lt; 750$ kg</th>
<th>751 – 950</th>
<th>951 – 1100</th>
<th>1101 – 1800</th>
<th>$&gt; 1800$ kg</th>
<th>Total</th>
</tr>
</thead>
<tbody>
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<td>23</td>
</tr>
<tr>
<td></td>
<td>13.0</td>
<td>52.1</td>
<td>13.0</td>
<td>8.9</td>
<td>13.0</td>
<td>100</td>
</tr>
<tr>
<td>751 – 950</td>
<td>2</td>
<td>13</td>
<td>8</td>
<td>14</td>
<td>5</td>
<td>42</td>
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<tr>
<td></td>
<td>4.7</td>
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<td>19.2</td>
<td>33.3</td>
<td>11.9</td>
<td>100</td>
</tr>
<tr>
<td>951 – 1100</td>
<td>1</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>4.3</td>
<td>34.7</td>
<td>26.4</td>
<td>17.3</td>
<td>17.3</td>
<td>100</td>
</tr>
<tr>
<td>1101 – 1800</td>
<td>–</td>
<td>4</td>
<td>–</td>
<td>2</td>
<td>–</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>66.6</td>
<td>33.4</td>
<td>–</td>
<td>–</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>37</td>
<td>17</td>
<td>22</td>
<td>12</td>
<td>94</td>
</tr>
</tbody>
</table>

|                  | 6.3        | 39.4      | 18.1       | 23.4        | 12.8        | 100   |

- The triangular form: In the case of an angled direction of between 45 and 75 degrees, or in collisions with a strong rotational motion of the colliding vehicles, deep localised intrusion in the surface of the door frequently results. Here, the B post has to absorb the main deformation stress load; in quite a considerable number of cases under review, the B post was torn away, thus making possible severe intrusion.

Examples of these forms of intrusion are furnished in figure 10.

In approximately 35 per cent of collisions in Areas II/III intrusion occurs, of which 60 per cent is triangular and some 40 per cent rectangular in form. Figure 11 shows the centre of deformation and the static depth of impression in triangular and rectangular intrusions in the area of the door, whereby—for clearer analysis—only those cases were studied in which documentary data on both vehicles were available.

The maximum intrusion in triangular form is to be found primarily in the area of the H-point of the occupant in front of the B post. Here, a static intrusion depth of 30 to 40 cm occurs with relative frequency. Rectangular intrusion, on the other hand, is distributed over the entire area of the door without any sharply defined point of maximum intrusion and, in the majority of cases under review, results in a static impression of 20 to 30 cm.

Figure 12 shows the area of maximum intrusion in a vertical direction. In almost 70 per cent of all cases, the maximum intrusion was in the region of the door centre line, extending over the entire vertical door area,
more frequently in triangular form than in rectangular form.

With few exceptions the doorsill is only glanced by the striking vehicle upon impact, so that the main energy dissipation must be absorbed by the door area and the B post.

By virtue of the frontal/side stress load on the B post, the roof is drawn downwards more often in triangular intrusion than in the case of rectangular intrusion, resulting in an additional risk of head injuries to the occupants on the impact side.

This review of the forms of intrusion should not, however, be regarded as an isolated factor; on the contrary, it must be considered in integral relationship to the collision severity and the resultant injuries.

Injuries to Occupants

The overall injuries suffered by occupants in respect to each collision area are listed in table 4.
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This is particularly evident in the direct comparison of risk in table 9, where the nonbelted opposite-side occupant is frequently thrown onto the occupant seated in the area of collision, adding to the latter's injuries.

The risk to which the impact-side occupant is exposed becomes even more evident when comparing the injuries to individual parts of the body (table 12). For simplification, only the injuries to drivers and front-seat passengers were taken into account. A total of 826 drivers and front-seat passengers were seated on the impact side and 606 on the opposite side. The impact-side occupant suffers injuries to all areas of the body—with the exception of the lower extremities—more frequently, abdominal injuries being the most prominent with 11.7 per cent as against 6.4 per cent in the case of opposite-side occupants. 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.

The direction of impact also has a decisive influence on the risk of injury. In table 13, injuries to the driver/front-seat passenger on the impact side are subdivided according to right-angled and other lateral directions of impact. These lateral directions showed a slightly greater risk of head injuries (53.2 per cent), injuries to the upper extremities (53 per cent), and the spine (22.1 per cent) than the right-angled collisions. In the case of right-angled directions of impact, abdominal injuries (14.4 per cent) are elevated and injuries to the chest and lower extremities being almost balanced. The significance of the side surface in relation to abdominal injuries becomes even more evident when comparing the risk of injury (such as severity degree AIS 3) in the case of almost right-angled direction of impact (5.1 per cent) with other lateral directions of impact (2.5 per cent). The 90-degree side test thus reflects, above all, the risk of abdominal injury, the risk of injury to other areas of the body being represented in all lateral directions of impact.

An important factor in assessing the risk of injury in side collisions is the comparison of occupant injuries between impact and opposite side. Table 10 takes into account injuries to all occupants. Table 11 lists only cases in which the cars were occupied by the driver and a front-seat passenger, thus allowing a direct comparison of risk.

Severe and fatal injuries occur two to three times more frequently on the impact side than on the opposite side. The influence on injuries exerted by the nature of the force load becomes evident upon comparison of severely injured occupants as from severity degree AIS 3. Whereas the risk of injury to occupants is about the same for both the impact and opposite sides, in the case of collisions in the frontal/side area I the frequency of severe injuries to the impact-side occupant in the case of collisions in Area II increases to double, and in Area III to three times that for the opposite-side occupant.
Figure 10. Typical exterior and interior deformation in triangular and rectangular intrusion characteristic.
The percentage of multiple rib fractures, pelvic and hip joint fractures in chest, and abdominal injuries is relatively high; in the case of surviving occupants (OSI 2-5), internal chest and abdominal injuries were not found very often, although these types of injury are a dominant factor in fatalities. Fractures to the femur, lower arm, and lower leg predominate in injuries to the extremities. A notable feature is the almost complete absence of patella fractures. The fractures to femur and lower leg would appear, above all, to result from lateral force initiation, as longitudinal force load would also lead to severe injuries to the knee. In collisions involving fatalities, severe injuries to the skull predominate (table 15).

The location of typical injuries to the side of the body exposed to or averted from the collision is shown in table 16. Practically all pelvic, femur, and rib fractures were suffered on the side of the body exposed to the collision. Fractures to the arms, large-area soft tissue injuries, and facial skull fractures are frequently found in cases where the occupants are thrown from one side of the vehicle to the other. Here, safety belt usage can bring about a reduction in such injuries.

A major problem in side collisions is the direct force load on the impact-side occupant. This initiation of force can emanate from the excessive relative impact speed of the occupant against the inadequately upholstered interior side surface or from excessive intrusion in the exterior side area. In real-life collisions, however, there is a causal cohesion between intrusion and speed variation of the occupant compartment in a sideways direction, so that reliable division of these factors relative to injury causes is, in the majority of cases, not possible.

Table 17 does not evaluate the intrusion relative to the injuries, it shows whether injuries of a certain degree of severity occur only if there is excessive intrusion, or whether such injuries also occur in the absence of or with only minor intrusion.

Severe injuries (severity degree AIS 3 and even AIS 4/5) occur numerically and relatively often, even where there is little or no static intrusion present. Pelvic and multiple
Figure 12. Location and depth of intrusion in vertical direction (car/vehicle accidents).

Table 10. Injury risk of all car occupants on impact and opposite side

<table>
<thead>
<tr>
<th>Impact area</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td><strong>Fatalities AIS 6:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact side</td>
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<td>7</td>
<td>5</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>16</td>
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<tr>
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<td>6.0</td>
<td>1.6</td>
<td>1.6</td>
<td>-</td>
<td>-</td>
<td>7.8</td>
</tr>
<tr>
<td>Opposite side</td>
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<td>3</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>7.8</td>
</tr>
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<td></td>
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<td></td>
</tr>
<tr>
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<td>11</td>
<td>23</td>
<td>3</td>
<td>3</td>
<td>-</td>
<td>54</td>
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<tr>
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<td>3.9</td>
<td>9.4</td>
<td>7.5</td>
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<td>5.9</td>
<td>-</td>
<td>6.0</td>
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<td>51</td>
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<td>703</td>
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<td>1</td>
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<td></td>
</tr>
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<td>25.4</td>
<td>25.0</td>
<td>-</td>
<td>21.8</td>
</tr>
</tbody>
</table>

Total occupants on the impact side (100%) | 362 | 117 | 308 | 62 | 51 | 5 | 905 |

Total occupants on the opposite side (100%) | 379 | 122 | 222 | 59 | 60 | 6 | 848 |
Table 11. Injury risk of driver and front-seat passenger on impact and opposite side (only cases with driver and front-seat passenger in the side-struck car)

<table>
<thead>
<tr>
<th>Impact area</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>Total</th>
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<td>–</td>
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<td>1.9</td>
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<td>–</td>
<td>3.3</td>
</tr>
<tr>
<td>Slightly injured persons AIS 1+2:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>–</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>18.5</td>
<td>33.8</td>
<td>40.7</td>
<td>39.3</td>
<td>–</td>
<td>–</td>
<td>26.5</td>
</tr>
<tr>
<td>Total occupants on the impact side (100%)</td>
<td>184</td>
<td>52</td>
<td>130</td>
<td>27</td>
<td>28</td>
<td>1</td>
<td>422</td>
</tr>
<tr>
<td>Total occupants on the opposite side (100%)</td>
<td>184</td>
<td>52</td>
<td>130</td>
<td>27</td>
<td>28</td>
<td>1</td>
<td>422</td>
</tr>
</tbody>
</table>

Table 12. Injuries to the individual body areas of driver and front seat passenger on the impact side in dependency upon the impact area.

<table>
<thead>
<tr>
<th>Injured body areas</th>
<th>AIS</th>
<th>Head</th>
<th>Chest</th>
<th>Abdomen</th>
<th>Upper extremities</th>
<th>Lower extremities</th>
<th>Spine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact side (total 826 occupants):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury severity</td>
<td>1</td>
<td>43.6</td>
<td>17.5</td>
<td>8.3</td>
<td>45.8</td>
<td>29.5</td>
<td>17.7</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5.7</td>
<td>2.9</td>
<td>0.1</td>
<td>4.6</td>
<td>1.2</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>3-5</td>
<td>2.0</td>
<td>1.8</td>
<td>2.6</td>
<td>0.8</td>
<td>1.0</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1.1</td>
<td>0.7</td>
<td>0.7</td>
<td>–</td>
<td>–</td>
<td>0.1</td>
</tr>
<tr>
<td>Injury frequency</td>
<td>–</td>
<td>52.4</td>
<td>22.9</td>
<td>11.7</td>
<td>51.2</td>
<td>31.7</td>
<td>20.1</td>
</tr>
<tr>
<td>Opposite side (total 606 occupants):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury severity</td>
<td>1</td>
<td>36.4</td>
<td>15.2</td>
<td>5.3</td>
<td>39.3</td>
<td>37.6</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>7.3</td>
<td>2.2</td>
<td>0.4</td>
<td>3.0</td>
<td>2.6</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>3-5</td>
<td>1.5</td>
<td>0.7</td>
<td>0.7</td>
<td>1.1</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.6</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Injury frequency</td>
<td>–</td>
<td>45.8</td>
<td>18.1</td>
<td>6.4</td>
<td>43.4</td>
<td>40.4</td>
<td>15.9</td>
</tr>
</tbody>
</table>
Table 13. Injuries to the individual body areas: driver and front-seat passenger versus direction of impact

<table>
<thead>
<tr>
<th>Direction of impact</th>
<th>AIS</th>
<th>Head</th>
<th>Chest</th>
<th>Abdomen</th>
<th>Upper extremities</th>
<th>Lower extremities</th>
<th>Spine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3-5</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right angled (Total 243 persons)</td>
<td>50.5</td>
<td>23.6</td>
<td>14.4</td>
<td>47.7</td>
<td>31.5</td>
<td>15.3</td>
<td></td>
</tr>
<tr>
<td>Injury severity of impact side</td>
<td></td>
<td>43.5</td>
<td>18.0</td>
<td>9.3</td>
<td>44.9</td>
<td>28.7</td>
<td>13.0</td>
</tr>
<tr>
<td>1</td>
<td>4.2</td>
<td>3.2</td>
<td></td>
<td>1.9</td>
<td>2.3</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.9</td>
<td>1.9</td>
<td>4.6</td>
<td>0.9</td>
<td>0.5</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>3-5</td>
<td>0.9</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.9</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other lateral (Total 583 persons)</td>
<td>53.2</td>
<td>22.6</td>
<td>10.6</td>
<td>53.0</td>
<td>31.3</td>
<td>22.1</td>
<td></td>
</tr>
<tr>
<td>Injury severity of impact side</td>
<td></td>
<td>43.5</td>
<td>17.4</td>
<td>7.9</td>
<td>46.0</td>
<td>29.7</td>
<td>19.6</td>
</tr>
<tr>
<td>1</td>
<td>6.4</td>
<td>2.7</td>
<td>0.2</td>
<td>5.8</td>
<td>0.8</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2.1</td>
<td>1.7</td>
<td>1.7</td>
<td>1.2</td>
<td>0.8</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>3-5</td>
<td>1.2</td>
<td>0.8</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.9</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

rib fractures, too, occur with about the same numerical frequency in collisions with minor and major intrusion. In table 15, it is, of course, not possible to reflect the fact that in all collisions resulting in little or no intrusion, the injuries are mostly only of a slight nature, whereas in collisions with severe static intrusion the percentage of severe injuries and, above all, fatal injuries, is very high. But, in summing up, it can be said that limited intrusion will lead to a reduction in the risk of fatalities, but that limitation of intrusion embraces only a part of the injuries from AIS 2/5.

A large proportion of these injuries occurred with no or minor intrusion, and a realistic improvement in the present-day high risk of injury in side impacts also requires, in particular, a better interior structure to reduce injuries to occupants.

SUMMARY

Based on an analysis of 1 009 car/vehicle side collisions with lateral direction of impact, the accident characteristics, the damage to the struck car, and the injuries to the car occupants are described. The definitions thereby developed are elucidated in detail, as a contribution to the urgently required international standardisation of terminology.

Side collisions represent a grave focal point of car collisions involving injuries to occupants. Twenty-eight per cent of all fatally injured car occupants are seated in cars struck from the side. About 57 per cent of all car collisions involve a lateral and 43 per cent a longitudinal direction of impact. Collisions with lateral directions of impact result, on the whole, in more serious injuries, the risk of fatal injury in side collisions with lateral and longitudinal direction of impact is about the same. In view of the completely differing impact phase sequence, these collision types should be treated independently.

In side collisions with lateral direction of impact—as dealt with in this study—great significance attaches to Collision Area II/III, which accounts for 59.6 per cent of all side collisions with severe injuries to occupants. In almost 50 per cent of these collisions, the main deformation extends across the entire area of the occupant compartment, the centre of damage being mostly in the area of the front doors. The directions of impact in the
### Table 14. Typical types of lesion with injury severity AIS 2-5

<table>
<thead>
<tr>
<th>Type of lesion</th>
<th>Impact side AIS 2</th>
<th>Opposite side AIS 2</th>
<th>Impact side AIS 3</th>
<th>Opposite side AIS 3</th>
<th>Impact side AIS 4+5</th>
<th>Opposite side AIS 4+5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Head:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensive laceration</td>
<td>16</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye injury</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Face fracture</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>7</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>Skull fracture</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Cerebral injury</td>
<td>23</td>
<td>19</td>
<td>8</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td><strong>Spine:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe whiplash</td>
<td>13</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Nerve root damage</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Thoracic spine fracture</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Lumbar spine dislocation</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Lumbar spine fracture</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td><strong>Thorax:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture 1-2 ribs</td>
<td>18</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>Fracture 3-4 ribs</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Fracture of more than 5 ribs</td>
<td>-</td>
<td>-</td>
<td>13</td>
<td>3</td>
<td>1</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Sternum fracture</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Intra-thoracic injury</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td><strong>Abdomen/pelvis:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelvis fracture</td>
<td>-</td>
<td>-</td>
<td>16</td>
<td>1</td>
<td>1</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Sacroiliac fracture</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Hip-joint fracture</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Intra-abdominal injury</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td><strong>Upper extremities:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensive laceration</td>
<td>2</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Shoulder dislocation</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Shoulder fracture</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Clavicle fracture</td>
<td>14</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Humerus fracture</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Forearm fracture</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Hand fracture</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td><strong>Lower extremities:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensive laceration</td>
<td>-</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Dislocations</td>
<td>5</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Femoral fracture</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Patella fracture</td>
<td>-</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Fibula/tibia fracture</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Foot fracture</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

### Table 15. Killed occupants: area of extremely severe injuries (AIS ≥ 4)

<table>
<thead>
<tr>
<th>Body area</th>
<th>Number of injuries (AIS ≥ 4)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>9</td>
<td>69.2</td>
</tr>
<tr>
<td>Chest</td>
<td>5</td>
<td>38.5</td>
</tr>
<tr>
<td>Abdomen</td>
<td>4</td>
<td>30.8</td>
</tr>
<tr>
<td>Spine</td>
<td>1</td>
<td>7.7</td>
</tr>
<tr>
<td>Killed occupants (injuries ascertainable)</td>
<td>13</td>
<td>100</td>
</tr>
<tr>
<td>Killed occupants (injuries not ascertainable)</td>
<td>10</td>
<td>-</td>
</tr>
</tbody>
</table>

The majority of cases are at an angle of 60-80 degrees to the longitudinal axis of the vehicle. In 95 per cent of the cases, the impact speed of the other vehicle was less than 60 km/h. Although the conversion of impact speed between real-life collision conditions (two moving vehicles) and test conditions (one stationary and one moving vehicle) has today still not been satisfactorily solved, it can nevertheless be estimated that car side collisions with impact speed of 50 km/h to a maximum of 60 km/h represent at least 90 per cent of all real-life collisions.

The impact speeds to be applied in crash...
Table 16. Location of the typical lesions on the body side

<table>
<thead>
<tr>
<th>Type of lesion</th>
<th>Injured body side</th>
<th>Impact side</th>
<th>Opposite side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Driver</td>
<td>Front seat passenger</td>
<td>Driver</td>
</tr>
<tr>
<td></td>
<td>Left</td>
<td>Centre</td>
<td>Right</td>
</tr>
<tr>
<td>Head:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensive lacerations</td>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Face fractures</td>
<td>-</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Skull fractures</td>
<td>-</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Chest:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture 1-2 ribs</td>
<td>10</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Fracture 3-4 ribs</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fracture of more than 5 ribs</td>
<td>8</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Upper extremities:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clavicle fracture</td>
<td>8</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Shoulder fracture</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Humerus fracture</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Forearm fracture</td>
<td>2</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Hand fracture</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Abdomen pelvis:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelvis fracture</td>
<td>6</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Hip-joint fracture</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Intra-abdominal injuries</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lower extremities:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Femur fracture</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fibula/tibia fracture</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Foot fracture</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

Tests depend, above all, on a real-life related set-up of crash test and type of deformation. In side collisions, light vehicles in the mass category up to 750 kg are over-represented; heavy vehicles as from 1 100 kg are under-represented. Even in the range between 750 and 950 kg, considerable possibilities are in evidence of influencing the risk of injury by way of improved construction.

In 70 per cent of side collisions, the striking vehicle had a mass of up to 1 100 kg but vehicles in the mass category 1 100-1 800 kg were also represented with 20 per cent.

Mass aggressiveness poses a considerable problem in side collisions. In 50 per cent of the collisions, the striking vehicle is only 10-20 per cent heavier than the struck car. Difficulties, however, arise above all at the 90 per cent point—due to car/truck collisions—with an increase of the mass ratio to M = 1.75 for side collisions involving all degrees of injury severity and to M = 2.4 in respect to side collisions with severe injuries.

This report aims at creating, with the aid of these results, a basis for a reality-related set-up of side crash tests. For this reason, the forms of intrusion damage in the Collision Areas II/III were discussed in great detail. The majority of real-life intrusions of the occupant compartment constitute a triangular impression in the area of the front doors, with the B post absorbing a large share of the deformation energy. This form of damage results in deeper intrusions than the rectangular form, which conforms to the present-day crash test and in which the deformation energy is distributed more between the A and B posts.

The door sill is frequently glanced by the striking vehicle and is thus included in the energy dissipation only to a limited extent.

Side collisions reveal characteristic focal points of injury, in particular to the chest, abdomen, and lower extremities. The major problem in side collisions is the risk of injury to the impact-side occupant, which is three to
### Table 17. Typical lesion of impact-side passenger and kind of intrusion of passenger compartment

<table>
<thead>
<tr>
<th>Type of lesion</th>
<th>None/minor</th>
<th>AIS 2</th>
<th>AIS 3</th>
<th>AIS 4/5</th>
<th>Moderate</th>
<th>AIS 2</th>
<th>AIS 3</th>
<th>AIS 4/5</th>
<th>Severe</th>
<th>AIS 2</th>
<th>AIS 3</th>
<th>AIS 4/5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensive laceration</td>
<td>14</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>16</td>
</tr>
<tr>
<td>Face fracture</td>
<td>3</td>
<td>3</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Skull fracture</td>
<td>1</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Cerebral injury</td>
<td>16</td>
<td>6</td>
<td>-</td>
<td>4</td>
<td>2</td>
<td>-</td>
<td>6</td>
<td>-</td>
<td>3</td>
<td>37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spine:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe whiplash injury</td>
<td>14</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Thoraco-lumbar spine fracture</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Chest:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture 1-2 ribs</td>
<td>11</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>18</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>Fracture 3-4 ribs</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Fracture of more than 5 ribs</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>14</td>
</tr>
<tr>
<td>Intra-thoracic injuries</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Clavicle fracture</td>
<td>11</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>17</td>
</tr>
<tr>
<td>Shoulder fracture</td>
<td>3</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Abdomen/pelvis:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pelvis fracture</td>
<td>-</td>
<td>8</td>
<td>-</td>
<td>3</td>
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<td>-</td>
<td>-</td>
<td>8</td>
<td>19</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>19</td>
</tr>
<tr>
<td>Hip-joint fracture</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Upper extremities:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensive laceration</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Shoulder dislocation</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Humerus fracture</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Forearm fracture</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Hand fracture/dislocation</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Lower extremities:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dislocations</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Femoral fracture</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Lower leg fracture</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Foot fracture</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Number of injuries on all body areas</td>
<td>91</td>
<td>31</td>
<td>3</td>
<td>18</td>
<td>15</td>
<td>2</td>
<td>11</td>
<td>19</td>
<td>7</td>
<td>197</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An overall reduction in the injuries sustained in side collisions—which is absolutely essential in view of the significance of side collisions—thus requires a further optimisation of the side structure from the aspect of both external and internal impact.

### REFERENCES


Description of Lateral Impacts

F. HARTEMANN, C. THOMAS, J. Y. FORET
BRUNO, C. HENRY, A. FAYON, and C.
TARRIERE
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l'Association Peugeot-Renault
C. GOT AND A. PATEL
Institut de Recherches Orthopediques de
l'Hopital Raymond Poincare

ABSTRACT

A representative sample of 296 severe lateral impacts that have caused occupant injuries occurring in the French network is characterised by:

- The distribution of impact points and angles
- The distribution of car-speed variation (ΔV)
- The frequency and degree of wall deformations

The effects of these various factors on the occupant's condition (type and severity of lesions) are analysed, and recommendations are made for efficient protection in this kind of impact.

INTRODUCTION

The difficulty in obtaining efficient protection during lateral impacts is obvious when it comes to producing acceptable industrial solutions. Compared with conditions specific to frontal collisions and on the basis of the first experimental results, it is suggested that an upper limit to actual protection could be stated for speed variations of about 35 km/h.

Much progress has been made in protection against risks encountered in frontal impacts in these last years. Thanks to close cooperation, the structure and equipment engineers, biomechanists, physicians, and accidentologists have been able to define the protection systems best suited to human tolerances and most capable of acting efficiently within a wide frontal accident range. Economic con-
hit, sometimes the lateral trajectory of the occupants), we believe it pertinent to include in this category of impacts (fig. 1):

- All those that involve a trajectory of the occupants included between the hour-hand clock positions of 1:30 and 4:30 or 7:30 and 10:30 (the longitudinal axis of the car corresponding with the 6-12:00 axis, the front oriented towards 12:00)
- The cases in which the trajectory is of a front or rear type, but the deformation of the lateral wall is at the level of the occupant on the impact side

**REPRESENTATIVE NATURE OF SAMPLE ANALYSED**

In the sample that was analysed the distribution of the vehicles involved as a function of the obstacle (table 1) is close to the national distribution (ONSER statistics, 1969).

<table>
<thead>
<tr>
<th>Category</th>
<th>Peugeot-Renault sample (%)</th>
<th>National sample (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>66</td>
<td>70</td>
</tr>
<tr>
<td>Truck</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>Fixed obstacle</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Other obstacles</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

The occupation ratio (1.96) is slightly higher than the national ratio given for all of France (1.87).

The severity of the impacts is higher, as shown in table 2.

These differences in severity are simply a reflection of the fact that we considered a smaller proportion of accidents with benign consequences for the occupant than is considered in national statistics.

**CONFIGURATIONS AND SEVERITY OF LATERAL IMPACTS**

**General Statement**

The great majority of lateral impacts are of the car-to-car type (table 3). Impacts against fixed and rigid obstacles occur four times less frequently, but their severity is such that they are responsible for 34 percent of the deaths. Trucks are the colliding vehicles in only 9 percent of the deaths; this is relatively small compared to their rate of involvement in fatal impacts against the front of cars.

The particular nature of impacts against fixed and rigid obstacles necessitates a separ-
Table 3. Distribution of overall AIS according to types of obstacles

<table>
<thead>
<tr>
<th>Obstacles</th>
<th>Side-impacted cars</th>
<th>Total, AIS as % of all occupants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% No.</td>
<td>% No.</td>
</tr>
<tr>
<td>AIS:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>23 90</td>
<td>25 12</td>
</tr>
<tr>
<td>% of all occupants</td>
<td>74</td>
<td>90</td>
</tr>
<tr>
<td>1.2</td>
<td>56 215</td>
<td>49 24</td>
</tr>
<tr>
<td>% of all occupants</td>
<td>69</td>
<td>90</td>
</tr>
<tr>
<td>3.4.5</td>
<td>14 54</td>
<td>16 8</td>
</tr>
<tr>
<td>% of all occupants</td>
<td>56</td>
<td>90</td>
</tr>
<tr>
<td>&gt;6</td>
<td>07 28</td>
<td>10 5</td>
</tr>
<tr>
<td>% of all occupants</td>
<td>50</td>
<td>90</td>
</tr>
<tr>
<td>Total, all occupants</td>
<td>100</td>
<td>387</td>
</tr>
</tbody>
</table>

rate discussion that will follow this discussion of the car-to-car collisions.

Car-to-Car Side Impacts

The ratio of the weight of the colliding cars influences the frequency and severity of the lesions undergone by the occupants of the cars in the collision (table 4). The differences found between the frequency of appearance of each class of car as the class of the colliding car and the class of car collided with arise from a systematic sampling bias.

In effect, the inclusion of a car in the study is most often determined by the presence of an injured occupant; as a consequence, the probability of one type of car being included depends on the frequency of its involvement in accidents and the quality of protection that it affords to the occupants.

In the case of lateral impacts, there is no reason for one category of car to be more collided with than colliding. On the other hand, a certain category of car will be frequently accepted in our study because it is either more vulnerable (for the reason indicated above), or, on the contrary, more "wounding," since in the latter case, it will appear as a colliding car (we systematically identify the two elements involved in our car-to-car collisions). (See figs. 2 and 3.)

Figure 3 represents the number of cases in which each class of car is involved in a lateral collision, either as a car collided with or as the colliding car. We assume that each category is as often collided with as colliding. The rectangles are in proportion to the representation of each category in a car park (gross estimate).

The hatched portions in the upper zone represent the number of cars collided with in each class in which no occupant was injured; in the lower zone, the hatched portion represents the number of colliding cars in the same

Table 4. Relative mass of vehicles involved in car-to-car side collisions

<table>
<thead>
<tr>
<th>Mass of impacted vehicles (kg)</th>
<th>Percentage of mass (kg) of impacting vehicles</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;750</td>
<td>750 to 950</td>
</tr>
<tr>
<td>&lt;750</td>
<td>2.6</td>
<td>13.4</td>
</tr>
<tr>
<td>750 to 950</td>
<td>3.6</td>
<td>16.0</td>
</tr>
<tr>
<td>950 to 1 150</td>
<td>2.6</td>
<td>5.1</td>
</tr>
<tr>
<td>&gt;1 150</td>
<td>2.0</td>
<td>3.1</td>
</tr>
<tr>
<td>Total</td>
<td>10.8</td>
<td>37.6</td>
</tr>
</tbody>
</table>
class in which no one in another car was injured.

We can easily understand that the probability of the classes being analysed is represented by the nonhatched surfaces. This is the sampling bias of any statistical analysis based solely on accidents with injuries.

In the absence of such bias, the differences in the severity rate between mass classes, that is:

\[
\frac{\text{killed + severely injured}}{\text{occupants}} \times 100
\]

would be more important. The severity rate (internal severity) for small cars (<750 kg) involved in lateral collisions is 29.8, twice as high as the rate they provoke in the cars of the heaviest class (>1150 kg). (See table 5.)

### Table 5. Comparison between internal severity (the impacted vehicle belongs to the class mentioned) and external severity (caused in any mass class vehicle impacted by vehicles of the class mentioned) in conjunction with a lateral impact

<table>
<thead>
<tr>
<th>Severity</th>
<th>Mass classes (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;750</td>
</tr>
<tr>
<td>Internal</td>
<td>29.8</td>
</tr>
<tr>
<td>External</td>
<td>14.9</td>
</tr>
</tbody>
</table>

The mean weight of the cars wherein severe injuries or deaths are found is 880 kg; they are collided with by cars whose mean weight is 1000 kg.

The points of impacts on the cars are distributed around a central point with maximum probability of impact situated 55 cm behind the A-pillar and about 20 cm forward of the Hx-point. With respect to only the impacts that involved severe or fatal injuries, the impact point is located approximately 15 cm further back, almost at the level of the Hx-point. We determined these points from the frequencies with which the various zones that distinguish the system of VDI classification (table 5) are affected. This system arbitrarily involves a discontinuity in the form of an all-or-nothing designation: Each of the three zones (front, passenger compartment, and rear) is, in effect, considered totally or not at all affected. (See fig. 4.)

We have thus restored real continuity by a probability method, taking for the mean dimensions:

- Width of the front of the cars: 1.50 m
- Zone F-area (from A-pillar to the bumpers): 1.40 m
- Zone P-area (passenger compartment): 1.80 m
- Zone B-area (from C-pillar to rear bumpers): 1 m

From these calculations, it can be deduced that the reproduction of the greatest number of lateral car-to-car collisions will occur through an impact in which the front centre of the colliding car is at a point situated 55 cm behind the A-pillar. The point will be 10 cm farther back if this involves representing severe or fatal collisions.
SECTION 4: TECHNICAL SEMINARS

occupants; the angle is slightly more open in cases of severe injuries and deaths.

A configuration representative of a car-to-car lateral impact that would be severe for an occupant would be the one where the front centre of one vehicle impacts the other laterally, 10 cm forward of the projection of Hx-point on the wall. Furthermore, speeds and collision angles should be arranged so that the apparent trajectory of the impacted vehicle's occupant makes a 70-degree angle with the longitudinal axis of the vehicle.

Speed Variation. The $\Delta V$ is calculated assuming that the impacted car is stationary. The longitudinal component is considered null. The computation method [5] requires the evaluation of either the energy absorbed during the impact of the cars or the respective equivalent test speeds (ETS). Such an evaluation is very difficult to make on the impacted vehicle; reference must be made to numerous experimental impacts. Now, we could ascertain that our evaluations were accurate enough. In fact, we have compared the $\Delta V$ estimated by the technicians of the accident investigation team with those deduced from

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**Figure 4. Distribution of impact probabilities along the side of the car by the front centre of the impacting car.**

**Figure 5. Distribution of occupant trajectory angles.**

71 occupants AIS $\geq$ 3
$55^\circ < \alpha < 85^\circ$ for 51% cases

All occupants (N = 196)
$45^\circ < \alpha < 75^\circ$ for 50% cases
the recordings on experimental lateral collisions. There is a correspondence of ±10 percent. The impacted car's ETS is estimated for a simulated test against a rigid obstacle. In the real accidents (shown in fig. 6), the impacted car ΔV (Peugeot 104) was estimated at 35 km/h; the impacting car's (Renault 16) collision speed was estimated at 65 km/h. The impact was recently simulated at 65 km/h (car impacted at standstill). It may be seen that the deformations are correctly reproduced.

The influence of a given car's ΔV on the condition of the occupant during a lateral impact is largely a function of the configuration of the impact. When an impact involves the passenger compartment to the right of the occupant and causes an intrusion, the contact between the wall and the occupant takes place at a speed that is often greater than the car's ΔV. Conversely, an impact involving the front or rear of the passenger compartment generally causes rotation of the car in such a way that the speed of occupant/wall contact will be lower than that indicated by the ΔV of the car. It is only in the case of an impact with no intrusion that the ΔV and speed of occupant/wall contact are very close. Cars are made in such a way that this occurrence is very rare.

For these reasons, the distribution curves of the cases as a function of ΔV (fig. 7) gain by being compared with the illustrations (fig. 6) on the effects of intrusion (also see table 6).

Intrusion. A passenger compartment intrusion increases the risk of lesions for two reasons.

1. On the one hand, a wall-sustaining intrusion moves at the beginning of impact at a speed that may be very close to the impacting vehicle's speed. Such is the case when the wall is very deformable and the impacting vehicle is aggressive. As to the occupant's risk contact speed with the wall will be all the higher because the occupant is closer to the wall before impact. In any case, the contact speed for a nearside occupant is higher than the speed (ΔV) at which the

Figure 6. Reconstruction of a real accident: Peugeot 104 struck by a Renault 16.

Figure 7. ΔV distribution in car-to-car collisions.

- A—All occupants (N = 384)
- B—Severely injured and deaths (N = 81)
whole vehicle is moved whenever the structure's strong members are acted upon by forces.

2. Intrusion deforms the inner face of the vehicle, and the occupant then impacts members that have become aggressive as a result of deformations.

It is obvious that evaluation of the speed at which a wall is displaced in a real accident is quite impossible. If there exists a relationship between the severity rate and the \( \Delta V \), it comes from the fact that contact speed between the occupant and the wall depends on the \( \Delta V \). But it is not a single function. At a constant \( \Delta V \), the relative velocity with which the occupant hits the damaged side varies on the one hand with the amount of intrusion occurring before his total car shifts sideways and with the initial distance between the occupant and the interior side; on the other hand, it also varies with the occupant's position with respect to the axis upon which his car is rotated when the impact occurs against the front or the rear part of the car. In the case of rotation, the relative velocity with which the occupant hits the interior side may be inferior to the \( \Delta V \). Furthermore, the contact with the side is more often oblique than perpendicular, as shown in Table 7. Table 7 illustrates the importance of this difference for \( \Delta V > 25 \text{ km/h} \) in comparison with the small difference observed in impacts with intrusion.

A nonintruded, occupant/wall contact within a closed angle is certainly less dangerous than a wall contact along a perpendicular trajectory. These concepts have been clearly introduced by Lister and Neilson [6]. Here are the main reasons why the differences between nearside occupant severity rates with intrusion and nearside severity rates without intrusion (Fig. 8 and Table 8) would not be automatically cancelled by a solution consisting of reinforcing cars to prevent intrusion. All things being equal, such a solution would necessarily bring an increase of \( \Delta V \).

It is very difficult to anticipate, on the basis of observation of real lateral impacts, the effects to be expected from measures combining intrusion reduction and padding of walls by means of shock-absorbing materials. It would be necessary to measure the specific effects of intrusion, those that are ascribable to the padding, and those resulting from a combination of both factors at various levels.

Now, on the one hand, nonintrusive impacts are very specific and are not suited to comparison with other impacts whereas, on the other hand, we did not take into account for purposes of case analysis, the shock-
one of an extreme violence and accompanied by a deep intrusion. In case of impact without intrusion, being close to the wall or far away from it certainly does not play a major part, unless it is perhaps to the closer occupant’s advantage since he may profit from a coupling with the wall before it reaches its maximum speed. This obviously depends on the shape of the acceleration pulse of the struck car.

The fact of being accompanied increases or reduces risks (whether the occupant is nearside or not) in proportions that are certainly different for impacts with or without intrusion. In case of intrusion, the effect of overload for the nearside occupant takes place after he has sustained the intruded-wall impact at a speed close to the impacting vehicle speed; it might be said that “all the bad is already done” when the overload occurs. For this reason, the increase of overload has to be proportionally lower for impacts with intrusion than for those without intrusion.

These assumptions are difficult to verify by accident statistics. Experimental impacts will verify these assumptions quicker than accident investigations.

Car-Rigid-Fixed Obstacle Impact

The fixed obstacles to be considered are street signposts and lampposts, trees, walls, and parapets: obstacles limiting the roads and most often impacted after skidding.

The distribution by mass classes for those cars involved in this type of accident differs from that of car-to-car collisions (table 9).

Impact points on a car are centred on the passenger compartment (table 10), and it is in this configuration that their consequences are the most detrimental to the occupants.

Table 8. Number of occupants plotted in figure 8

<table>
<thead>
<tr>
<th>Occupants</th>
<th>Classes of ΔV (km/h)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;15</td>
<td>16 to 25</td>
</tr>
<tr>
<td>Nearside:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With intrusion</td>
<td>14 48</td>
<td>27 10</td>
</tr>
<tr>
<td>Without intrusion</td>
<td>25 45</td>
<td>12 10</td>
</tr>
<tr>
<td>Offside:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With intrusion</td>
<td>19 37</td>
<td>21 18</td>
</tr>
<tr>
<td>Without intrusion</td>
<td>21 35</td>
<td>13 9</td>
</tr>
</tbody>
</table>
Table 9. Distribution of cars by class of mass as a function of the type of obstacle

<table>
<thead>
<tr>
<th>Type of obstacle</th>
<th>Mass classes (kg)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;750</td>
<td>750 to 950</td>
</tr>
<tr>
<td>Fixed obstacle (%)</td>
<td>6.4</td>
<td>50.5</td>
</tr>
<tr>
<td>Car obstacle (%)</td>
<td>27.9</td>
<td>35</td>
</tr>
</tbody>
</table>

Table 10. Distribution of cases as a function of impact areas in car-to-fixed-obstacle collisions

<table>
<thead>
<tr>
<th>Category</th>
<th>Impact areas</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Y</td>
</tr>
<tr>
<td>Vehicles:</td>
<td>No.</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>17</td>
</tr>
<tr>
<td>Occupants:</td>
<td>No.</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>16</td>
</tr>
<tr>
<td>Severely injured and killed:</td>
<td>No.</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>13</td>
</tr>
</tbody>
</table>

By using the same method used in car-to-car impacts, the probability was determined for each side point of the car to be situated within the impact interface in case of collision against fixed obstacle (fig. 9). The latter obstacle is similar to a pole 400 mm in diameter.

The apparent occupants' trajectory angles relative to the vehicle's longitudinal axis are between 49 degrees and 75 degrees for the majority of occupants that have sustained the most severe lesions (AIS $\geq 3$) (fig. 10).

The $\Delta V$ constitutes the principal factor of severity for the occupant (fig. 11). The mean severity is very high because 52 percent of the occupants involved in this type of lateral impact are killed or severely injured; this explains why the $\Delta V$ curves are very similar.

Figure 9. Impact points distribution in side impacts against fixed obstacles.
considered that this difference is an estimate of the average difference between an intruded-wall contact speed and an unintruded-wall contact speed, or a speed corresponding to the car's $\Delta V$, for which the wall is responsible.

These rather theoretical considerations lead us to be pessimistic. Limiting the intrusion risks is not very useful in reducing the severity of impacts against fixed obstacles, although it prevents the passenger compartment’s padding from losing its efficiency. Intrusion, in effect, could modify padding positions relative to the occupant trajectories.

An example of high-efficiency padding is given in figure 13. Impact speed and $\Delta V$ are estimated at 40 km/h. One has a 70-cm measured intrusion (rear displacement of B-pillar). Seatback and headrest have played the part of providential padding. The driver, alone in the car, has sustained only minor thoracic contusion.

**Characteristics of Representative Lateral Impacts**

In car-to-car impacts the contact point of impacting the vehicle’s centre is located 10 cm in front of the Hx-point. The impact angle
Figure 13. Case D—Peugeot 504: $ETS = \Delta V = 40 \text{ km/h}$. The seat is twisted and works as padding. Driver AIS: 1.
SECTION 4: TECHNICAL SEMINARS

Figure 12. $\Delta V$ distributions for severe and fatal side collisions.

will be such that the apparent trajectory of occupants will make a 70-degree frontward angle to the longitudinal axis of impacted car (fig. 14).

Because of mean masses of confronted vehicles (1 000 kg for impacting cars against 880 kg for impacted cars), a $\Delta V$ considered as a superior limit for 50 percent of the killed and severely injured (33 km/h) could be achieved during a test with an impact speed of 62 km/h. A percentage of 75 percent would correspond to a $\Delta V$ of 43 km/h and an impact speed of 81 km/h. These are high speeds, however, and do not take into account the fact that the cases in our sample are more severe than those in the national lateral impact sample (concerning severe or fatal injuries to occupants).

For car impacts against a fixed-rigid obstacle, the impact was about 20 cm forward of the Hx-point against a 400-mm in diameter pole. The direction was fixed so that the occupant trajectory would be between 48 and 75 degrees (fig. 14).

An impact speed of 34 km/h accounts for 50 percent of accidents causing severe injuries or death. In order to reach 75 percent of the distribution, a speed of 42 km/h would be required.

Frequency, Severity, and Causes of Injuries

Most fatalities are caused by impacts against the passenger compartment (table 11). Impacts involving the front or rear portion of the car are especially dangerous because
secondary ejection that did not aggravate their condition.

The lesions per body area and the distribution of their severity are shown in table 12.

The abdomen, thorax, and head are nearly equally exposed to severe lesions for AIS \( \geq 4 \). These lesions are summarily classified by body area in table 13.

The exposure of the various body areas is unequal. Certain areas are frequently injured but below the average severity; others, on the contrary, are very seldom involved but severely affected. It is interesting to assign to each one a value integrating the frequency and the severity of lesions sustained and to take into account the fact that discrepancies between AIS levels are respected when each AIS is cubed.

The societal cost of the injured increases proportionally to the cube of the overall AIS [7]. By cubing the AIS of head, neck, thorax, abdomen, and pelvis of each occupant involved in a lateral impact, and then adding AIS 3 for each body area, and relating the sum to the overall total, one obtains (fig. 15):

<table>
<thead>
<tr>
<th>Body area</th>
<th>AIS &lt;4</th>
<th>AIS ( \geq 4 )</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>244</td>
<td>24</td>
<td>268</td>
</tr>
<tr>
<td>Neck</td>
<td>31</td>
<td>2</td>
<td>33</td>
</tr>
<tr>
<td>Thorax</td>
<td>108</td>
<td>22</td>
<td>130</td>
</tr>
<tr>
<td>Abdomen</td>
<td>12</td>
<td>31</td>
<td>43</td>
</tr>
<tr>
<td>Pelvis</td>
<td>48</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>Lower members</td>
<td>30</td>
<td>0</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 12. Injuries: frequency and severity per body area

<table>
<thead>
<tr>
<th>Impact area</th>
<th>AIS 0.1.2</th>
<th>AIS 3.4.5</th>
<th>AIS ( \geq 6 )</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>To front or rear of passenger compartment:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonejected nearside occupants</td>
<td>114</td>
<td>6</td>
<td>2</td>
<td>122</td>
</tr>
<tr>
<td>Ejected nearside occupants</td>
<td>17 (0)</td>
<td>7 (6)</td>
<td>8 (6)</td>
<td>32</td>
</tr>
<tr>
<td>Nonejected offside occupants</td>
<td>93</td>
<td>11</td>
<td>0</td>
<td>104</td>
</tr>
<tr>
<td>Ejected offside occupants</td>
<td>13 (0)</td>
<td>3 (1)</td>
<td>1 (1)</td>
<td>17</td>
</tr>
<tr>
<td>In passenger compartment:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonejected nearside occupants</td>
<td>105</td>
<td>19</td>
<td>14</td>
<td>138</td>
</tr>
<tr>
<td>Ejected nearside occupants</td>
<td>6 (0)</td>
<td>1 (0)</td>
<td>3 (0)</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 11. AIS as a function of the impact area, and seating position relative to the impacted side

NOTE. Numbers in parentheses indicate ejected occupants whose lesions are the result of ejection.
Table 13. Type of lesion per body area

<table>
<thead>
<tr>
<th>Type of lesion</th>
<th>AIS 2</th>
<th>AIS 3</th>
<th>AIS 4</th>
<th>AIS 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skull:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture</td>
<td>5</td>
<td>4</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Cerebral concussion and unconsciousness</td>
<td>80</td>
<td>9</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Internal lesions</td>
<td></td>
<td></td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Face fracture</td>
<td>3</td>
<td>5</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Neck:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dislocation</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture</td>
<td></td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Chest:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clavicle fracture</td>
<td>3</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 fractured ribs</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/4 fractured ribs</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5/6 fractured ribs</td>
<td></td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flail chest</td>
<td></td>
<td></td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Internal lesions</td>
<td></td>
<td>10</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Abdomen:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spleen rupture</td>
<td></td>
<td></td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Liver rupture</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Spleen and liver lacerations</td>
<td></td>
<td></td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Liver and kidney</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Spleen and kidney</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Kidney rupture</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Colon</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Pelvis fracture</td>
<td>9</td>
<td>13</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lower member, femur fracture</td>
<td></td>
<td>23</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Head: 0.35
- Neck: 0.05
- Thorax: 0.25
- Abdomen: 0.26
- Pelvis: 0.09

Extremely severe injuries (AIS ≥ 4) to head, chest, abdomen, and pelvis are divided according to the impacted area inside the car, as follows (table 14).

The most severe lesions sustained by 27 people killed and autopsied are distributed as follows:

- Skull lesions: AIS 4 or 5 for 78 percent killed.
- Thoracic lesions: AIS 4 or 5 for 60 percent killed.
- Abdominal lesions: AIS 4 or 5 for 33 percent killed.

The association of the above-mentioned severe lesions with AIS 3 lesions affecting other body regions is frequent. Death is caused by abdominal lesions in two cases only. In other cases, abdominal lesions contribute to aggravating the condition of very severely injured people.

**Occupant Protection**

A great deal of research is currently devoted to lateral impact protection, but the results are not yet available. Consequently, it is still not possible to indicate accurately the effectiveness of protection measures. The wearing of safety belts mainly avoids the risks of ejection.

If the 59 killed occupants had been belt restrained without any other extra equipment, 5 of them would probably have been saved.

A comparison between belted and unbelted occupants concerning affected body areas shows that the differences are negligible (table
Measures combining the limitation of intrusion and internal padding with shock-absorbing materials should give good results. An indication of this performance is given by a test performed with a cadaver at a 90-degree lateral impact. The subject is seated adjacent to a wall having characteristics like those of the Renault Basic Research Vehicle mounted on a sled. The sled speed was 28 km/h with a 24-cm stopping distance.

Calculated head impact criteria (HIC) vary between 218 and 226 according to accelerometers combinations; the severity index (SI) varies from 338 to 489.

The autopsy showed rib fractures corresponding to an AIS 3 level at the thorax. Acceleration peaks reached 40 g at the thorax and 70 g at the pelvis.

The same test was performed on a conventional dummy:

- Head SI: 349
- Head HIC: 212
- Thorax max. γ: 46 g

Additional experiments are necessary to establish with accuracy the performances that may be expected from the solutions now being studied. The biomechanics of lateral impacts also requires additional study.

Typical Cases of Side Impacts

Car-To-Car—Case A—Renault 16 and Peugeot 104.

- Estimated impact speed: 65 km/h
- ΔV: 35 km/h (Peugeot 104)
EXPERIMENTAL SAFETY VEHICLES

Table 15. Frequency of AIS $\geq$3 for various body areas of occupants, with and without seatbelts, nearside or offside, involved in car-to-car lateral impacts

<table>
<thead>
<tr>
<th>Occupant</th>
<th>AIS $\geq$3</th>
<th>Overall index$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Head</td>
<td>Neck</td>
</tr>
<tr>
<td>Nearside:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belted (N=26)</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Unbelted (N=160)</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Offside:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belted (N=32)</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Unbelted (N=149)</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

$^a$Overall index is calculated by dividing the number of AIS $\geq$3 by the overall number of exposed body areas (5 areas multiplied by the occupants number). The index is converted into a percentage.

The impact was centred on the left front door (see printings of the two Renault 16 headlamps, fig. 16A). The statical maximum intrusions recorded at the door level are, respectively, 45 and 55 cm on the left A- and B-pillars and 35 and 45 cm on the sill level (figs. 16B and 16C and fig. 17).

Peugeot 104—Occupants’ Medical Balance. Driver: Male, 38 years old, 1.80 m tall, 85 kg, OSI: 6; died 1 hour after the accident. Cranio-facial fracas (fatal injury); impact against roof frame; fractures of second, third, fourth, and fifth left ribs; left pneumothorax, pelvis, left femur, and head fractures; possible

Figure 16. Case A—Peugeot 104, $\Delta V = 35$ km/h.
Case B—BMW 3.0 against BMW 1602.
- Estimated impact speed: 60 km/h
- $\Delta V$: 25 km/h (BMW 3.0).

The impact was centred on the right back door (see printings of BMW 1602 headlamps on the right front door and right B-pillar, in fig. 18). Maximum statical intrusion recorded: 35 cm on both sill and beltline all along the contact area.

BMW 3.0—Occupants’ Medical Balance.
Driver: Male, 52 years old, 1.83 m tall, 80 kg, belted, OSI: 1. Thoracic contusion (impacted by right front passenger) and contusion on right leg.

Figure 18. Case B—BMW 3.0, $\Delta V = 25$ km/h.

injuries to internal organs (no autopsy made).

Right-Front Passenger. Male, 40 years old, 1.75 m tall, 80 kg, OSI: 6; 17 days’ hospitalization. Cerebral concussion, third and fourth left ribs fractured, left femur fracture, and abdominal contusion.

Left-Rear Passenger. 8-year-old child, OSI: 1. Cerebral concussion, parietal hematoma on right side, and right abdominal contusion.

Middle-Rear Passenger. 11-year-old child, OSI: 1. Cerebral concussion, parietal hematoma on right side.

Right-Rear Passenger. Female, 31 years old, 1.58 m tall, 62 kg, OSI: 2; 6 days’ hospitalization. Cerebral concussion, 15 minutes of unconsciousness, and cervical aches.

Renault 16 (fig. 17)—Occupant’s Medical Balance. Driver: alone, belted (first generation belt, five strands broken). Male, 29 years old, 1.70 m tall, 75 kg, OSI: 1. Root of the nose wounded. Head impact against the upper rim of the steering wheel, and thorax impact against its lower rim. The driver was wearing his seatbelt too loosely.
Right-Front Passenger. Female, 48 years old, 1.71 m tall, 58 kg, belted, OSI: 6. Death occurred within 13 days after accident. Fractures of 10 right ribs and 3 left ribs (these last fractures due to the driver's impact), abdominal trauma, rupture of spleen, wounded liver, cerebral concussion, unconsciousness, and traumatic amnesia for 10 hours.

BMW 1602 (fig. 19)—Occupants' Medical Balance. Driver: Male, 34 years old, 1.63 m tall, 61 kg, belted, OSI: 1. Thoracic contusion.

Right-Front Passenger. Female, 34 years old, 1.55 m tall, 50 kg, OSI: 2. Sternum fracture, lumbar aches.
Middle-Rear Passenger. 3-year-old child, uninjured.

Case C—Renault 15 against Citroën DS.

- Estimated impact speed: 50 km/h
- $\Delta V$: 25-30 km/h (Renault 15)

The impact was centred on the right B-pillar (figs. 20A and 20B). The maximum statical deformation recorded on beltl ine level of left B-pillar was 45 cm. Maximum intrusion on sill: 20 cm.

Renault 15—Occupants’ Medical Balance.
Driver: Male, 28 years old, 1.70 m tall, 70 kg, OSI: 1. Cerebral concussion.

Right-Front Passenger. Female, 30 years old, 1.65 m tall, 58 kg, OSI: 6. Death occurred 20 hours after accident. Scalp wounded, cerebromeningeal bleeding without skull fracture (head impact against roof frame) (fig. 20C). Right second, third, fourth, fifth, and sixth ribs fractured with right pleural effusion, spleen rupture, hematoma of right nephric logis, pelvic fracture at right side, and fracture of right iliac crest.

Citroën DS—Occupants’ Medical Balance.
Two unbelted passengers, OSI: 1 (fig. 21).

Case D—Car Against Fixed Obstacle: Peugeot 504 Against Street Lamp.

- Estimated speed and $\Delta V$: 40 km/h

The impact was centred on left B-pillar. There is a 70-cm reduction of left B-pillar and a complete crushing of the back of the left front seat.

Peugeot 504—Occupant’s Medical Balance.
Driver: alone, belted. Male, 46 years old, 1.76 m tall, 70 kg, OSI: 1. Thorax contusion, right leg wounded.

In this accident, the driver was protected by his seatback and its headrest. The assembly turned around and formed a screen between the occupant and the lateral wall: an exceptional situation but of particular interest as
regards seatback and headrest protection in this position.

Case E—Opel Kadett Against a Tree. Tree marks were situated just in front of B-pillar (fig. 22).

- Estimated speed and $\Delta V$: 20 km/h
- Residual intrusion: 0.30 m

Opel Kadett—Occupant’s Medical Balance. Driver: alone, unbelted, 36 years old, 1.75 m tall, 80 kg, OSI: 5, 65 days’ hospitalization. Cerebral concussion and unconsciousness (6 hours), fracture of the skull (left side), left facial injuries, flail chest (fractures of first, second, and third left ribs), and spleen rupture. Head impacted the obstacle directly.

COMMENTS

The first observations made by A. L. Burgett and M. W. Monk [8] indicated that there was a high rate of killed and severely injured people in violent collisions ($\Delta V \geq 37$ km/h for 50 percent of them). The present study sets slightly lower values. However, we might have overestimated slightly the violences higher than $\Delta V \geq 25$ km/h. Sufficient experimental data are not yet available. The performance of experimental impacts at impact speeds between 50 and 100 km/h will make it possible to validate our estimates.

There is a lack of available biomechanical data because of the absence of references obtained with experimental vehicles equipped

Figure 22. Case E—Opel Kadett, ETS = $\Delta V = 20$ km/h (driver AIS: 5).
with efficient lateral protection devices tested at speeds over 50 km/h. However, an attempt may be made to define an order of magnitude with the results obtained during a frontal collision. This will, at least, enable us to estimate the difficulties to be overcome to secure minimum protection.

To convince oneself thereof, one must think of the deceleration distances available to the occupant for his own protection during a frontal collision. For a $\Delta V$ in the order of 50 to 60 km/h, the occupant has at his disposal within the passenger compartment a deceleration distance of about 500-700 mm according to his size and the vehicle’s design.1 To the above-mentioned distance, there must be added a percentage of deformation length of the vehicle’s front structure. Such deformation, in asymmetrical frontal impacts, which are the most frequent, averages 700 mm. The percentage actually available to the occupant depends on the coupling factor within the passenger compartment. In conventional restraint systems, calculated factors are on the order of 0.25 to 0.50, which corresponds to a deformation length of frontal structure useful to the occupant of at least 200 mm. This length may be increased substantially by using more sophisticated restraint systems (for example, a safety belt pretension device).

As a matter of fact, there is available a distance of about 700 to 900 mm. It can be seen that a situation as favourable as this one would be reached only if current cars are doubled in width or designed as monoseaters cars (one occupant for each seat row).

Another material example can be the basis for a comparison between frontal and lateral situations. It is the padding-based passive protection test that was presented on some experimental vehicles at ESV conferences. They were equipped with dashboards of substantial volume filling nearly the whole space available in the passenger compartment in front of the occupants. A favourable factor in frontal collisions must be stressed, namely, the projection of the occupant against the absorbing device. This factor most often results from the driver’s emergency braking, in which case there is a maximum coupling as well as the utilization of most of the impacted vehicle’s deformation.2

This argument leads us to think that it is probably an illusion to hope that occupants may be saved in a lateral collision with $\Delta V$‘s over 35 km/h, namely, at impact speeds of 70 km/h, without questioning the service rendered by current vehicles (lateral habitability)—at least for those located at impact level.

This must be the background when examining the European Experimental Vehicles Committee (EEVC) proposal to secure lateral protection on future vehicles for an impact speed of 40 km/h. The difficulty is that at the present time nobody can define the measures to be introduced on the vehicles, concerning both structural changes and the characteristics of energy-absorbing devices.

What percentage of the seriously and fatally injured occupants could be saved with a procedure equivalent to that of the EEVC (London, 1974) [9] and protection criteria comparable to those retained for frontal collision?

It must be understood that the test proposed by the EEVC retains the most severe conditions for the occupant. The axis of impacting vehicle being centered on the Hx-point of the dummy-driver, it is in such a configuration that the probability of severe lesions is the highest at low speeds. This is confirmed by the analysis of available data: 50 percent of severely and fatally injured occupants are involved in collisions occurring with a $\Delta V$ of 30 km/h when the impact is localized on the occupant’s side door.

It seems obvious that the countermeasures adopted to meet protection criteria in this test configuration would be more efficient for

---

1 The situation is different as far as the passenger or the driver is concerned. For the latter, the distance is much shorter because of the steering wheel; the steering wheel, however, is deformable and can contribute to the occupant/vehicle coupling. The statistical balance sheet is very difficult to draw: The steering wheel does not have a solely negative effect; its role is much more complex.

2 We have at our disposal many examples—some very dramatic—of the influence of such factors in very severe collisions, when unrestrained occupants are luckily unhurt or only slightly injured.
all those where the impact does not occur at occupant levels (belted offside occupants and impacts not localized at passenger compartment level). The protection afforded under EEVC conditions is most likely to save a large proportion of occupants currently killed at higher ∆V's and in locations other than at impact level.

CONCLUSIONS

The simulation of a very representative car-to-car side impact would be the one where the front centre of the striking car impacts the side of the other car at a point located 10 cm forward of the projection of the Hx-point on the door. Furthermore, speeds and collision angles should be such that the apparent trajectory of the impacted occupant makes a 70-degree angle with the longitudinal axis of car.

The relative velocity with which the nearside occupant hits the intruded side is higher than the ∆V of his own car; the difference is greater as the initial distance between the occupant and the wall is shorter, as the wall is weaker and as the impacting vehicle's front structure is more rigid. Furthermore, impacting and impacted cars are sometimes designed so incompatibly that the impacted car may sustain a substantial intrusion before the rigid members of its structure are acted upon by forces. This accounts for the fact that out of 100 fatal or severe injuries sustained by nearside occupants with intrusion, 50 have occurred in cars whose ∆V was never over 29 km/h.

Owing to the fact that the average mass of impacting cars amounts to 1 000 kg and the average mass of impacted cars amounts to 880 kg, a ∆V of 29 km/h corresponds to an impact speed of 54.5 km/h. The impacted car is assumed to be at a standstill.

The first results of the biomechanical tests lead us to believe that the favourable effects resulting from occupant coupling with the wall (assuming a certain intrusion distance) and absorption by padding might substantially reduce the risk of death or severe injury below the ∆V of 29 km/h within the near future.

The exposure of various body areas arrived at by value integrating the frequency and severity of lesions sustained (by cubing the AIS of each main body area) appears to be 0.35 for the head, 0.25 for the thorax and the abdomen, and only 0.09 for the pelvis and 0.05 for the neck.

Out of 31 lesions with AIS 5, 21 involved the head by contact against A- or B-pillars, roof frames, or obstacles with occasional interposition of side glass. As it is very difficult to design or provide efficient padding in such locations, it is advisable to continue the research on head and neck tolerances, with the assumption that energy-absorbing material would be insured up to shoulder height and would permit a notable shift of the head sideways.

The devices intended for limiting intrusion into passenger compartments may also alter the trajectories of the cars involved by making them repel one another very shortly after the initial contact. As a result, lateral impact severity can be reduced.

Lateral impacts against fixed and rigid obstacles along roads account for more than one-third of lateral impact fatalities. Their average violence is high and protection against such impacts is very difficult compared with car-to-car impacts. A great number of the fatalities in this category could be avoided through better road design.

The safety belt's main advantage is in avoiding ejection during lateral impacts. Ejection occurs most frequently when the car is impacted at the front or the rear quarter, causing a rotational motion.

Much biomechanical data remain to be collected, and impact experiments must be performed with proposed assemblies and sub-assemblies prior to developing a realistic timetable for the implementation of the arrangements that would permit minimising risks in case of lateral impacts.

ACKNOWLEDGMENTS

The data used in the present study were excerpted from the investigation conducted by Peugeot and Renault in close cooperation with the Orthopedics Research Institute.
SECTION 4: TECHNICAL SEMINARS

headed by Professor A. Patel and assisted by Professor C. Got and C. Roy-Camille.

We wish to extend our thanks to the Paris Area Police Forces who have contributed by collecting accident data and more particularly the Direction of “Hauts de Seine” Police Forces, the C.R.S. N° 2 and the Poissy Police Team.

This paper has been prepared and illustrated by the Biomechanics Laboratory in close cooperation with the Regulations Department of the Peugeot-Renault Association.

REFERENCES


Traffic Accidents to Cars With Directions of Impact from the Front and Side

B. S. RILEY and C. P. RADLEY
Transport and Road Research Laboratory
Department of the Environment
Crowthorne, Berkshire

ABSTRACT

The paper gives a background of road traffic accident data in Great Britain showing the distribution of different types of car accidents and the associated car occupant injury levels.

The frequency of occurrence of car accidents according to object struck, directions of impact, and the related car occupant injuries are discussed. The more frequent frontal and side impacts are considered in detail.

Frontal impacts are subdivided according to direction of impact and proportion of frontal width of the car impacted. The velocity changes during impact are estimated for the overall frontal impact situation.

Side impacts are similarly distributed by directions of impact and parts of the cars struck. The importance to the occupant of being near to or remote from the site of impact is also discussed.

The data enable car impact test procedures to be suggested which simulate the crash conditions of the real accident situation.
INTRODUCTION

If cars are to be improved to give adequate protection to their occupants in the event of a traffic accident, then it is important to know how the occupants are injured in existing cars. In this way, priority can be given to those improvements giving the most benefit.

It is also important that a simulated crash procedure used to test both existing and improved cars should relate to the real accident. To be able to do this, accident data are required detailed enough to indicate directions of impact, areas of impact, changes of vehicle velocity and vehicle decelerations during the impact.

This paper discusses the frequency of the various types of accidents in Great Britain and for the more commonly occurring frontal and side impacts, their distributions for various factors. Their relationships with severities of injury received by the car occupants are presented.

THE ACCIDENT DATA

The main accident sample is that collected between 1970 and 1974 by the Accident Investigation Division at the Transport and Road Research Laboratory (TRRL). This is detailed information from accidents happening within about 50 km of the laboratory, in which at least one person was detained in hospital (seriously injured) or killed. The part of the sample used here consists of impacted cars or car derivative vans where full information is known on all the people involved in the accident, whether injured or not. This results in a sample of approximately 500 impacted cars and 1,000 car occupants, of whom about 11 per cent were restrained by seatbelts. Some minor details are derived from the data on all road accidents in Great Britain in which someone was injured. This information is collected by the police and then stored on the computer at TRRL. This sample includes about 3,000 fatally and 40,000 seriously injured car occupants each year.

OVERALL CAR IMPACTS

Directions of Impact

When a car is struck in an accident, the occupant tends to move relative to the car towards the point of impact, or parallel to the direction of impact. If the occupant is not belted, he strikes the surrounding car structure in an area depending mainly on the direction of impact and his original position. Some directions of impact occur more frequently than others. The directions used in this report are as shown in figure 1. Frontal impact is to the front of the car having a direction of impact as shown within a cone of 90 degrees, symmetrically placed about the centre line of the vehicle. Sideswipe-type impacts where the front of the car is not damaged have been excluded, but they amount to only an additional 5 per cent of frontal impacts. Side impact has a direction from within a pair of 90-degree cones about the transverse axis and rear impact in from behind the car within a cone of 90 degrees. These directions of impact are defined in reference 1 and do not specify the point of impact.

The proportions of each direction of impact present in the TRRL and Stats 19 samples are as shown in table 1. The Stats 19 sample consists of most of the fatal and serious car accidents for two months. Distributions from other countries and another sample from this country come from reference 2. Definitions of directions of impact and the severity of accidents are similar for all the samples.

The TRRL and Stats 19 samples show lower proportions of side impacts than the other samples. The TRRL data have a larger proportion of rural accidents than would be present nationally, and the relatively few road intersections present may account for the low proportion of side impacts. The Stats 19 sample is nationally representative but the precise direction of impact is more uncertain.

In spite of the differences between the samples it is clear that in terms of frequency the important directions of impact are from the front and sides.

Table 2 is derived from the TRRL data and shows the percentage distribution of severities
Table 1. Directions of impact on cars

<table>
<thead>
<tr>
<th>Direction of impact</th>
<th>TRRL sample</th>
<th>Great Britain Stats 19</th>
<th>France</th>
<th>Federal Republic of Germany</th>
<th>Italy</th>
<th>Birmingham University (Great Britain)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Great Britain Stats 19</td>
<td></td>
<td>Federal Republic of Germany</td>
<td>Italy</td>
<td>Birmingham University (Great Britain)</td>
</tr>
<tr>
<td>Frontal impacts</td>
<td>74.6</td>
<td>64</td>
<td>56.8</td>
<td>63.0</td>
<td>57.0</td>
<td>63.8</td>
</tr>
<tr>
<td>Side impacts</td>
<td>13.9</td>
<td>19</td>
<td>31.2</td>
<td>30.0</td>
<td>24.7</td>
<td>21.6</td>
</tr>
<tr>
<td>Rear impacts</td>
<td>2.3</td>
<td>6</td>
<td>2.0</td>
<td>4.0</td>
<td>12.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Other impacts</td>
<td>9.2</td>
<td>11</td>
<td>10.0</td>
<td>3.0</td>
<td>5.9</td>
<td>11.4</td>
</tr>
<tr>
<td>Number of cars impacted (100%)</td>
<td>531</td>
<td>2 064</td>
<td>3 340</td>
<td>Unknown</td>
<td>2 200</td>
<td>500</td>
</tr>
</tbody>
</table>

Table 2. Severities of injury for each direction of impact

<table>
<thead>
<tr>
<th>Direction of impact of cars</th>
<th>Injured car occupants for each direction of impact (%)</th>
<th>Number of car occupants (100%)</th>
<th>Number of cars impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
<td>Severe</td>
<td>Moderate</td>
</tr>
<tr>
<td>Frontal impact</td>
<td>7.5</td>
<td>31.4</td>
<td>26.2</td>
</tr>
<tr>
<td>Side impact</td>
<td>11.3</td>
<td>26.8</td>
<td>25.4</td>
</tr>
<tr>
<td>Rear impact</td>
<td>6.9</td>
<td>0</td>
<td>6.9</td>
</tr>
<tr>
<td>Other impacts</td>
<td>10.3</td>
<td>13.4</td>
<td>8.3</td>
</tr>
<tr>
<td>Total</td>
<td>85</td>
<td>288</td>
<td>244</td>
</tr>
<tr>
<td>Percent</td>
<td>8.3</td>
<td>28.1</td>
<td>23.8</td>
</tr>
</tbody>
</table>

of injury for each direction of impact. The severities used are defined in reference 3, but minor severity is approximately AIS 1, moderate AIS 2, and severe AIS 3, 4, and 5.

The injury rates for the rear impacts are interesting to note, mainly because out of the 29 occupants involved, about 80 per cent were uninjured.

Objects Struck by Cars

The objects struck by cars for different directions of impact are shown in table 3. The proportions of various objects struck in frontal and side impacts are very similar with about two-thirds of the cars hitting other cars in the sample. Rear impact is rather different in that all the impacts are car-to-car, but the sample of 12 cars is insufficient to make firm conclusions.

Table 4 shows the severities of injury related to objects struck by the car. The severity of injury is worse when the car strikes or is struck by a fixed nonvehicular object or a vehicle heavier than itself. In the car-to-car impacts the fatality rate is about two-thirds of that in the other car impacts and the uninjured rate is twice that for other impacts. Although the car-to-car impact is less severe, it accounts for nearly 60 per cent of the fatally and severely injured occupants.

The Important Impacts

If improvements are to be made to cars to reduce the severity of occupant injuries, then the chosen areas for improvement should be those giving the most benefit. This may result in less effort being made to improve occupant
Table 3. Objects struck by cars for each direction of impact

<table>
<thead>
<tr>
<th>Direction of impact</th>
<th>Object in collision with car (%)</th>
<th>Number of cars impacted (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Post or other nonvehicle object</td>
<td>Car</td>
</tr>
<tr>
<td>Frontal impacts</td>
<td>21.0</td>
<td>63.6</td>
</tr>
<tr>
<td>Side impacts</td>
<td>20.3</td>
<td>70.2</td>
</tr>
<tr>
<td>Rear impacts</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Other impacts</td>
<td>18.4</td>
<td>67.3</td>
</tr>
</tbody>
</table>

Cars impacted:

- Number: 107
- Percent: 20.2
- Vehicle definitions:
  - Car — Cars and car derivative vans.
  - MCV — Commercial vehicles up to 3 tons, unladen.
  - HCV — Commercial vehicles larger than MCV, but including 12 public service vehicles.

Table 4. Severities of injury for each type of object struck by car

<table>
<thead>
<tr>
<th>Object struck by car</th>
<th>Injured car occupants for each type of object struck (%)</th>
<th>Number of cars impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
<td>Severe</td>
</tr>
<tr>
<td>Post or other nonvehicle object</td>
<td>10.6</td>
<td>33.2</td>
</tr>
<tr>
<td>Car</td>
<td>7.0</td>
<td>25.0</td>
</tr>
<tr>
<td>MCV</td>
<td>11.5</td>
<td>27.0</td>
</tr>
<tr>
<td>HCV</td>
<td>11.7</td>
<td>39.3</td>
</tr>
</tbody>
</table>

Total: numbers

- 85
- 288
- 244
- 222
- 185
- 1 024

Percent

- 8.3
- 28.1
- 23.8
- 21.7
- 18.1

This section of the paper shows how the various types of car impacts leading to serious injury occur in traffic accidents. The data presented show that frontal and side impacts are the most frequent. Rear impact in this country and several other European countries appears to be a much smaller problem.

In the following sections the frontal and side impact situations are discussed in more detail.

FRONTAL IMPACTS

The accident statistics [2] from several European countries indicate that frontal impacts account from over one-half to nearly three-quarters of the serious impacts to cars.

This section of the paper shows how various factors, such as vehicle damage and change in velocity for a given severity of impact, influence the injuries received by car occupants. Knowledge of the effect of these factors indicates the types of simulated crash...
test procedures needed to assess the protection offered by cars.

Head-on and Oblique Frontal Impacts

Frontal impacts in this paper have a direction of impact within a cone of 90 degrees (see “Directions of Impact”). In table 5, head-on is an impact from very nearly straight ahead within a cone of approximately 10 degrees and all other impacts are oblique offside or nearside (fig. 1). The proportion of head-on impacts is lower than reported in reference 2 for other European countries where the average percentage is about 66 per cent. Not too much importance can be attached to this because the proportion depends to a certain extent on the cone angle used to define head-on impacts.

Table 5. Distribution of head-on and oblique frontal impacts

<table>
<thead>
<tr>
<th>Frontal impacts (%)</th>
<th>Number of cars impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head-on</td>
<td>Offside</td>
</tr>
<tr>
<td>56.1</td>
<td>22.4</td>
</tr>
</tbody>
</table>

Figure 1. Directions of impact on a car.

NOTE. The arrows indicate direction of impact only and do not indicate sites of impact or extent of damage.
The injuries received by the car occupants in the three types of frontal impact are shown in Table 6. The proportions of fatally and severely injured occupants for head-on and oblique offside directions of impact are similar but the proportion for oblique nearside impacts is lower, particularly regarding the proportion of occupants killed. This may be because there is not necessarily a nearside occupant.

**Proportion of Frontal Width Impacted**

Impact damage to the front of a car can vary from all across the front to just a small proportion of the overall width. Overlap is defined in this paper as the proportion of the full width of the car struck by the striking vehicle or object measured from one side. Photographs and other relevant data from 143 of the 396 frontally impacted cars have been examined to determine the overlaps occurring in the TRRL accident sample. Four ranges of overlap have been used in Table 7.

The distribution of overlap within each of the three directions of frontal impact is similar, and the overlap range (0.25-0.50) has the largest proportion of impacts.

The severities of injury received by the car occupants for each overlap range are shown in Table 8. Less than a fifth of the occupants of cars with overlaps up to a quarter receive fatal or severe injuries compared with up to a half of the occupants of cars with overlaps greater than a quarter. The 0-0.25 overlap impact occurs when, for example, only a wing is damaged. Often in this type of accident the vehicles tend to glance off each other, or the car glances off the object being struck, resulting in lower velocity changes and fewer injuries. The damage, on the other hand, can often extend into the foot area of the passenger compartment causing injury to the front seat occupants by intrusion but the

---

**Table 6. Severities of injury for each direction of frontal impact**

<table>
<thead>
<tr>
<th>Direction of impact</th>
<th>Injured car occupants for each direction of frontal impact (%)</th>
<th>Number of car occupants (100%)</th>
<th>Number of cars impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
<td>Severe</td>
<td>Moderate</td>
</tr>
<tr>
<td>Head-on</td>
<td>8.0</td>
<td>34.2</td>
<td>25.4</td>
</tr>
<tr>
<td>Oblique offside</td>
<td>9.9</td>
<td>32.0</td>
<td>29.7</td>
</tr>
<tr>
<td>Oblique nearside</td>
<td>3.8</td>
<td>20.3</td>
<td>24.7</td>
</tr>
<tr>
<td>Total</td>
<td>57</td>
<td>237</td>
<td>198</td>
</tr>
<tr>
<td>Percent</td>
<td>7.5</td>
<td>31.4</td>
<td>26.2</td>
</tr>
</tbody>
</table>

**Table 7. Distribution of overlap for frontally impacted cars**

<table>
<thead>
<tr>
<th>Direction of frontal impact</th>
<th>Cars with various amounts of overlap for each direction of impact (%)</th>
<th>Number of cars impacted (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overlap 0-0.25</td>
<td>Overlap 0.25-0.50</td>
</tr>
<tr>
<td>Head-on</td>
<td>14.3</td>
<td>38.1</td>
</tr>
<tr>
<td>Oblique offside</td>
<td>22.6</td>
<td>29.0</td>
</tr>
<tr>
<td>Oblique nearside</td>
<td>17.9</td>
<td>42.8</td>
</tr>
<tr>
<td>Cars impacted:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>24</td>
<td>53</td>
</tr>
<tr>
<td>Percent</td>
<td>16.8</td>
<td>37.1</td>
</tr>
</tbody>
</table>
### Table 8. Distribution of severities of injury for each range of overlap

<table>
<thead>
<tr>
<th>Overlap</th>
<th>Injured car occupants for each range of overlap (%)</th>
<th>Number of car occupants (100%)</th>
<th>Number of cars impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
<td>Severe</td>
<td>Moderate</td>
</tr>
<tr>
<td>0.0-0.25</td>
<td>2.6</td>
<td>15.4</td>
<td>41.0</td>
</tr>
<tr>
<td>0.25-0.50</td>
<td>11.2</td>
<td>30.3</td>
<td>33.7</td>
</tr>
<tr>
<td>0.50-0.75</td>
<td>13.3</td>
<td>22.2</td>
<td>28.9</td>
</tr>
<tr>
<td>0.75-1.00</td>
<td>16.7</td>
<td>33.3</td>
<td>27.8</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>67</td>
<td>79</td>
</tr>
<tr>
<td>Percent</td>
<td>11.8</td>
<td>27.4</td>
<td>32.2</td>
</tr>
</tbody>
</table>

The number and severity of these injuries is low. In the type of accident where most of the frontal width of the car is damaged (overlap 0.75-1.00) the impact deformation does not often extend back to the passenger compartment but because of the car structural stiffness, the decelerations during impact are higher. The vehicles do not tend to glance off each other as much as in the lower overlap cases, resulting in higher velocity changes; more severe injuries are usually received.

**Velocity Changes During Frontal Impacts**

The change of velocity of the car during an impact is important because it could be expected to relate to the severity of injury to the occupants, particularly for those not restrained by seatbelts. Impact damage is an indicator of energy absorbed by the car structure during the crash but is not necessarily an indicator of the velocity change. For example, a car crashing head-on into a large solid block at 30 km/h and coming to rest without glancing off or rebounding, absorbs the same amount of energy as the same car hitting the block at 50 km/h and after impact continuing in the same direction at 40 km/h. The velocity change is, however, 30 km/h in the first case, but only 10 km/h in the second.

Velocity change is not easily derived from accident data as it can be greatly affected by how the cars collide and whether they glance off each other. Impact energy must also be estimated, and this is not straightforward when the damage may be over only part of the front of the car. Estimates of velocity change in car frontal impacts have been made from just over 100 car impacts in the TRRL accident sample in connection with research into steering column testing. Some caution is needed in using the estimates as most of the 106 cars in the sample have a seatbelted occupant in them. However, many of the cars have seriously injured occupants who are not seatbelted.

The car impacts have been separated into three categories. The first is when a car occupant has been fatally injured (14 cars). The second is when one of the car occupants has been, at worst, severely injured (59 cars) and the third is when no occupant has been more than moderately injured (28 cars). The mean velocity changes for the three categories are 52, 47, and 40 km/h, respectively; each having a standard deviation of about 10 km/h.

**SIDE IMPACTS**

Fourteen per cent of the TRRL sample of car impacts are side impacts resulting in data on 74 impacts and 142 occupants available for analysis. The numbers are small but some indications are given of the important aspects of the problem.

**Perpendicular and Oblique Side Impacts**

Directions of side impacts are defined in figure 1. Table 9 shows how the 74 impacts are distributed. The oblique side impacts
EXPERIMENTAL SAFETY VEHICLES

Table 9. Distribution of perpendicular and oblique side impacts

<table>
<thead>
<tr>
<th>Direction of side impact</th>
<th>Perpendicular</th>
<th>Oblique</th>
<th>Number of cars impacted (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Offside</td>
<td>Nearside</td>
<td></td>
</tr>
<tr>
<td>Perpendicular</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front offside</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rear offside</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front nearside</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rear nearside</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cars impacted (%)</td>
<td>16.2</td>
<td>14.9</td>
<td>24.3</td>
</tr>
<tr>
<td></td>
<td>4.1</td>
<td>31.1</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>74</td>
</tr>
</tbody>
</table>

There is little difference between the severities of injuries received by the occupants in perpendicular and oblique impacts.

Areas of Car Damage in Side Impacts

The impacts in table 11 are subdivided into those where damage to the side of the car included damage to the passenger compartment and those where it did not, with the former comprising three quarters of the total. A smaller proportion of the oblique impacts had damage to the passenger compartment compared with the perpendicular impacts.

Table 12 gives the occupant injuries related to whether the passenger compartment was forward of perpendicular are the larger proportion of impacts and account for 55 percent of the total. They outnumber those from the rear by a factor of 4. Overall the impacts from the offside and nearside are similar in number with slightly more from the nearside.

It must be remembered that the direction of impact is equivalent to the direction of the resultant force on the car and tells little about the angle of approach between the vehicles before impact. In just over half of the impacts between vehicles the actual angles between their centreline just before impact were between 80 and 100 degrees.

The injuries received by the occupants in the side impacted cars are shown in table 10.

Table 10. Distribution of occupant injuries for perpendicular and oblique side impacts

<table>
<thead>
<tr>
<th>Direction of impact</th>
<th>Injured car occupants for direction of side impact (%)</th>
<th>Number of car occupants (100%)</th>
<th>Number of cars impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
<td>Severe</td>
<td>Moderate</td>
</tr>
<tr>
<td>Perpendicular</td>
<td>11.6</td>
<td>25.6</td>
<td>25.6</td>
</tr>
<tr>
<td>Oblique</td>
<td>11.1</td>
<td>27.3</td>
<td>25.3</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>38</td>
<td>36</td>
</tr>
<tr>
<td>Percent</td>
<td>11.3</td>
<td>26.8</td>
<td>25.4</td>
</tr>
</tbody>
</table>

Table 11. Sites of impact for perpendicular and oblique side impacts

<table>
<thead>
<tr>
<th>Direction of side impact</th>
<th>Perpendicular, site of impact</th>
<th>Oblique, site of impact</th>
<th>Number of cars impacted (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Passenger compartment</td>
<td>Not passenger compartment</td>
<td>Passenger compartment</td>
</tr>
<tr>
<td>Cars impacted (%)</td>
<td>25.7</td>
<td>5.4</td>
<td>48.6</td>
</tr>
</tbody>
</table>
damaged or not. Apart from the fact that there were no uninjured occupants when the passenger compartment was damaged the distribution of injuries is similar. Although the numbers are small, an interesting fact emerges from a detailed examination of the accident data. In the impacts where the passenger compartment is not damaged, 8 out of the 25 occupants were ejected from the cars, including the three fatally injured. The other five were at least moderately injured. In the cars with passenger compartment damage, only 9 out of the 117 occupants were ejected, including three of the fatally injured. This latter ejection rate is not a lot higher than that for the frontal impacts. The probable reason for this difference is that in cars where the compartment is undamaged the impact is at one end of the car. This tends to rotate the car violently at impact resulting in the occupants being thrown around within the car with more chance of being ejected. The use of seatbelts in such circumstances would in most cases prevent the ejections and such occupants would be less severely injured.

Seating Positions of Injured Occupants in Side Impacts

In side impacts the impact itself is in most cases much closer to the occupants than for frontal impacts where there is often a metre or so of car structure in front of the passenger compartment. Table 13 shows the distribution of injuries received by the occupants for various seating positions. The most severe injuries were received when the occupant was seated at the site of the impact resulting in 60 per cent of them being severely or fatally injured in this sample of occupants in serious injury accidents. The

<table>
<thead>
<tr>
<th>Position of occupant relative to site of impact</th>
<th>Injured occupants for each position of occupant (%)</th>
<th>Number of car occupants (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
<td>Severe</td>
</tr>
<tr>
<td>Same side of car as impact, at site of impact</td>
<td>15.8</td>
<td>44.7</td>
</tr>
<tr>
<td>Same side of car as impact, away from site of impact</td>
<td>13.0</td>
<td>26.2</td>
</tr>
<tr>
<td>Opposite side of car to impact</td>
<td>8.6</td>
<td>18.5</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>38</td>
</tr>
<tr>
<td>Percent</td>
<td>11.3</td>
<td>26.8</td>
</tr>
</tbody>
</table>
severities of injury were reduced when the occupant was on the same side of the car as the impact but was not at the site of impact (about 40 per cent severely or fatally injured). When seated on the opposite side of the car to the impact, the injuries were reduced further to less than 30 percent severely or fatally injured and nearly one-quarter of these 81 occupants were uninjured.

CONCLUSIONS RELATED TO SIMULATED IMPACT TESTS

It is important that any simulated impact test procedure should be similar to common real traffic accidents. The direction and speed of impact and the amount and type of damage produced should be similar to those found more frequently in practice for the more serious occupant injury accidents. If possible, the selected test should show up any weak features of the car structure. For example, in a frontal impact, a car may give satisfactory results when damage to the front extends all across the width of the car but may perform differently when the damage is to one-half or less of the frontal width.

Frontal Impact Tests

A specification for a car frontal impact test procedure can be defined in terms of the object to be struck, direction of impact, proportion of the car to be damaged, and speed of impact.

We have shown that about two-thirds of the impacts are car-to-car, although the severities of injury to the occupants are worse when the car hits a solid object or heavier vehicle. The mechanism of car structural collapse and injury causation is similar in car-to-car and car-to-solid object impacts which together account for 86 per cent of the total impacts. It is therefore reasonable to base a test procedure on these types of accidents. Though it is more convenient to run the car into a solid object, the type of test must be arranged to give results similar to car-to-car impacts in terms of damage, deceleration pattern, velocity change, and it must allow for mass ratio considerations. Fifty-six per cent of the impacts have a direction of impact which is head-on, but the injuries received by the occupants do not differ much between head-on and oblique impacts; therefore a head-on direction is acceptable for test purposes.

The proportion of frontal width damaged (overlap) is important because for a given speed of impact this quantity largely influences the level of deceleration and the amount of intrusion into the passenger compartment. In the past, full car width tests into a solid block at 50 km/h have mostly been used. These lead to high decelerations and also give little indication of what might happen if a smaller proportion of the width of the car was struck. This can be important from the point of view of testing the passenger compartment strength. More than a third of the injury-producing road accident impacts involve overlaps of between a quarter and a half. For overlaps greater than a quarter, the injury severities do not get much worse and it seems reasonable to develop a test representing an overlap between a quarter and a half.

Estimates of the velocity changes of the cars during impact have been made, although the imprecise methodology for estimating velocity change and the suitability of the samples studied prevent definite conclusions being drawn. The mean velocity change in impacts leading to fatal injuries for at least one occupant was just over 50 km/h and for severe injuries just under 50 km/h. This does not imply that a test procedure should be set up at this speed, because a given degree of injury protection also depends on the choice of maximum permitted tolerance loadings which may be set to protect any set proportion of the population. Also designers adopt differing margins for given standards and the change in injury probability that occurs for impacts more severe than those studied is not precisely known.

The work reported here suggests that a test to represent car-to-car frontal impacts with about a 40-per cent overlap may be the most appropriate for a single test. However, a test for design purposes must be car-to-
rigid or mobile barrier and some experimental work to find such a test is reported in reference 4.

Side Impact Tests

As for frontal impacts, the most common object struck is another car but more severe injuries occur in impacts with both solid objects and heavier vehicles. In specifying a test procedure for car side impact it is more important than in the frontal impact case to use a car or similar structure as the impactor because there is little structure between the impactor and the occupants.

The direction of impact has been shown in the section on perpendicular and oblique side impacts to be more frequently oblique and forward of perpendicular but, as with frontal impacts, the injuries received by the occupants for each direction of impact are not very different. Also the actual angle between the vehicle centrelines, when cars are struck in the side by other vehicles, is close to 90 degrees in over half the cases. For these reasons a perpendicular direction of impact, or one almost so, is suitable for simulated impact tests. Most of the side impacts involve damage to the passenger compartment, and this is the area of the car that should be struck in a test.

No attempt has been made to estimate the velocity changes occurring in side impacts. The accident data available do not contain sufficient information on such quantities as distance moved after impact. Also, compared with frontal impacts, there is little knowledge available on energy absorbed by cars damaged in the sides. A suitable speed for side impact tests might be 40 km/h, but this might need revising after comparison of cars tested in this way with accident findings.

ACKNOWLEDGMENT

The work described in this paper forms part of the programme of the Transport and Road Research Laboratory and is published by permission of the Director.

REFERENCES


Respective Effects of Delta V, Mean Gamma, and Intrusion on the Severity of Injuries Suffered by Occupants Not Wearing Seatbelts in Frontal Impact

F. HARTEMANN, C. HENRY, and C. TARRIERE
Laboratoire de Physiologie et de Biomecanique de l’Association Peugeot-Renault

It is probably because the assistance services to highway accident victims encounter more wounded than unwounded people outside of vehicles whose interior has been very damaged that accidentologists have long considered deformations of the passenger compartment to be the major cause of the severity of accidents. In effect, there is a strong tendency to hastily give preference to the variable, out of all the possible explanatory variables, whose observation is most convenient when new areas of investigations must be confronted. Moreover, if the manifestations of this variable correspond well with the a priori idea that has been created concerning the causes of the phenomenon which must be explained, the latter has every chance of being considered the decisive causal variable. The mistake is eventually fostered by several statistical stratagems. The longevity of the myth of “survival space” can be explained in this way.

Recent developments in theoretical and experimental work on interaction phenomena between the occupant and his vehicle during impact and on the human reactions to the forces of the impact were necessary for accidentology to begin to classify real accidents by means of pertinent parameters based on the results of these investigations.

It is now admitted that the severity of accidents for the occupants is essentially a function of delta V and the law of deceleration with respect to the characteristics of the impact. Proof of this has been produced by experimental impacts. In the study that follows, our purpose is to confirm the fact that the severity of bodily injuries is closely related to the above parameters and not to the variable expressing the importance of the reduction in pseudo survival space and to confirm this by using accidententological analyses.

We will show how a summary interpretation of the data is related to true statistical mystification.

The occupants concerned were not wearing seatbelts at the time of their accident; this decreases the possibilities of generalizing the relationships observed between the variables related to the impact and the variables which characterize the severity of the lesions; however, the alleged pertinence of the notion of survival space does not imply that seatbelts are worn.

CHARACTERISTICS OF THE SAMPLE USED

Peugeot and Renault have been conducting an in-depth investigation into accidents involving particular cars of all makes and types since 1970. The sample used here is composed of cars which have undergone frontal impact and for which the delta V and the mean gamma could be evaluated. In order to obtain a good proportion of cases in which the passenger compartment was decreased, the value of delta V selected as the threshold of inclusion in the sample was fixed at 35 km/h. We thus retained 133 cars (see fig. 1).

Distribution of 197 occupants in the front seat of OAIS class\(^1\) can be found in table 1.

The distribution of occupants by delta V class can be found in table 2.

The distribution of the occupants as a function of the mean gamma vehicle is given in table 3.

The decrease in the passenger compartment was assessed in the following manner: the space which separates the occupant from the frontal elements of the passenger com-

---

\(^1\) OAIS = overall AIS = global severity of lesions.
Figure 1. Distribution of 133 vehicles in the sample as a function of delta V and mean gamma.
Table 1. Distribution of occupants by OAIS level

<table>
<thead>
<tr>
<th>OAIS</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>2</td>
<td>26</td>
<td>42</td>
<td>35</td>
<td>21</td>
<td>13</td>
<td>48</td>
<td>197</td>
</tr>
<tr>
<td>Percent</td>
<td>1</td>
<td>18</td>
<td>21</td>
<td>18</td>
<td>11</td>
<td>7</td>
<td>24</td>
<td>100</td>
</tr>
</tbody>
</table>

The passenger compartment (windshield, dashboard, and so forth) is divided into three zones (fig. 1). For each zone, the intrusion can be:
- Minimum (≤ 20-percent decrease): value 0
- Moderate (20-50-percent decrease): value 1
- Important (≥ 50-percent decrease): value 2

By adding the values of the three zones, we can at best obtain a total of 0; at worst, a total of 6 for a given occupant. The expression of the degree of intrusion in percentage of reduction adopted for simplification would be inappropriate if the dimensions of the passenger compartment varied greatly according to the models studied; but this is not the case of the dimensions in which we are interested in the European cars that made up our samples. In addition, regrouping the cases into three categories, which we will do below, minimizes the discrepancies between a classification established according to absolute values and a classification done as a function of the percentages.

The distribution of the intrusion values is indicated in table 4.

METHODS OF USING THE DATA

Three indices are computed for each occupant, each corresponding to one of the three parameters: delta V, gamma, and intrusion. Each index expresses the inclusion of the occupant either in the upper third or in the lower two-thirds of the distribution of values observed for the parameter. This division into the upper third of each distribution

Table 2. Distribution of occupants as a function of delta V

<table>
<thead>
<tr>
<th>ΔV (central class values)</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>65</th>
<th>70</th>
<th>&gt;70</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of occupants</td>
<td>17</td>
<td>58</td>
<td>31</td>
<td>34</td>
<td>22</td>
<td>7</td>
<td>22</td>
<td>3</td>
<td>197</td>
</tr>
<tr>
<td>Percent</td>
<td>9</td>
<td>29</td>
<td>16</td>
<td>17</td>
<td>11</td>
<td>4</td>
<td>11</td>
<td>1.5</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 3. Distribution of mean gamma

<table>
<thead>
<tr>
<th>Mean γ (in g)</th>
<th>5-6</th>
<th>7-8</th>
<th>9-10</th>
<th>11-12</th>
<th>13-14</th>
<th>15-16</th>
<th>17-18</th>
<th>19</th>
<th>25</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of occupants</td>
<td>17</td>
<td>34</td>
<td>37</td>
<td>46</td>
<td>24</td>
<td>28</td>
<td>7</td>
<td>1</td>
<td>3</td>
<td>197</td>
</tr>
<tr>
<td>Percent</td>
<td>9</td>
<td>17</td>
<td>19</td>
<td>24</td>
<td>12</td>
<td>14</td>
<td>3</td>
<td>0.5</td>
<td>1.5</td>
<td>100</td>
</tr>
</tbody>
</table>
SECTION 4: TECHNICAL SEMINARS

Table 4. Distribution of the sample as a function of the degree of intrusion of the passenger compartment

<table>
<thead>
<tr>
<th>Intrusion value</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. occupants</td>
<td>116</td>
<td>24</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>2</td>
<td>13</td>
<td>197</td>
</tr>
</tbody>
</table>

allows better identifying the most severe conditions.

We will use the following symbols:

- $\Delta$: upper third in delta $V$
- $\delta$: lower two-thirds in delta $V$
- G: upper third in mean deceleration
- g: lower two-thirds in mean deceleration
- I: upper third in intrusion value
- i: lower two-thirds in intrusion value

We can thus obtain eight different combinations.

Table 5 shows how the 197 occupants are distributed.

In addition, the occupants are separated into two groups in the dependent variable expressed by the OAIS. The level of division is determined in such a way that the effective values differ as little as possible. That is:

- OAIS $\leq 3$: 115 cases
- OAIS $> 3$: 82 cases

We then obtain the distribution indicated in table 6 where the occupants in the eight combinations are distinguished by their membership in one of the two OAIS classes.

This table gives an initial idea of the way in which the three variables can be ordered in their contribution to the severity of the injuries. At this stage of using the data, we can easily show how expeditious use of the statistical tests results in excessive conclusions. Thus, we will only retain intrusion as the explanatory variable of the severity. In totaling the OAIS $\leq 3$ of the occupants undergoing or not undergoing intrusion (combinations including the index "i"), we draw effective values $1 + 6 + 10 + 72 = 89$ from table 6. The corresponding OAIS $> 3$ gives $13 + 6 + 12 + 11 = 42$.

The occupants who underwent intrusion (combinations including the index "I") are distributed in severity in this way: 26 OAIS $\leq 3$, and 40 OAIS $> 3$, which is summarized in table 7.

The $\chi^2$ test will give $\chi^2 = 14.53$ and will permit a categorical rejection of the hypothesis that states: the gravity of the lesions is

<table>
<thead>
<tr>
<th>Impact parameter</th>
<th>OAIS $\leq 3$</th>
<th>OAIS $&gt; 3$</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta G$</td>
<td>6</td>
<td>22</td>
<td>28</td>
</tr>
<tr>
<td>$\Delta g$</td>
<td>1</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>$\Delta I$</td>
<td>4</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>$\Delta i$</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>$\delta G$</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>$\delta g$</td>
<td>10</td>
<td>12</td>
<td>22</td>
</tr>
<tr>
<td>$\delta I$</td>
<td>15</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>$\delta i$</td>
<td>72</td>
<td>11</td>
<td>83</td>
</tr>
<tr>
<td>Total</td>
<td>115</td>
<td>82</td>
<td>197</td>
</tr>
</tbody>
</table>

Table 5. Effective values from combining the three impact parameters having two levels each

<table>
<thead>
<tr>
<th>Impact parameter</th>
<th>No. of occupants</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta G$</td>
<td>28</td>
</tr>
<tr>
<td>$\Delta g$</td>
<td>14</td>
</tr>
<tr>
<td>$\Delta I$</td>
<td>12</td>
</tr>
<tr>
<td>$\Delta i$</td>
<td>12</td>
</tr>
<tr>
<td>$\delta G$</td>
<td>2</td>
</tr>
<tr>
<td>$\delta g$</td>
<td>22</td>
</tr>
<tr>
<td>$\delta I$</td>
<td>24</td>
</tr>
<tr>
<td>$\delta i$</td>
<td>28</td>
</tr>
<tr>
<td>Total</td>
<td>197</td>
</tr>
</tbody>
</table>

Table 6. Distribution of occupants into moderate (OAIS $\leq 3$) and serious (OAIS $> 3$) victims in each of the three impact parameters

Table 7. Severity as a function of intrusion

<table>
<thead>
<tr>
<th>Intrusion</th>
<th>Severity of OAIS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OAIS $\leq 3$</td>
</tr>
<tr>
<td>I</td>
<td>26</td>
</tr>
<tr>
<td>i</td>
<td>89</td>
</tr>
</tbody>
</table>
not greater when the impact reduces the dimensions of the passenger compartment.

In fact, orthogonalization of the data prevents this type of error—one that predicts that the association observed can be due to correlations between the alleged explanatory variable and the other variables whose effect is preponderant but not free.

A simple orthogonalization method consists of taking the distribution of the cases into the two classes of severity as the basic data in each combination after having converted this distribution into percentages. In this condition, we can independently estimate the effect of delta V, of the mean gamma, and intrusion on the severity. The correlations that connect these three parameters are annulled.

The data in table 6, converted into percentages, are found in table 8.

In order to evaluate the effect of an impact parameter on the severity of the lesions, we compare the mean percentage of severely injured occupants (OAIS > 3) for the high values of the parameter selected with the percentage corresponding to the low values of the same parameter. Thus, the effect of delta V will be estimated in the following way:

- Mean percentage of OAIS > 3 in combinations including delta:
  
  \[ 79 + 93 + 57 + 50/4 = 72.25\% \]

The data in table 6, converted into percentages, are found in table 8.

We observed that the effective value corresponding to certain combinations is low. A risk of error that would justify the calculation of the limits of reliability in the frequencies observed results from this. The method requires that the sample to which it is applied be important.

Daimler-Benz has conducted a multiple regression analysis on our raw data; this is a much more sophisticated method that has the advantage of losing less information since it does not regroup the data. The equation found is written:

\[
\text{OAIS} = (3,37 ± 1,56) + \left(1,60 ± 0,48 \frac{\Delta V}{48,0} - 1\right) + \left(1,56 ± 0,34 \frac{\gamma_m}{11,05} - 1\right) + \left(0,22 ± 0,07 \frac{\text{intrusion}}{1,22} - 1\right)
\]

the result of this is that the influence of delta V and mean gamma (1.60 and 1.56) is approximately eight times greater than the effect of intrusion (0.22). The results obtained with an extremely simple, but relatively unrefined method are confirmed.

### Table 8. Severity as a function of combinations of parameters related to impact (distribution in percentage)

<table>
<thead>
<tr>
<th>Impact parameter</th>
<th>OAIS ≤ 3</th>
<th>OAIS &gt; 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔGI</td>
<td>21</td>
<td>79</td>
<td>100</td>
</tr>
<tr>
<td>ΔGi</td>
<td>7</td>
<td>93</td>
<td>100</td>
</tr>
<tr>
<td>Δgl</td>
<td>33</td>
<td>67</td>
<td>100</td>
</tr>
<tr>
<td>Δgi</td>
<td>50</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>δGI</td>
<td>50</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>δGi</td>
<td>45</td>
<td>55</td>
<td>100</td>
</tr>
<tr>
<td>δgl</td>
<td>63</td>
<td>37</td>
<td>100</td>
</tr>
<tr>
<td>δgi</td>
<td>87</td>
<td>13</td>
<td>100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>58</td>
<td>42</td>
<td>100</td>
</tr>
</tbody>
</table>

### STUDY OF THE INTERACTIONS

It is possible to estimate the degree to which the effect of a parameter differs according to the value taken by the others. Several results are presented graphically in figure 3. The percentages of occupants with
The severity of the injuries increases in the presence of a high delta V but the effect of mean gamma is also very important. The effect of delta V is slightly less pronounced when gamma is high: (63-54) (58-19).

The influence of intrusion is low in the presence of a moderate delta V and practically null when delta V is high. Only delta V has an important effect.

The effect of intrusion is rather accentuated when the mean gamma is moderate, but its effect decreases when the mean gamma is high.

CONCLUSIONS

Orthogonalization of the data allows estimating the respective effects of delta V, mean gamma, and intrusion on the severity of lesions. The latter is closely connected with the delta V and mean gamma, while intrusion does not significantly increase the level of danger for the occupants, contrary to what expeditious statistical tests may suggest.

The same method of treating data concerning occupants wearing seatbelts would undoubtedly yield different results; in fact, the decrease in deceleration space is one of the factors that contributes to limiting the effectiveness of the seatbelt in many models currently in circulation, since their passenger compartment is destroyed before the limit of the violence of impact that an occupant can tolerate without injury is reached.
Phase II RSV Accident Analysis Techniques

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Minicars, Inc. Staff Analyst
Goleta, California

ABSTRACT

The Research Safety Vehicle (RSV) Phase I accident analysis was upgraded to more accurately reflect the real-world distribution of injuries and accident modes by velocity. This analysis was accomplished by revising the accident file corrections used in Phase I to be more representative of larger files that, in turn, were corrected to represent the total number of annual real-world U.S. accidents and fatalities. From these files, detailed examination identified the velocities and modes contributing most of the societal costs of accidents.

The results of the analysis have more specifically identified the crashworthiness and injury reduction goals of the Minicars RSV program. These goals, in turn, have led to recommended test matrices for the Phase IV efforts.

INTRODUCTION

To enable a more rational and cost/benefit-related design of the RSV, extensive analyses have been performed to achieve maximum safety payoff. In analyzing societal loss by accident mode, a description of cumulative societal loss for various selected damage area impact modes was obtained. The Multi-Disciplinary Accident Investigation (MDAI) file was adjusted to describe unrestrained occupant accidents in vehicle-to-vehicle and fixed object impacts in six selected modes. The resulting data permit proper weighting of costs among various modes in conjunction with CALII1 Abbreviated Injury Scale (AIS) distributions in each mode, within one accident analysis program. Preliminary relationships between unrestrained occupant injury measures were related to societal cost. Velocity relationships for selected damage area impact force combinations were identified, and side impact test modes were selected. Alternative test philosophies were considered to assure optimum test selection.

A detailed description of the analytical techniques used has been prepared for publication in the RSV Phase II final report. Because of its length, for this paper we have selectively included details in some basic controversial sections but have summarized most other sections.

ADJUSTING THE MDAI FILE

To describe cumulative societal loss as a function of velocity change (ΔV) and closing velocity (VCL) for unrestrained occupants in vehicle-to-vehicle and fixed object impacts in six selected modes, it was necessary to change the procedure used during Phase I RSV work to adjust the MDAI file. This change was made within the basic Phase I framework by linearly correcting over virtually the full ΔV range. However, a larger data file has been used, and the adjustment would include injury level zero cases in addition to allowing an apportioning of the results according to impact object and damage area. Thus, within one accident analysis program, proper weighting of costs among various modes can be achieved in conjunction with the CALII AIS distributions within each mode.

The CALII AIS distributions within various Damage Area and Impact Object (DAIO) modes were established by referring to a set of bivariate tables obtained from the University of Michigan Highway Safety Research Institute (HSRI). The six modes selected for study were vehicle-to-vehicle front, side, and rear, and fixed object front, side, and rollover.

Initially only unrestrained vehicle occupant cases were analyzed. However, because a significant number of vehicle occupant cases were classified as lacking data pertaining to the degree of restraint, these were apportioned in each DAIO mode and AIS

1Calspan Accident Data File—level II investigations.
level by the ratio of known unrestrained to known restrained occupants (as obtained from the bivariate tables). The CALII unrestrained occupant cases are described in each of 42 cells for the six DAIO modes and AIS 0-6+ levels (table 1). Corresponding cases in the unadjusted MDAI file were then identified. The resulting matrix appears in table 2. The mean velocity for each AIS level within the respective DAIO modes was determined for later use in CMDAI2 (see table 3). The velocity correction in CMDAI2 is now made at 1 mi/h increments of ΔV.

Adjustment factors were calculated from the results of tables 1 and 2 and equation (1):

\[
\text{FI} (M, \text{IL}) = \frac{\text{CALII} (M, \text{IL}) \times \text{MDAI} (M, 6+)}{\text{MDAI} (M, \text{IL}) \times \text{CALII} (M, 6+)} \tag{1}
\]

where FI (M, IL) is the adjustment factor for a particular mode (M) and injury level (IL), and CALII (M, IL) and MDAI (M, IL) refer to the number of cases in a given mode and injury level for the CALII and MDAI data, respectively. The adjustment factor matrix is shown in table 4.

Although utilizing these adjustment factors enables the AIS distribution within modes to be correct, the correct overall

<table>
<thead>
<tr>
<th>Mode</th>
<th>AIS levels</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Vehicle-to-vehicle:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>10 724</td>
<td>846</td>
</tr>
<tr>
<td>Side</td>
<td>7 853</td>
<td>595</td>
</tr>
<tr>
<td>Rear</td>
<td>5 070</td>
<td>339</td>
</tr>
<tr>
<td>Fixed object:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>1 198</td>
<td>219</td>
</tr>
<tr>
<td>Side</td>
<td>510</td>
<td>55</td>
</tr>
<tr>
<td>Rollover</td>
<td>120</td>
<td>216</td>
</tr>
<tr>
<td>Total</td>
<td>25 475</td>
<td>2 125</td>
</tr>
</tbody>
</table>

*a*Cells in parentheses were grouped to calculate adjustment factors.

<table>
<thead>
<tr>
<th>Mode</th>
<th>AIS levels</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Vehicle-to-vehicle:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>404</td>
<td>1 263</td>
</tr>
<tr>
<td>Side</td>
<td>198</td>
<td>625</td>
</tr>
<tr>
<td>Rear</td>
<td>84</td>
<td>216</td>
</tr>
<tr>
<td>Fixed object:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>166</td>
<td>508</td>
</tr>
<tr>
<td>Side</td>
<td>53</td>
<td>153</td>
</tr>
<tr>
<td>Rollover</td>
<td>62</td>
<td>165</td>
</tr>
<tr>
<td>Total</td>
<td>967</td>
<td>2 930</td>
</tr>
</tbody>
</table>

*a*Cells in parentheses were grouped to calculate adjustment factors.
Table 3. Mean velocity (mi/h) for each cell – MDAI file

<table>
<thead>
<tr>
<th>Mode</th>
<th>AIS levels</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle-to-vehicle:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td></td>
<td>11.5</td>
<td>15.4</td>
<td>20.3</td>
<td>25.8</td>
<td>31.2</td>
<td>31.2</td>
<td>–</td>
</tr>
<tr>
<td>Side</td>
<td></td>
<td>10.6</td>
<td>11.3</td>
<td>14.6</td>
<td>15.3</td>
<td>20.0</td>
<td>20.0</td>
<td>–</td>
</tr>
<tr>
<td>Rear</td>
<td></td>
<td>10.0</td>
<td>10.3</td>
<td>11.3</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Fixed object:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td></td>
<td>17.4</td>
<td>22.9</td>
<td>26.1</td>
<td>30.3</td>
<td>35.7</td>
<td>35.7</td>
<td>–</td>
</tr>
<tr>
<td>Side</td>
<td></td>
<td>21.5</td>
<td>25.1</td>
<td>30.5</td>
<td>29.6</td>
<td>33.1</td>
<td>33.1</td>
<td>–</td>
</tr>
<tr>
<td>Rollover</td>
<td></td>
<td>28.9</td>
<td>38.0</td>
<td>41.1</td>
<td>42.9</td>
<td>47.8</td>
<td>47.8</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 4. Adjustment factor matrix for CMDAI

<table>
<thead>
<tr>
<th>Mode</th>
<th>AIS levels</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle-to-vehicle:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td></td>
<td>67.8</td>
<td>1.71</td>
<td>2.15</td>
<td>1.23</td>
<td>0.493</td>
<td>0.493</td>
<td>1.0</td>
</tr>
<tr>
<td>Side</td>
<td></td>
<td>189.0</td>
<td>4.53</td>
<td>4.27</td>
<td>2.27</td>
<td>0.985</td>
<td>0.985</td>
<td>1.0</td>
</tr>
<tr>
<td>Rear</td>
<td></td>
<td>173.5</td>
<td>4.51</td>
<td>7.86</td>
<td>1.00</td>
<td>1.000</td>
<td>1.000</td>
<td>1.0</td>
</tr>
<tr>
<td>Fixed object:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td></td>
<td>146.0</td>
<td>8.71</td>
<td>7.64</td>
<td>5.05</td>
<td>2.400</td>
<td>2.400</td>
<td>1.0</td>
</tr>
<tr>
<td>Side</td>
<td></td>
<td>108.0</td>
<td>4.04</td>
<td>5.27</td>
<td>1.53</td>
<td>1.000</td>
<td>1.000</td>
<td>1.0</td>
</tr>
<tr>
<td>Rollover</td>
<td></td>
<td>11.8</td>
<td>2.62</td>
<td>4.09</td>
<td>2.56</td>
<td>1.000</td>
<td>1.000</td>
<td>1.0</td>
</tr>
</tbody>
</table>

relationship between modes is not ensured. Hence, a set of six mode-weighting factors (DISTMODE) was formulated for CMDAI based on the CALII data, as shown in Table 5. Analysis indicates that the frontal fixed object impact mode could be used as the reference mode and that the vehicle-to-vehicle frontal mode would require the largest weighting factor.

A societal loss breakdown is presented in Table 6 as indicated from data resulting for unrestrained occupant accidents.

ANALYSIS OF SOCIETAL LOSS BY ACCIDENT MODE

Impact test matrices for Phases II and IV of the RSV program were determined from data relative to the cumulative societal loss as a function of velocity change (ΔV) and closing velocity (V_{CL}) for unrestrained occupants in vehicle-to-vehicle and fixed object impacts. Six impact accident modes, defined by Case Vehicle Damage Area (CVDA) as coded in the MDAI files, were selected.

Data were obtained by replacing the MDAI data file used in Phase I with a new

Table 5. Mode-weighting factors

<table>
<thead>
<tr>
<th>Mode</th>
<th>Weighting factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed object:</td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>1.000</td>
</tr>
<tr>
<td>Side</td>
<td>1.943</td>
</tr>
<tr>
<td>Rollover</td>
<td>3.330</td>
</tr>
<tr>
<td>Vehicle-to-vehicle:</td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>8.075</td>
</tr>
<tr>
<td>Side</td>
<td>4.297</td>
</tr>
<tr>
<td>Rear</td>
<td>5.310</td>
</tr>
</tbody>
</table>
Table 6. Societal loss breakdown by mode as indicated by CMDAI2

<table>
<thead>
<tr>
<th>Mode</th>
<th>Total societal loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed object:</td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>9.1</td>
</tr>
<tr>
<td>Side</td>
<td>5.8</td>
</tr>
<tr>
<td>Rollover</td>
<td>7.9</td>
</tr>
<tr>
<td>Vehicle-to-vehicle:</td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>47.5</td>
</tr>
<tr>
<td>Side</td>
<td>25.4</td>
</tr>
<tr>
<td>Rear</td>
<td>4.3</td>
</tr>
</tbody>
</table>

MDAI file containing 13,093 cases and by using the computer program CMDAI2 to adjust the file so that the AIS distribution in each of the six modes represents that of the corresponding six modes in the CALII accident file.

Distribution of the total CVDA mode loss by impact force direction was defined in each DA mode. Based on past results, however, cumulative cost versus \( \Delta V \) for various impact force directions within a given DA mode were not expected to follow the overall curve. In other words, for a given DA mode, the \( \Delta V \) at which 75 percent of societal loss is reached for an impact force direction \( \theta_1 \) would not be the same as that for another direction \( \theta_2 \) in the same mode (fig. 1).

The cumulative societal loss as a function of either \( \Delta V \) or \( V_{CL} \) for the six DA modes analyzed is presented in figures 2 through 5. The total cumulative costs described by these curves represent about 90 percent of all unrestrained occupant injury costs. The remaining 10 percent is attributed to costs incurred in such side impact modes as side-front, side-rear, or side-distributed damage areas. Tables 7 and 8 break down the impact force within each of these modes for vehicle-to-vehicle and fixed object impacts, respectively.

![Figure 1. Total cumulative cost versus BEV for impact force directions \( \theta_1 \) and \( \theta_2 \).](image)

\[ M(1, \theta_1) = \text{Total cumulative cost of DA mode 1 with impact force direction } \theta_1, \]
\[ M(1, \theta_2) = \text{Total cumulative cost of DA mode 1 with impact force direction } \theta_2. \]
SELECTION OF SIDE IMPACT TEST MODES

The side impact test modes selected should be representative of actual accidents. The selection was based on a detailed examination of computerized accident data files in general and on the adjusted MDAI file in particular.

Any given impact can be completely described by the impact configuration and by the impact velocity relationship. For
copolanar vehicle-to-vehicle accidents, the impact configuration is completely defined by three parameters: $S_1$, $S_2$, and $\alpha$ (fig. 6). The point of impact on the case vehicle and on the corresponding point on the other vehicle are described by $S_1$ and $S_2$, respectively. The best indicators of $S_1$ and $S_2$ (as coded in the accident files) are the horizontal damage areas of the case vehicle and the other vehicle, respectively, each of which may be grouped according to clock position. The third parameter — the impact angle $\alpha$ — describes the relative orientation of the vehicle centerlines.

The velocity relationship is illustrated in figure 7. It is apparent that three additional parameters are required: (1) impact velocity $V_1$ of the case vehicle, (2) impact velocity $V_2$ of the other vehicle, and (3) angle $\gamma$ between the velocity vectors. Given the
values of these parameters, it is possible to calculate the closing velocity as follows:

\[ V_{CL}^2 = V_1^2 + V_2^2 + 2V_1 V_2 \cos \gamma \]  \hspace{1cm} (2)

Unfortunately, the angle \( \gamma \) is not included in the accident data. However, the direction of primary impact force is known for each vehicle. As indicated in figure 8, impact force direction for the case vehicle is \( \theta_1 \), the angle between the closing velocity vector and the centerline of the case vehicle. Similarly, \( \theta_2 \) is the impact force direction for the other vehicle. It can also be seen that the impact velocity vector for each vehicle may not be parallel to the vehicle centerline; that is, each vehicle may be yawing or side-slipping. The yaw angles for the case vehicle and the other vehicles are denoted as \( \beta_1 \) and \( \beta_2 \), respectively.

One useful insight derived from figure 8 is that impact angle \( \alpha \) may be calculated from the impact force directions \( \theta_1 \) and \( \theta_2 \) as follows:

\[ \alpha = \theta_1 - \theta_2 \]  \hspace{1cm} (3)
SECTION 4: TECHNICAL SEMINARS

for example, when the front of the one car strikes the side of a stationary car — a relatively rare event. The importance of this observation relates to the fact that the layout of the test facility cannot be determined solely on the basis of $\theta_1$, the struck vehicle impact force direction, if that facility is used for representative impacts.

From the geometry of figure 8, the closing velocity and the angle between the velocity vectors may be derived as follows:

$$\gamma = \beta_2 - \beta_1 + \theta_1 - \theta_2 \quad (4)$$

$$V_{CL} = V_1 \cos (\theta_1 - \beta_1) + \sqrt{V_2^2 - [V_1 \sin (\theta_1 - \beta_1)]^2} \quad (5)$$

$$V_{CL} = V_1 \cos (\theta_1 - \beta_1) + V_2 \cos (\theta_2 - \beta_2) \quad (6)$$

Unfortunately, the yaw angles $\beta_1$ and $\beta_2$ are not coded, so for purposes of analysis it must be assumed that neither vehicle is skidding sideways; that is, both angles must be assumed to be zero, in which case:

$$\gamma = x = \theta_1 - \theta_2 \quad (7)$$

$$V_{CL} = V_1 \cos \theta_1 + \sqrt{V_2^2 - (V_1 \sin \theta_1)^2} \quad (8)$$
Equations 7 and 9 were used in the manipulation of file data to determine the appropriate side impact test modes.

To consider all possible approaches in specifying side impact conditions, an additional study was conducted to actually measure side impact angles from MDAI case study reports. The approach was to identify side impact data set from which vehicle-to-vehicle impacts having a side-center and front damage area were identified. These cases were collected and analyzed for various parameters including societal loss, impact angle, V1, V2, and vehicle characteristics. The result confirmed previous results in which the predominant impact configuration by societal loss and frequency was found to be 9 and 3 o’clock impact angle sector ($90^\circ \pm 15^\circ$, $270^\circ \pm 15^\circ$). Previous characteristics relating to $V_{CL}$ and V1/V2 were also confirmed.

SELECTION OF TEST MODES FOR PHASE IV

One RSV program goal is to develop a lightweight vehicle which will have significant safety payoff. To evaluate whether the safety payoff projected in Phase I has been achieved, the completed system must be thoroughly evaluated in an accident environment representative of the 1985 time frame. In addition, since accidents occur in every conceivable way, those reproducible configurations which contribute significantly to total societal loss must be identified. Identification of these modes and subsequent testing within them allows the restraint/structure system benefits which would accrue through implementation of RSV concepts to be calculated. Each mode must be completely tested since the methodology used to evaluate safety payoff considers each impact mode and evaluates the difference in societal loss as a function of closing velocity within that mode. Performance is weighted by the probability of impact with various vehicle classes.

To determine pertinent test modes, the cumulative loss distribution is described as a function of closing velocity for each case vehicle damage area mode. In addition, the distribution of loss by the other vehicle damage areas or object type is considered for each case vehicle damage mode. This provides a basis for identifying priorities in impact configurations on the basis of contribution to societal loss. It also enables closing velocities to be specified on the basis of cumulative societal loss. In addition to considerations of configuration and closing velocities, the characteristics of the other vehicle are pertinent. Clearly there is a distribution that describes the probability of impact with other vehicle classes. Based on Phase I projections of vehicle mileage by vehicle class for 1985, the distribution appears in histogram form with mean weights within classes as indicated in figure 9. In addition, assuming equal closing velocities, it is recognized that the threat to the RSV class increases as the weight of the other vehicles increases within a given mode. Thus, contribution to the total societal loss as a function of other vehicle mass can be established within each mode of interest, if the average loss to the struck vehicle of interest is identified as a function of other vehicle mass and combined with the probability of impact with the other vehicle.

![Figure 9. Phase I projections of mileage distribution by vehicle class.]
Preliminary efforts to establish such a set of relationships were undertaken. For the frontal mode the average loss for case vehicles in the 1 500-2 500 lb weight class as a function of other vehicle mass was identified as in figure 10. Consideration of side impacts has two facets. The first considers the RSV class struck in the side. For this mode the average loss in 1 500-2 500-pound vehicles as a function of other vehicle mass was identified. Consideration of aggressivity should examine the average loss by mass in vehicles struck in the side by the 1 500-2 500-pound vehicles. This relationship was also established.

Multiplying the probabilities of impact by the average loss yields the loss distribution within each mode (table 9). These data enable other vehicle test weights to be specified on the basis of contribution to societal loss within each mode.

It is recommended that the primary other vehicle masses be selected at the vehicle mass corresponding to the median societal loss point within each mode under consideration. Since indicator tests should be conducted with fringe weight groups to evaluate the performance degradation and improvement that will result during impact with these groups, their selection might specify the vehicle masses corresponding to the 25th- and 75th-percentile vehicle masses as indicated by the cumulative societal loss distribution within each mode. In table 10 the primary other vehicle test mass is identified for each mode as well as vehicle masses for less intensive indicator testing as discussed above.

By combining the above information, a test matrix can be formulated that will allow the safety payoff of the RSV to be evaluated. The matrix as shown in table 11 is arranged by priority as assigned by group contribution to societal loss. The corresponding test mode descriptions appear in figure 11. Braking considerations have been

![Figure 10. Average societal loss as a function of other vehicle mass in the frontal mode for all 1 500- to 2 500-pound vehicle occupants.](image)

<table>
<thead>
<tr>
<th>Vehicle class</th>
<th>Frontal modea</th>
<th>Side mode RSV class strucka</th>
<th>Side mode RSV class strikingb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-subcompact</td>
<td>5.8</td>
<td>10.1</td>
<td>17.4</td>
</tr>
<tr>
<td>Subcompact</td>
<td>24.5</td>
<td>31.8</td>
<td>41.1</td>
</tr>
<tr>
<td>Compact</td>
<td>20.5</td>
<td>19.9</td>
<td>18.2</td>
</tr>
<tr>
<td>Intermediate</td>
<td>15.6</td>
<td>13.3</td>
<td>9.1</td>
</tr>
<tr>
<td>Standard</td>
<td>33.6</td>
<td>24.9</td>
<td>14.0</td>
</tr>
</tbody>
</table>

*aLoss is for RSV class vehicle.  
*bLoss is for struck car.

Table 10. Recommended other vehicle weights in vehicle-to-vehicle test modes

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Frontal modes</th>
<th>Side mode RSV class struck</th>
<th>Side mode RSV class striking</th>
<th>Rear modes</th>
</tr>
</thead>
</table>
| Primary tests:  
Vehicle A | 3 000-3 200 lb | 2 700-2 900 lb | 2 300-2 500 lb | 2 700-2 800 lb |
| Indicator tests:  
Vehicle B | 2 400 lb | 2 000 lb | 1 900 lb | 2 000 lb |
| Vehicle C | 4 200 lb | 4 000 lb | 3 200 lb | 4 000 lb |
Table 11. Recommended RSV Phase IV crash test matrix

<table>
<thead>
<tr>
<th>Test</th>
<th>No. of RSV R's required</th>
<th>Number of other vehicles required</th>
<th>Other vehicles&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Braking involved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>3 1 1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>3 1 1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3A</td>
<td>6</td>
<td>3 1 1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3B</td>
<td>6</td>
<td>3 1 1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4A</td>
<td>5</td>
<td>2 1 1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4B</td>
<td>5</td>
<td>2 1 1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4C</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5A</td>
<td>5</td>
<td>2 1 1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5B</td>
<td>5</td>
<td>2 1 1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5C</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6A</td>
<td>5</td>
<td>2 1 1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6B</td>
<td>5</td>
<td>2 1 1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6C</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>8</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>2+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>3</td>
<td></td>
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<td></td>
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<tr>
<td>Total</td>
<td>79</td>
<td>24 10 10 10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>See table 9.

included in the test matrix because braking occurs in a significant portion of real-world impacts as identified in Phase I.

INJURY MEASURE

Societal loss that accrues from occupant injuries resulting from side impacts involving different types of vehicles can be affected by the stiffness built into the front-end structure of the striking vehicle. Many factors must be considered in determining the significance of this stiffness on societal loss, that is, occupant restraint systems and accident configuration parameters involved. However, to minimize societal loss in vehicle-to-vehicle accidents, injuries that occur to occupants of both the struck and striking vehicles should be considered. Significant overall societal benefits may not accrue by increasing occupant safety in one vehicle at the expense of reducing occupant safety in other vehicles.

The front-end stiffness specification can be determined within other design considerations through an optimization process that minimizes the total societal loss, considering both struck and striking vehicles. This optimization process can be highly complex; however, it can be simplified by considering only those conditions that appear to drive the analysis.

Vehicle-to-vehicle impact conditions that involve the RSV front end and contribute significantly to current societal loss are:

- RSV front to other front
- RSV front to other side
- RSV front to RSV side
- RSV front to other rear

Generally, in frontal accidents the 2,000-lb vehicle under consideration might be expected to undergo most of the velocity change because the vehicle will be on the low tail of the weight distribution for the vehicle population.

In the side mode the RSV struck by an RSV front can be eliminated because the side structure/padding system is expected to provide excellent occupant protection regardless of the striking vehicle characteristics. The remaining mode then is the RSV front to an “other” vehicle side. Since low injury loss would be expected to occupants of the striking vehicle in a side impact, consideration in this mode is focused on the struck “other” vehicle occupant injuries.

As a result, the optimization procedure trades off the societal loss or benefit to the RSV occupants in front-to-front impacts against the societal loss or benefit to the occupants of the struck “other” vehicle in side impact collisions.

To quantify the losses which accrue with the RSV front-end in a manner conducive to analytical simulation of vehicle-to-vehicle impacts, a continuous relation is needed between occupant injury measures and societal loss.

The details of the study conducted to
Section 4: Technical Seminars

Figure 11. Test mode descriptions.

- 1, 2, 3a, 3b: Frontal vehicle-to-vehicle test modes
- 4a, 4b, 4c, 5a, 5b, 5c: Side vehicle-to-vehicle test modes
- 6a, 6b, 6c: Rear vehicle-to-vehicle test modes
- 7, 8, 10: Fixed object test
- 9, 11, 12: Rollover
formulate such a relationship for occupants involved in side impacts are too lengthy for inclusion in this paper. The results are shown in figures 12 and 13. A complete description of the methodology used in the injury measure analysis and a demonstration will be included in detail in the Final Report for the Phase II effort.

Figure 12. Injury measure to societal loss relationships for occupants of all seating positions.

Figure 13. Injury measure to societal loss relationships for nearside occupants.
A Study of Seatbelt Effectiveness Based on a Methodology for Analyzing General Categorical Data With Misclassification Errors

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ABSTRACT

Most studies examining the effectiveness of seatbelts in reducing injury due to automobile accidents have been based on police-level data. Due to the circumstances surrounding the officer's investigation of the crash, such data generally contain misclassification errors relating to belt use and injury sustained, which can seriously bias any effectiveness estimates derived from that data.

In this paper, a methodology for analyzing general categorical data with misclassification errors is described and the procedure applied to the seatbelt effectiveness question. The technique utilizes an original large sample based on police-reported accidents together with a relatively small supplementary sample that is cross-classified by the police and by a more reliable classification mechanism.

The procedure is illustrated using police-reported North Carolina accidents for the first 8 months of 1975 as the original sample. The true classification of the supplementary sample of accidents is assumed to be obtained through hospital reports for injured occupants and through telephone interviews for the non-injured. Comparisons are then made of the belt-associated relative risks thus obtained.

INTRODUCTION

The magnitude of the injury-reducing potential of safety belts has long been an issue of controversy. This is due to a variety of problems which make it difficult to obtain a definitive evaluation of safety belt effectiveness. These problems and the difficulties they impose have recently been examined by several researchers (such as Griffin, 1973; Mela, 1974; Kahane et al., 1975; and Hochberg, 1976).

One of the major problems discussed in Mela (1974) and in Hochberg (1976) is the bias in the estimates of safety belt effectiveness resulting from misclassification errors in the police reports of safety belt usage and/or degree of injury. These biases can seriously affect any inference about safety belt effectiveness.

The following discussion explores this problem a little further, based on the theoretical development given in chapter 4 of Hochberg (1976).

Consider a $2 \times 2$ table of proportions of belt usage (yes or no, say), by injury (yes or no, say). Let $U$, $B$, $I$, and $N$ indicate "unbelted," "belted," "injured," and "not injured," respectively. Denote by $\pi(I,U)$ the true proportion of injured-unbelted occupants and similarly let $\pi(N,U)$, $\pi(N,B)$, and $\pi(I,B)$ represent the other (true) proportions. Theoretically, a total of 12 independent misclassification errors might arise when classifying individuals into such a table. Let $\alpha(I,U|N,B)$ denote the probability that the police will report an actually belted—not injured occupant as being injured and unbelted. Similar notation is used for the other 11 possible misclassification errors. Finally, the observed biased proportions based on police reports are denoted by $\gamma(\cdot,\cdot)$'s instead of $\pi(\cdot,\cdot)$'s.

Formulas that relate the $\gamma(\cdot,\cdot)$'s to the $\pi(\cdot,\cdot)$'s are easily derived; see, for example, Hochberg (1976). In that report, an effort was made to evaluate the resulting biases in estimates of safety belt effectiveness, based on the $\gamma(\cdot,\cdot)$'s corresponding to a range of some educated guesses that were then simulated for the actual values of the $\pi(\cdot,\cdot)$'s and the $\alpha(\cdot,\cdot)$'s. The setup in Hochberg (1976) was further simplified by the following two assumptions on the misclassification errors:
• In no case will an uninjured person be classified as injured.
• Probabilities of simultaneous errors in both characteristics are given by multiplying the corresponding one-way error probabilities, e.g.,

$$\alpha(I,B|N,U) = \alpha(N,B|N,U) \alpha(I,U|N,U).$$

Even under that limited setup and the restricted simulated values for the $$\pi(\cdot;\cdot)$$'s and $$\alpha(\cdot;\cdot;\cdot)$$'s, it was noted (Hochberg, 1976) that:

- The bias in the resulting measures of effectiveness could be as high as 150 percent. For example, this is the case when “injured” indicates fatalities and one assumes:
  - 15-percent belt usage.
  - Probability of fatality when using the belt = .0025 and probability of fatality when not using the belt = .005.
  - $$\alpha(N|I,B) = .10, \alpha(B|N,U) = .15, \alpha(U|I,B) = .05$$ and all other error probabilities equal .01.
- The range of values of the biases was very large (from -50 to +150 percent).

Thus, the main impact of that simulated study and of some pilot surveys (see Hochberg, 1976) was the definite need for a more reliable information source than merely the police accident reports for studying the effectiveness of safety belts.

What, then, are the major alternatives?

1. Draw inference on safety belt effectiveness entirely from police reported data. The main motivations for such an approach (that has been the prevailing one until recently) would be:
   - There is a large quantity of such data.
   - Maybe the biases are not large, either because of low probabilities for misclassification errors or because those errors interact in different directions so as to partially cancel one another.

2. Obtain an independent reliable sample by some better classification mechanism and base inference entirely on that sample. That approach is undertaken in Kahane, et al. (1975), where the reader should see some additional motivations for so doing in addition to reducing the effects of misclassification errors.

One must be aware of the costs involved when adopting approach (2), because if estimates of belt effectiveness are to be entirely based on such a sample, its size must be sufficiently large to reach satisfactory accuracy. The risks of using approach (1) were detailed earlier.

3. Obtain a relatively small (in comparison to (2)) supplementary sample which must then be cross-classified by both police reports and some more reliable source. Then utilize the methodology in Hochberg (in press) (to be described in the sequel) to obtain statistically sound estimates based on the “large” police-reported data in conjunction with the “small” supplementary cross-classified sample.

The section on proposed methodology contains a description of the methodology developed by Hochberg (in press) in conjunction with this final alternative. In the third section, on the effectiveness of safety belts, the procedure is demonstrated utilizing actual data from North Carolina's accidents in the first 8 months of 1975 and a supplementary sample of hospital/telephone data. The fourth section contains a summary discussion.

THE PROPOSED METHODOLOGY

The methodology for analyzing general misclassification categorical data presented in Hochberg (in press) makes further use of Tenenbein's (1970, 1971, 1972) double sampling scheme originally introduced for estimating the parameters of a multinomial distribution when misclassification errors prevail. The following experimental situation is assumed. There are two classification devices available. (The reader should not adhere to the mechanical connotation of the term "device.") One device is expensive to apply and gives "correct" results, while the other is relatively inexpensive but "fallible." The experimental setup referred to is very often met in reality in problems where the distinction between a true or a false classification...
device simply relates to making or not making an extra effort to obtain more reliable data.

Such experimental situations are frequently met by researchers in various domains of science. For example, Diamond and Lilienfeld (1962) discuss an experimental situation in public health research where the true classification device is the physician's examination whereas the fallible classifier is a questionnaire completed by the patient.

In real problems, it is often the case that the true classification device uses different scales than those used by the fallible device. The experimenter's knowledge of the degree of correspondence between the levels of two such scales may vary from none to complete. For the first example, a nominal scale for a patient's response to a questionnaire may have four levels, A, B, C, and D, while the physician's report may use some standard scale with levels 1, 2, 3, 4, 5, and 6. The correspondence between the patient's scale and the physician's scale may be clear (for example, A ↔ (1 or 2), B ↔ (3 or 4), C ↔ 5, D ↔ 6) or, as more often is the case, it may be quite unclear. Note that we refer to correspondence between these scales as implied by the a priori definitions of the scales and their levels. Even in cases where such a relation is completely known, fixed bias errors of misclassification may very well prevail.

The procedures to be discussed here have a double motivation in such experimental situations. First, they can be used to resolve the problems of misclassification errors. Secondly, even when misclassification errors do not exist, the procedures enable one to carry out an efficient study expressing results in terms of the finer scale utilized in the relatively small supplementary sub-sample.

The setup considered in Hochberg (in press) is general in the sense that either some or all the variables under study can be subject to misclassification errors, and the original contingency table can be of any dimensions.

In our specific application, the “fallible” classification device is the police-reported information and the “true” classification derives from hospital reports for injured occupants and intensive telephone interviews of the non-injured. The question of interest is that of the effectiveness of wearing “lap only” versus “none” and of “lap and shoulder” versus “lap only” in U.S. and in foreign cars.

The first sample consists of all police-reported accidents in North Carolina during the first 8 months of 1975. The second, more reliable sample, was cross-classified by the two classification devices on the variables: belt use and injury. All other variables under study (such as, model year of car, sex of injured occupant, and type of accident) were assumed to have been correctly reported by the police.

Let \( j_1 \) and \( j_2 \) index the police-reported status of belt use (none, lap only, lap and shoulder) and of injury (not injured, injured), respectively, and let \( j = (j_1, j_2) \). Similarly, let \( i_1, i_2 \) index the “true” levels of belt use and of injury, respectively, as reported by the more reliable source, and put \( \tilde{j} = (i_1, i_2) \). Finally, let \( \tilde{\ell} \) index the specific combination of levels of all the variables under study that are assumed to be correctly reported by the police. In our example of the third section, \( \tilde{\ell} \) assumes only two values, namely, “U.S. cars” or “Foreign cars,” due to data limitations. To denote combinations of these multiple indices we simply adjoin them, for example, \( (ij) \) indexes a specific combination of police-reported levels for belt use and injury and of non-police-reported levels for these two variables.

Let \( N(\tilde{\ell}) \) denote the first sample frequency of occupants with levels \( j \) on belt usage and injury and level \( \tilde{\ell} \) on type of car. Similarly, let \( n(\tilde{\ell}) \) denote the second sample frequency of occupants reported as having injury levels \( j \) and car types \( \tilde{\ell} \) by the police while the “true” classification for belt use and injury was given by \( \tilde{j} \). The corresponding unknown population proportions are denoted by \( \alpha(\tilde{\ell}) \) and \( \beta(\tilde{ij}) \), respectively. To denote quantities computed from marginal tables (such as, row and column tables), we omit the unnecessary indices: \( \alpha(\tilde{\ell}) \) denotes the sum of all \( \alpha(\tilde{ij}) \) across all levels \( j \).

The intermediate parameters of interest
are the \( \alpha_{ij} \) that describe the overall true distribution of occupants involved in accidents across the levels of (belt usage) \( \times \) (injury) \( \times \) (type of car). The first phase of inference in the methodology of Hochberg (in press) amounts to obtaining efficient estimators of the \( \hat{\alpha}_{ij} \) and the approximate common distribution of these estimators. In the second phase of inference, these estimators are further analyzed to obtain true estimates of safety belt effectiveness across levels \( \xi \) of car type.

We now outline these two phases of inference. As noted earlier, in the first phase of inference, “efficient” estimators for \( \hat{\alpha}_{ij} \) are obtained. By that we mean Maximum Likelihood (ML) estimators or some other estimators that are asymptotically equivalent to the ML estimators. One class of estimators that are asymptotically equivalent to the ML’s is that based on asymptotic weighted least squares (LS) as in Grizzle et al. (1969).

Since ML estimators are considered most efficient in our setup, and since we have found their use in these problems more convenient than that of the LS principle, we have used only them in our applications.

The ML estimators \( \hat{\alpha}_{ij} \) of the \( \alpha_{ij} \) are obtained by summing across all levels of \( j \) the ML estimators of the \( \beta_{ij} \) which are given by:

\[
\hat{\beta}_{ij} = \frac{N(ij) + n(jj)}{N + n} \cdot \frac{n(ij)}{n(jj)},
\]

where \( N \) and \( n \) are the total sample sizes of the first and second samples, respectively.

The asymptotic distribution of the \( \hat{\alpha}_{ij} \) is multivariate normal (being ML estimators).

Having obtained the \( \hat{\alpha}_{ij} \), one must be able to produce a consistent estimator of their covariance matrix in order to proceed into the second phase of inference. The determination of the variance matrix of the \( \hat{\alpha}_{ij} \) for both the ML and LS approaches are detailed in Hochberg (in press).

The “True” Effectiveness of Safety Belts for American and Foreign Cars: An Example

The data for this example is given in tables 1 and 2. The total number of observations for the first sample is 81,617. These were available with no extra effort. (Note that “injury” in table 1 refers to the standard police K, A, B, C, 0 scale.)

Table 2 presents belt use and injury information for the supplementary sample of 2,372 occupants, cross-classified by police and non-police data sources. Note that within each cell of the table, the cases falling along the diagonal (from top left to bottom right) reflect agreement between the two sources of belt information. Those falling above or below the diagonal represent disagreement. The results generally indicate that the police are more likely to report “no belt” and less likely to report “lap belt” or “lap and shoulder belt” in comparison with the response obtained via the hospital or the telephone interview. (Note that the “non-police”-reported injury refers to the AIS scale.)

If only the police-reported data were used for analysis, the resulting estimated risks and effectiveness would be as in table 3. However, if the methodology proposed in the second section of this paper is adopted in order to utilize the true classification of occupants in the “second” sample, then the estimated risks and effectiveness are as displayed in table 4.

Table 1. Police-reported frequencies of occupants in North Carolina’s accidents during the first 8 months of 1975

<table>
<thead>
<tr>
<th>Injury</th>
<th>U.S.</th>
<th>Foreign</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>Lap only</td>
</tr>
<tr>
<td>Injured</td>
<td>11,546</td>
<td>1,074</td>
</tr>
<tr>
<td>Not injured</td>
<td>52,139</td>
<td>6,502</td>
</tr>
</tbody>
</table>
Table 2. Police and nonpolice cross-classification of injury and belt use,\(^a\) controlling for car type

<table>
<thead>
<tr>
<th>Police</th>
<th>Nonpolice</th>
<th>U.S. Cars</th>
<th>Foreign Cars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Not Injured</td>
<td>Injured</td>
<td>Not Injured</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>L</td>
<td>LS</td>
</tr>
<tr>
<td>Not injured:</td>
<td>U</td>
<td>1086</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>13</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>LS</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Injured:</td>
<td>U</td>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>LS</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^a\) U = Unbelted; L = Lap belt; LS = Lap and shoulder belt

Table 3. Estimated risks and effectiveness\(^a\) based on police-reported data only

<table>
<thead>
<tr>
<th>Car make</th>
<th>Belt use(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U.S.</td>
</tr>
<tr>
<td></td>
<td>U</td>
</tr>
<tr>
<td>Injured (%)</td>
<td>18.13</td>
</tr>
<tr>
<td>STD(^c)</td>
<td>.15</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>-</td>
</tr>
<tr>
<td>STD(^c)</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^a\) Effectiveness of "L" = \(100 \times \frac{\text{injury for "N"}}{\text{injury for "L"}}\)

Effectiveness of "LS" = \(100 \times \frac{\text{injury for "L"}}{\text{injury for "LS"}}\)

\(^b\) U = Unbelted; L = Lap belt; LS = Lap and shoulder belt

\(^c\) STD = Standard Deviation of Estimate

If the estimated risks and effectiveness of table 4 are the true ones, then the bias in the police-based estimates is quite substantial. Hence, the low Standard Deviation of Estimates (STD's) of the estimates in table 3 are not true indicators of accuracy. Rather than looking at the STD's, we must compute the mean square error (MSE) of each estimator (MSE = variance + (bias)\(^2\)). In doing so for the police-reported data, we find that these are too large and thus do not enable very accurate statistical statements on belt effectiveness.

Unfortunately, due to the small size of our supplementary sample, this limitation also applies when attempting statistical valid inferences from table 4. This is further discussed in the following summary section.
Table 4. Estimated risks and effectiveness\(^a\) based on the two-sample methodology

<table>
<thead>
<tr>
<th>Car make</th>
<th>Injured (%)</th>
<th>Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>30.50</td>
<td>21.33</td>
</tr>
<tr>
<td>STD(^c)</td>
<td>.90</td>
<td>2.05</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>30.10</td>
</tr>
<tr>
<td>STD(^c)</td>
<td>-</td>
<td>7.11</td>
</tr>
</tbody>
</table>

\(^a\)Effectiveness of “L” = 100 × \(\frac{\text{% injury for “N”} - \text{% injury for “L”}}{\text{% injury for “L”}}\)

\(^b\)U = Unbelted; L = Lap belt; LS = Lap and shoulder belt

\(^c\)STD = Standard Deviation of Estimate

DISCUSSION

As we saw in the third section, few conclusive statements can be made regarding safety belt effectiveness as a result of the investigation. This is due to the large standard deviations (STD’s) of the estimates which, in turn, are partially due to the size of the supplementary sample. As noted earlier, the supplementary sample used to demonstrate the methodology presented in this paper consisted of only 2,372 occupants. As HSRC discovered, it was no little task to collect the supplementary hospital and telephone interview information on even this (relatively) small sample size.

It now appears that, in order to make statistically significant statements on safety belt effectiveness using this two-sample methodology, one should probably have (roughly speaking) a three-fold or four-fold size supplementary sample. Thus, the data presented in this paper should be regarded primarily as a tool to demonstrate a new technique, rather than as decisive evidence of safety belt effectiveness.

It should be noted, at this point, that the sample size also limited the extent to which the data could be broken down during analysis. For the purposes of this paper, the data on injury level and belt use were broken down by only one variable—car type (U.S. versus foreign). The small sample size precluded the possibility of studying the effects of any two or three of these variables simultaneously.

Similar problems of low accuracies for belt effectiveness when the data are broken down by several factors of interest were encountered in the Restraint Systems Evaluation Project (RSEP) (Reinfurt et al., 1976). In this study, seatbelt effectiveness was evaluated based on a single sample of 15,818 weighted occupants involved in towaway crashes. The data were of a “Level II” nature, with special emphasis placed on obtaining accurate measures of safety belt use.

While increasing the size of the supplementary sample will improve the accuracy of the belt effectiveness estimates based on the two-sample methodology, additional research is needed to further improve upon the technique. More specifically, research is needed to incorporate smoothing models for the entries in the supplementary sample, based on (hopefully) only a few parameters for the misclassification errors. The methodology as it now stands does not allow for using model-predicted estimates of the frequencies in the supplementary cross-classified sample prior to “merging it statistically” with the original sample.

It is very reasonable to expect that the
very large number of misclassification errors (that introduce too many degrees of freedom in the procedures described) could be structured by an appropriate statistical model, resulting in lower STD’s for the predicted frequencies. The author hopes to be able to carry out this research in the near future.

ACKNOWLEDGMENT

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REFERENCES

A New Approach to Vehicle Dynamic Analysis of Severe Steering and Braking Inputs

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INTRODUCTION

In the United States in 1974 3.9 percent of all accidents involving 14 percent of all fatal accidents concerned vehicles overturning without a preceding collision on the roadway [1]. This demonstrates that such accidents belong to that group characterized by potentially severe occupant injuries.

A high percentage of these occurrences transpired after the vehicle had left the road, whereas approximately one-sixth were caused by forces generated at the tire/road interface. It is probable that a large percentage of such accidents can be attributed to tripping mechanisms of various types.

The low frequency of vehicle dynamics-related upsets indicate that upset resistance requirements must not be permitted to detrimentally affect other dynamic properties of a motor vehicle, such as responsiveness and accident avoidance capabilities.

This paper describes possible procedures for the evaluation of vehicle behavior prior to an upset due to the friction between the tire and road surfaces. Suitable test methods are also described, including a closed-loop method and an open-loop method. The results are merely intended to demonstrate the practicability of the test procedures described and not to analyze the performance of a specific vehicle or vehicle type. Both open- and closed-loop methods were used because each approach has its particular advantages. With the aid of the closed-loop method, it is possible to obtain information about operating functions such as steering, braking and accelerating which can cause the upset, without major test expenditures. The open-loop method offers, in addition to this, the opportunity for a systematic investigation of vehicle reactions to reproducible operating functions developed in the closed-loop tests.

SELECTION OF UPSET-RELATED DRIVING MANEUVERS

Vehicle upsets on the road are usually caused by collisions with other vehicles or obstacles, or by mechanical tripping. The least frequent cause is the effect of tire side forces.

The test procedures for vehicle upset resistance related to vehicle handling characteristics should not include on-road collision situations with subsequent upset. Furthermore, steering and/or brake maneuvers in upset resistance tests should be within the space limits given by the dimensions of roads, and should not be disproportionate to prudent driving practices under given conditions.

Three types of steering/braking input maneuvers are felt to be useful because they are assumed to reflect realistic situations [2]. At this time there are no relevant statistics available.

- Severe lane change maneuver with sinusoidal steering input
- Sinusoidal steering input maneuver during cornering at a given lateral acceleration
• Drastic steering and braking input maneuvers

Severe Lane Change Maneuver

The severe lane change maneuver with sinusoidal steering input is a sudden maneuver to avoid obstacles on a straight course. The individual phases in this maneuver are:
• Driver recognition of the situation;
• Driver steering input to initiate avoidance maneuver;
• Corrective steering input to resume previous course and vehicle directional control.

The steering input is the simplified configuration of a sine wave. Figure 1 shows the individual phases of such a maneuver within a sine wave.

Sinusoidal Steering Input During Cornering

The sinusoidal steering maneuver during cornering is an obstacle avoidance maneuver performed in a steady-state turn, with the avoidance course being directed toward the inside of the turn. The individual phases are similar to those in the obstacle avoidance maneuver conducted on a straight course with the exception of the prevailing steering input when the vehicle entered the turn. It is assumed that the driver applies steering input during the steady-state constant radius driving pattern without having changed the position of his hands on the wheel. This assumption, however, does not necessarily reflect driver behavior under actual operating conditions on the highway.

Figure 2 shows the individual phases and the simplified steering-angle input during such a maneuver.

This type of maneuver was conducted only in open-loop testing within the scope of this study.

**Figure 1. Phases of avoidance maneuver on straight road, simplified steering input.**

Drastic Steering and Brake Maneuver

The drastic steering and braking input maneuver is a sudden obstacle avoidance maneuver that may have to be performed on highways. This maneuver requires sudden reduction of the vehicle velocity to avoid a
EXPERIMENTAL SAFETY VEHICLES

Figure 2. Phases of avoidance maneuver while cornering, simplified steering input.

collision. The vehicle's intended course is obstructed by obstacles or other vehicles. Figure 3 shows the individual phases of the maneuver with the simplified time histories of input functions.

The closed-loop tests have been performed in such a way that the brakes were applied and released during a sinusoidal sequence of steering inputs.

METHODS FOR ANALYZING STEERING/BRAKING MANEUVERS

Two basic methods can be employed for the experimental evaluation of the maneuvers described previously:

- The closed-loop method, in which the driver translates information according to the driving task and situation into satisfactory driving inputs
- The open-loop method, in which vehicle reaction is evaluated in light of definitely reproducible driving inputs

Closed-Loop Method

Closed-loop tests producing upsets were performed with vehicles of various types and sizes by experienced test engineers. The test cars were in standard condition except for some modifications made for driver protection. All vehicles were equipped with outriggers. Two typical maneuvers were performed:

- Straight approach, followed by a sinusoidal sequence of steering inputs (steering oscillation), similar to the method described above
- Straight approach, followed by a sinusoidal sequence of steering inputs with brake-lock and release during the second half of the sine wave, as described above

Open-Loop Method

Programmable Driving Machine. A programmable driving machine was developed for the experimental verification of the open-
SECTION 4: TECHNICAL SEMINARS

Avoidance and recognition of the braking necessity

**Figure 3. Phases of a simulated drastic steer and brake maneuver, simplified steering and braking input.**

loop method. The use of the driving machines in motor vehicle driving tests is useful and indicated in the following situations:

- When driver influence is to be eliminated as a factor, or when driver input, perception, or behavior is not necessary for the evaluation of vehicle performance
- When good test reproducibility by drivers cannot be achieved for the formulated test purpose
- When driver safety can be compromised

As the driving machine replaces the driver, the machine must be able to drive (accelerate), steer, and brake the vehicle. Furthermore,

- The weight of the driving machine should not substantially exceed the weight of a driver plus seat
- The configuration, dimensions, and adjustment devices of the machine must be so designed that the machine can be exchanged quickly and easily between vehicles
- The performance capability (operating forces and speeds) should exceed those of a driver under the circumstances of the test
- The vehicle velocity should be fairly variable between 0 and 100 km/h, and the machine should be able to maintain a constant vehicle velocity during the actual vehicle dynamics test. The adjustment speed of the throttle should be adapted to the longitudinal vehicle dynamics.

All these requirements are met by the system developed by Volkswagenwerk AG. Figures 4 and 5 show the entire test apparatus consisting of vehicle, on-board equipment, and control stand.

The driving machine is remote-controlled by radio to start and maneuver the vehicle. Once a given test velocity has been reached,
EXPERIMENTAL SAFETY VEHICLES

programmed test procedures can be applied to conduct certain maneuvers. The control functions include steering, throttle operation, and braking input. The end of the test can be determined either by programmed test duration or, for safety reasons, by an override via wireless remote control. For safety reasons, two independent hydraulic brake circuits can be used to operate the brake system. Figure 6 shows the remotely controlled vehicle during a test.

FIRST TEST RESULTS

Test Vehicle for Open-Loop Tests

The first test series utilizing the open-loop method primarily served to evaluate the driving machine. It was to be determined whether the maneuvers described previously could be driven with the driving machine. Simultaneously, it was noted whether the test vehicle entered an upset situation under the influence of the corresponding steering and/or braking maneuver. An upset was defined as contact of the outboard end of the outrigger with the pavement.

The first randomly selected test vehicle for the initial open-loop test series was a VW Golf described by the following data:

- Wheelbase: 2,400 mm
- Track width: front 1,390 mm, rear 1,350 mm
- Tires: Continental TS 155 SR 13
- Tire pressure P_v/h 1.8/1.8 atm.
- Disc wheel 5J X 13, ET 45
- Axle load, front 605 kp, rear 374 kp

In no case did the maneuvers conducted in the open-loop series lead to an upset condition. More precise parameters for vehicle upsets will be sought in future test series and will then be compared to actual driving situations.

Severe Lane Change Maneuver

Open-Loop Tests. Figure 7 shows the vehicle control inputs given by the driving machine.

Because a vehicle shows the most severe yaw reaction to steering input at its natural
The parameter combination inputs \( v, \Delta_{SW}, \) and \( t_1 \) were each repeated five times.

In no case did the test vehicle reach a critical situation.

Closed-Loop Tests. A sinusoidal sequence of steering inputs resulted in upsets for the vehicles listed in Table 1.

The time history of the steering input is described qualitatively in Figure 8.

\[
t_1 = K_t \frac{1}{f_e}
\]

where \( f_e \) is the natural yaw frequency of approximately \( 0.85 \frac{1}{S} \) and \( K_t \) is a factor.

The following equation results in the following equation

\[
\Delta_{SW} = \text{approximately 300°, varying due to vehicle size, steering ratio, wheelbase}
\]

\[
t_1 = \text{approximately two seconds}
\]

Table 1. Vehicles upset by sinusoidal sequence of steering inputs

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Approximately curb weight [lb]</th>
<th>( \frac{h}{S} )</th>
<th>( \frac{S_v^2}{f^2} )</th>
<th>Maneuver</th>
<th>Initial velocity [mph]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact</td>
<td>2 500</td>
<td>0.381</td>
<td>0.467</td>
<td>Steer oscillation</td>
<td>45</td>
</tr>
<tr>
<td>Subcompact</td>
<td>1 600</td>
<td>0.423</td>
<td>0.469</td>
<td>Steer oscillation</td>
<td>30/32</td>
</tr>
<tr>
<td>Subcompact</td>
<td>1 900</td>
<td>0.43</td>
<td>0.425</td>
<td>Steer oscillation</td>
<td>25/23</td>
</tr>
<tr>
<td>Subcompact</td>
<td>2 100</td>
<td>0.426</td>
<td>0.441</td>
<td>Steer oscillation</td>
<td>37</td>
</tr>
</tbody>
</table>

\( C_g \) = Center of gravity

\( S \) = Track width

\( h \) = Height of \( C_g \) above ground

\( S_v \) = Longitudinal distance between front wheel center and \( C_g \)
Sinusoidal Steering Maneuver During Cornering

Figure 9 shows the time history of steering angle input into the test vehicle. The given lateral acceleration was 0.4 g—a rate that can sometimes be attained during fast cornering. Prior to reaching such lateral accelerations, of course, a driver would receive informational feedback indicating the severity of the maneuver in which he was engaged.

The input parameter combination v, ΔSW, and t1 were each repeated five times. The test vehicle did not enter a critical driving situation during these test runs.

Drastic Steering and Braking Maneuver

Open-Loop Tests. The time histories for steering wheel angle and brake line pressure

Figure 9. Test parameters for the sinusoidal steering maneuver while cornering.

Table 2. Drastic steering and braking input maneuver

<table>
<thead>
<tr>
<th>t1 [s]</th>
<th>t2 [s]</th>
<th>tbr [s]</th>
<th>ΔSW [°]</th>
<th>v (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.17</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>180</td>
</tr>
<tr>
<td>1.76</td>
<td>0.21</td>
<td>0.21</td>
<td>0.21</td>
<td>180</td>
</tr>
<tr>
<td>2.35</td>
<td>0.29</td>
<td>0.29</td>
<td>0.29</td>
<td>180</td>
</tr>
<tr>
<td>1.17</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>225</td>
</tr>
<tr>
<td>1.76</td>
<td>0.21</td>
<td>0.21</td>
<td>0.21</td>
<td>225</td>
</tr>
<tr>
<td>2.35</td>
<td>0.29</td>
<td>0.29</td>
<td>0.29</td>
<td>225</td>
</tr>
<tr>
<td>2.35</td>
<td>0.29</td>
<td>0.29</td>
<td>0.29</td>
<td>225</td>
</tr>
</tbody>
</table>

for the drastic steering and braking maneuver are shown in figure 10.

Table 2 shows the parameter combinations of the various tests performed.

Three runs were performed for each parameter combination. None of these tests resulted in a critical situation.

In contrast to the closed-loop maneuvers described next, a brake application was made during the first half of the sinusoidal steer input. Future tests will be similar to the closed-loop tests in this respect.

Figure 10. Time histories of steering wheel angle and brake application for the drastic steer and brake maneuver.
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Closed-Loop Tests. A sinusoidal sequence of steering inputs with brake lockup and release during the second half of the vehicles listed in table 3.

Steering wheel angle and brake application followed a time function which is qualitatively described in figure 11.

CONCLUSION

It may be possible to examine the upset resistance of given automobiles by use of specified steering and braking inputs in specific non-tripping situations.

The maneuvers to be selected have to be reasonably close to conceivable driving situations.

Table 3. Closed loop test results with braking.

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Approximate curb weight (lb)</th>
<th>(\frac{h}{s})</th>
<th>(\frac{S_v}{1})</th>
<th>Maneuver</th>
<th>Initial velocity (mi/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcompact</td>
<td>2 000</td>
<td>0.373</td>
<td>-</td>
<td>Steer+brake</td>
<td>50</td>
</tr>
<tr>
<td>Subcompact</td>
<td>2 600</td>
<td>0.371</td>
<td>-</td>
<td>Steer+brake</td>
<td>50</td>
</tr>
<tr>
<td>Intermediate</td>
<td>2 900</td>
<td>0.374</td>
<td>0.442</td>
<td>Steer+brake</td>
<td>50</td>
</tr>
<tr>
<td>Compact</td>
<td>3 000</td>
<td>-</td>
<td>-</td>
<td>Steer+brake</td>
<td>50</td>
</tr>
<tr>
<td>Subcompact</td>
<td>2 000</td>
<td>-</td>
<td>-</td>
<td>Steer+brake</td>
<td>43/37</td>
</tr>
<tr>
<td>Compact</td>
<td>2 500</td>
<td>0.402</td>
<td>0.439</td>
<td>Steer+brake</td>
<td>40</td>
</tr>
<tr>
<td>Subcompact</td>
<td>2 600</td>
<td>0.365</td>
<td>0.424</td>
<td>Steer+brake</td>
<td>45</td>
</tr>
<tr>
<td>Compact</td>
<td>3 000</td>
<td>0.367</td>
<td>-</td>
<td>Steer+brake</td>
<td>44</td>
</tr>
<tr>
<td>Full size</td>
<td>3 800</td>
<td>0.371</td>
<td>0.469</td>
<td>Steer+brake</td>
<td>50</td>
</tr>
</tbody>
</table>

Figure 11. Steering and braking input during closed-loop testing.

\(C_g\) = Center of gravity
\(S\) = Track width
\(h\) = Height of \(C_g\) above ground
\(S_v\) = Longitudinal distance between front wheel center and \(C_g\)
Further research into the qualities and capabilities of the normal (average) driver needs to be done.

They must not adversely affect vehicle design so as to exert a negative influence upon vehicular handling and response characteristics or accident avoidance capabilities.

With the aid of the closed-loop method it was to be determined which of the steering and/or braking maneuvers that can be executed by a driver can lead to vehicular upset. The open-loop method, made practicable by miniaturization and other progress in the electronic field, now, however, permits evaluation of vehicle response to specific reproducible inputs under controlled pre-selected conditions. Future efforts will have the aim of determining more specific parameters for vehicle upset maneuvers. Both will undoubtedly play important roles as research tools in the future.

Complimentary use of open- and closed-loop evaluations reasonably permits the systematic examination of the behavior of vehicles under realistic conditions. Accident cause investigation must provide information identifying those steering and braking maneuvers that precede actual vehicular upsets and data concerning driver behavior as well as steering and braking inputs in vehicular accidents. Development of such data will enable relevant test parameters for the closed- and open-loop methods to be quantified.

REFERENCES


Crosswind Sensitivity: A Study Carried Out Through The Driver Vehicle System

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INTRODUCTION

Considerable efforts have been made to define the essential features of a vehicle from the viewpoint of accident avoidance. Theoretical and experimental studies are aiming mainly at the replacement of subjective sensations, not always correlative to valid safety criteria, with objective evaluation methods.

The more or less satisfactory results of these studies, from various motor vehicle firms, led to the definitions of their own testing methods and to proposals of general rules from university institutes and public administration. The most interesting proposals made up to now are:

- Measure of the understeering of the vehicle during steady state
- “Breakaway test” intended to define the behaviour of a highly-engaged vehicle when cornering in the acceleration and deceleration stage
- “Braking in a turn” test to define the directional control of the vehicle when decelerating
- Yaw velocity of the vehicle in the transient state in order to evaluate the steering response speed
- “Crosswind sensitivity” test intended as deviation from the straight path of the vehicle

This is undoubtedly an interesting set of tests, which are, however, insufficient for a clear determination of the car safety features. We notice particularly that the results of some of these tests depend on the driver’s skill, while other tests can be considered as sufficiently objective. Regarding the former, the criticism is obvious; for the others the difficulty arises in determining the acceptability limits of the parameters concerning road holding because the behav-
beaviour of the driver/car system, in real road operating conditions, is not yet well known. For the above reasons, Alfa Romeo has conducted an extensive, experimental study of the real behaviour of the driver/car system and, simultaneously, to the study of a mathematical model capable of generalizing the obtained experimental results and giving clear, quantitative indications on the acceptability limits of the vehicle dynamic features. We have obtained some encouraging results that we presented in the previous Experimental Safety Vehicle (ESV) conferences [1, 2]. We now intend to concentrate on a particular aspect of the driver's behaviour: crosswind sensitivity. In this report we will consider the problem during straight driving, cornering, and overtaking maneuvers; we will evaluate the influence of the most important vehicle dynamic parameters in connection with different driving behaviour and different drivers' skills.

THE DRIVER/VEHICLE SYSTEM SCHEMATIZATION

We will briefly summarize the basic concepts that have inspired our mathematical model of the driver/vehicle system. The mathematical simulation of car behaviour, although complex, does not present any difficulty, however, from the conceptual point of view, the simulation of the driver's behaviour is difficult to obtain.

In our model, the driver is engaged only with the steering wheel and makes continuous corrections in the immediate position and the deviation that the vehicle, in a certain time and according to the driver's evaluation, will assume with respect to the desired path. In other words, the driver anticipates the control to compensate for the delay of the vehicle response.

During his estimation, the driver makes appraisal errors on his position and acts on the steering wheel with a given delay. Proper error and delay coefficients characterize the driver.

The above-mentioned appraisals are made in connection with all the data that are useful to the driver, such as road edges, lines defining the lanes, various obstacles, and so on; the errors in these appraisals are computed with probability methods [1, 2]. The mathematical model, briefly explained above, presents many difficulties in calculation that can only be surmounted with high powered and high speed computers.

All the characteristic data of the vehicle, the driver, and the road must be supplied to the computer, which, mathematically, simulates the driver's behaviour and, step by step, supplies the path of the vehicle with the relative slip angles and accelerations.

By changing the characteristics of the driver, the car, and the road, it is possible to study many cases that would be difficult to perform experimentally with the necessary characteristics of repeatability and safety for the test driver.

DRIVER CHARACTERISTICS

In our simulation we considered a skilled driver and an unskilled one. The definition of the skilled driver's characteristics (that is, the definition of the driver's time constant and driver's characteristic distance that is linked to the precision in the evaluation of the extrapolated path) has been obtained by a satisfactory theoretical and experimental comparison during overtaking maneuvers at high speeds [1].

According to our results, a skilled driver is characterized by:

- Time response (including the physiological delay): 0.7 ± 0.8 seconds
- Characteristic distance: 100 ± 150 metres

The unskilled driver is characterized (by extrapolation) by a doubled time response and a halved characteristic distance. It is our opinion that these values characterize a particularly unskilled driver.

VEHICLE CHARACTERISTICS

The vehicle used in the simulation is a rear-drive, medium-size sedan (Alfa Romeo 2000), the data of which are shown in reference 3. The definition of the vehicle
characteristics, in the understeering basic configuration, has been obtained by the comparison of theoretical and experimental results in steady-state tests (steering pad at various lateral accelerations and speeds) and transient tests (steering wheel step input at different speeds and lateral accelerations, response to a given steering law, and so on). As far as the vehicle basic configuration is concerned we have considered different understeering degrees and different positions, vertical and longitudinal, of the centre of pressure (cp = the point of application of the sideward force, table 1 and figure 1). The steady and transient state responses of the vehicle (in the basic aerodynamic configuration) are shown in figures 2 and 3 in connection with the previous ESV limits. It can be seen that every vehicle falls into the previous acceptability limits. We recall that the definition of the oversteering vehicle is purely conventional and related to the considered vehicles. As far as the basic configuration is concerned we have considered the following longitudinal positions of cp:

(1) cp at the front wheels
(2) cp at half of the half front wheelbase
(3) cp at one quarter of the half front wheelbase

In cases (1) and (4), it has been considered a cp height of 0.50 m., while in the configuration (3) the height of cp has been changed to ± 0.25 m. (fig. 2).

TEST DESCRIPTION: STRAIGHT PATH RUN

The vehicle is running at 70 mi/h along a straight path when it is subjected to a lateral wind step; the front of the wind is 20-feet wide and the speed is 50 mi/h. Road dimensions, corresponding to those of a motorway, are shown in figure 2. The simulation provides the path of the vehicle in the open-loop test and in the "closed-loop" test obtained by the considered drivers.

"Open-Loop" Test

In figure 4 the paths of the vehicle in the considered configurations are plotted versus time.

With the same position of cp (vehicles a, b, c, d) the lower deviations from the straight path take place with the higher understeering vehicles.

For these vehicles the static margin (ratio to the wheelbase of the distance between the car's center of gravity and the point of application of the total lateral forces) and, therefore, the stability is increased. With the same understeering degree (vehicles a and e) the removing of the cp from the cg towards the front wheels is equivalent to a greater unstabilizing effect; the effective static margin of the vehicle (that is, considering also
Aerodynamic forces) is reduced and then greater lateral deviations take place [3]. The influence of the vertical positions of cp (vehicles a, g, f) is, on the contrary, negligible.

"Closed-Loop" Test

In figures 5 and 6 the paths of the vehicles obtained for the considered drives are plotted. With the same position of cp (fig. 5 vehicles a, b, c, d) the skilled driver has no difficulty in keeping the vehicle on a straight path; in figure 5 we have referred only to vehicles d and b that present the greater deviations. For the unskilled driver, the

NOTE: Steady state lateral acceleration = 0.4 g

Figure 2. Steady state yaw response versus tangential velocity.
Figure 3. Transient yaw response versus time.
lower deviations are obtained with the more understeering vehicle (vehicle c). With the basic understeering vehicle (vehicle a) it is necessary to use all the available road surface; with the less understeering vehicle (vehicle b) and, even more, with the over-
The different understeering degrees of the vehicles affect only the amplitude of the steering wheel angle necessary to perform the maneuver.

The unskilled driver, on the contrary,
performs the maneuver only with vehicle a (basic understeering); bad road holding, caused by the excessive understeer, inhibits the driver in keeping the car on the road when leaving the corner (fig. 11). Low stability, due to the insufficient understeer, inhibits the driver in keeping his vehicle on the road despite the large opposite lock used in the final part of the maneuver (fig. 10).

**Maneuver With Crosswind Step**

In figures 12, 13, and 14 the paths and the steering wheel angles for vehicles a, b, c, and the considered drivers are plotted. On the same figures, the paths of the vehicles in the corresponding tests without crosswind step are drawn in dashed lines. The skilled driver performs the maneuver with all the vehicle following paths that are almost the same as those obtained without the crosswind step (figures 12, 13, 14).

The unskilled driver performed the maneuver correctly with vehicles a and c (basic understeering and more understeering vehicles, figs. 12 and 14), and with vehicle b (less understeering, fig. 13). When leaving the corner, the driver was forced into large countersteering maneuvers trying to correct the divergent trend of the path. These increasing countersteering actions quickly cause a loss of adhesion on the rear wheels.

**DESCRIPTION OF THE OVERTAKING MANEUVER**

**Maneuver Without Crosswind Step**

The cornering maneuver and high-speed overtaking maneuver have been simulated to evaluate the obtainable performances.

The test conditions and the road dimensions are shown in figure 15, while in figures
Due to the engagement of the test, the skilled driver performs the maneuver only with vehicles a and c (basic understeering and more understeering, figs. 16 and 17). Vehicle b (less understeering, fig. 17) loses adhesion on the rear wheels during the first part of the maneuver; in fact, the low stability of the vehicle obliges the driver to make continuous corrections with increasing steering wheel angles.

The unskilled driver performed the test only with vehicle a (basic understeering), even if the path exceeded the pre-established limits of the track for the overtaking maneuver (fig. 16).

With vehicles b (less understeering, fig. 17) and c (more understeering, fig. 18), the driver was not able to keep his car on the road.

Maneuver With Crosswind Step

Figures 19, 20, and 21 show the paths
SECTION 4: TECHNICAL SEMINARS

Figure 15. Test conditions and road dimensions overtaking maneuver.

Figure 16. Overtaking maneuver—vehicle a.
and the steering wheel angles for vehicles a, b, c. On the same figures, the paths obtained in the corresponding tests without crosswind step are drawn with dashed lines.

With the established speed, the skilled driver performed the test with all the vehicles and without crossing the limits of the pre-established track (figs. 19, 20, 21). The unskilled driver performed the maneuver only with vehicle c (more understeering) exceeding, nevertheless, the limits of the track (fig. 21).

With vehicle a (basic understeering, fig. 19) the driver was not able to keep the car on the road in spite of the large steering wheel corrections.

Vehicle b (less understeering, fig. 20) loses adhesion on the rear wheels during the final part of the maneuver. In this connection it is interesting to notice the divergent trends of the path of the vehicle and of the low steering wheel angle that confirm the low stability of the car.

CONCLUSIONS

For crosswind sensitivity in a straight path run, the following conclusions are presented:

- With the same position of cp but changing the understeering degree, the open-loop and closed loop tests give the same indications, allowing a correlation to be established.
- With the same understeering degree but changing the cp position on the above-mentioned example, a correlation is poor.
- The same thing happens when simultaneously changing the understeering degree and the cp position.
- We think that the open-loop test might be
Figure 18. Overtaking maneuver—vehicle c.

NOTE. Vehicle speed: 60 mi/h
Figure 19. Overtaking maneuver with crosswind step—vehicle a.

Unskilled driver

Skilled driver

Path with crosswind step
Path without crosswind step
Steering wheel angle
0.2 second
Figure 20. Overtaking maneuver with crosswind step—vehicle b.
proposed provided that the allowable lateral deviation is reduced; however, such a reduction might penalize the solutions (as in vehicle e) that, in the closed loop test have an acceptable behaviour.

The same conclusions may be reached for crosswind sensitivity in cornering and overtaking maneuvers for the considered vehicles. In all the examined situations, the understeering degree of the vehicle appeared to be a very important parameter.

The results of this report give a further confirmation of the objective complexity of the general problem of road holding; but, above all, in our opinion, they show what a correct basis to reach a regulation in active safety matters may be.

What we mean is the formulation of a series of open-loop tests correlated with real maneuvers and situations in which the driver is always engaged. To this end it is our opinion that the mathematical simulation of the driver-vehicle system has been and will be, in the future, an essential tool.

REFERENCES

Criterion Levels for Minimum Braking and Handling Performance

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Ford Motor Company
Detroit, Michigan

ABSTRACT

Since 1970 an extensive research program has been in progress within the United States to identify appropriate criterion levels for minimum braking and handling performance of passenger cars. The predominant methodology has been oriented toward skid pad performance measures on the assumption that vehicles that perform well in skid pad maneuvers will have fewer accidents than poor performers. This approach has been adopted because accident reporting and investigation procedures have not been structured in a way that would permit positive identification of the role of vehicle handling factors in accident causation.

When indirect measures of safety performance are used, vehicle design should be evaluated in context with other elements of the driver-highway system that influence braking and handling qualities. A pilot study was conducted using indirect measures of safety performance. The results indicated that tire-pavement traction is the dominant factor in vehicle braking performance on public roads. This finding is consistent with other published evidence that small differences in pavement friction levels produce detectable differences in accident rates. It is concluded that accident data sensitive enough to detect such effects should also be sensitive enough to detect differences in accident rates produced by vehicle cornering and braking capabilities.

BACKGROUND

In November 1970, the Highway Safety Research Institute (HSRI) of the University of Michigan, published results from a National Highway Traffic Safety Administration (NHTSA) research contract [1] that outlined the overall technical approach for evaluating passenger car handling and braking qualities. This approach, summarized below, appears to have guided subsequent government research and rulemaking actions:

- Standards for handling and braking quality should be based on vehicle performance rather than design considerations.
- Tests of vehicle performance should be objective and drivers should be excluded from the control loop when vehicle performance is tested.
- Test severity should be sufficient to grade vehicle performance at the "limit" of tire-road adhesion.
- Pass/fail performance criterion levels should be selected to discriminate against "outlier" vehicles that have poor accident records.

Present efforts by NHTSA to establish braking and handling requirements are based on skid pad performance under the assumption that vehicles that perform well in skid pad maneuvers will have fewer accidents than poor performers. This approach has been adopted because, according to NHTSA "Present accident reporting and investigation procedures are not structured in a way that would permit positive identification of the role of vehicle handling factors in accident causation." [2]

Some researchers apparently feel that the problem of relating accident data to vehicle characteristics is inherent in the complexity of vehicle-in-use phenomena. Ervin and Segel state "...that such a correlation is not likely to be realizable either in the near or far term and perhaps never, since vehicle-in-use factors can conceivably mask whatever differences in handling qualities may have been extant in the as-new vehicle population." [3]

On the other hand, an equally feasible speculation is that vehicle parameters do not play a very important role in accident causation. At least, the range of parameters char-
characteristic of U.S. passenger cars may not affect accident rates. Nor may the poorest performing production passenger vehicle validly represent the boundary of minimum safe performance on public roads. At any rate, these arguments will never be proved or disproved by using information that is developed by having skilled test drivers or automatic controllers exercise production passenger cars at the limits of their cornering and braking performance on skid pads. The answers, if there are any, will be found by studying what takes place every day on public roads.

A number of studies by various highway engineering agencies have shown that small differences in pavement friction can produce detectable differences in accident rates. [4, 5, 6, 7] Accident data sensitive enough to detect such pavement effects should also be sensitive enough to detect variations in accident rates caused by the braking and cornering properties of passenger cars. If accidents are caused by inadequate maneuverability, and maneuverability can be degraded either by vehicle design or by pavement properties, then accident data that detect submarginal pavement should also detect inadequate passenger car designs. To date, the influence of car handling parameters on accident data has not been apparent. However, a comprehensive reappraisal of present accident reporting and investigation methodology for the evaluation of passenger car braking and cornering is being conducted for NHTSA by HSRI. Because the development of a proper methodology must necessarily precede the acquisition of appropriate data, evidence that will conclusively define the degree of relationship between vehicle handling and accident causation is not likely to be seen in the near future.

If criterion levels for minimum passenger car braking and cornering performance must be established in the absence of valid accident data, care should be used when substituting indirect measures of safety performance. Also, the indirect measure should be incorporated into an evaluation model that will put the accident avoidance potential of vehicle design into perspective with other driver, highway, and traffic factors that can be corrected with accident data.

The performance model might be patterned after one developed in the Federal Highway Administration's (FHWA) skid reduction program [8]. The model is illustrated in figure 1. It is designed to establish relationships between pavement friction levels and accident rates. The model could be adapted to include passenger car design parameters. In figure 1, we have expanded the box entitled "Vehicle and tire performance model" to include vehicle design factors that might influence the accident avoidance potential of passenger cars.

One important output from the FHWA model is a performance measure called the "distribution of margin of safety" shown near the bottom of figure 1. In this specific FHWA application, the "margin" refers to the difference between the severity of maneuvers performed by drivers on public roads and the levels of pavement friction available to perform those maneuvers. In other words, the model demands that levels of minimum performance be derived from field observation data that define what kinds of maneuvers are being performed by drivers on public roads and at what levels of severity.

A STUDY OF BRAKING EFFICIENCY USING INDIRECT SAFETY MEASURES

Ford performed a short traffic observation study to demonstrate how the "margin of safety" concept can be applied to vehicle brake performance as well as pavement friction evaluation.

The principal indirect measure of safety performance was the proportion of drivers who exceeded speeds that would allow them to stop in time if a vehicle or pedestrian were standing in the road just beyond a blind turn in an expressway exit ramp.

Objective

A short traffic observation study was conducted to demonstrate how the concept, "margin of safety," can be applied to vehicle braking performance on wet pavements.
Figure 1. Vehicle tire evaluation process shown within FHWA Plan to Define Frictional Requirements to reduce skidding accidents (DOT-FH-8275).

Method

Traffic speeds were measured for a total of 5 hours on the southbound exit ramp of Interstate 94 at Oakwood Boulevard in Dearborn, Michigan, during July and September 1976.

The expressway exit contained one blind turn. Vehicles or pedestrians standing on the road beyond the turn could not be seen by drivers who had just entered the ramp. The ramp is illustrated in figure 2.

During the 5-hour period of traffic observation, no vehicles or pedestrians stopped on the exit ramp just past the blind turn. No accidents were observed; however, the ramp terminates at a T-intersection with a stop sign. It was observed that vehicles could accumulate at the stop sign and form a standing platoon that extends back to the blind turn. If so, drivers entering the exit ramp above certain speeds could not avoid a collision by using limit braking. The proportion of drivers who were under these maximum speeds was used as the indirect measure of safety performance.

Figure 2. The expressway exit ramp.
Results and Interpretation of the Study

Figure 3 shows driving speeds on the ramp 312 feet upstream from the blind turn. Separate curves are plotted for wet and dry pavements. Speeds on wet and dry pavements were nearly identical. By visual inspection alone, these drivers had no way of knowing if the wet-pavement friction of the exit ramp was extremely low. It can be concluded, therefore, that wet-pavement friction can vary over a wide range without influencing traffic speeds. What does change with the level of friction is the “distribution of margin of safety.” In this example, the margin of safety is defined as the proportion of drivers under the maximum speed that would allow them to stop short of a vehicle standing in the blind turn 312 feet ahead.

The maximum speed for cars with 100 percent “braking efficiency” on high wet-friction concrete ($\mu_{peak} = .76$) was calculated to be 54.9 mi/h.\(^1\) From figure 3, it can be seen that approximately 97 percent of the drivers who used the ramp were under the maximum speed.

The maximum speed for a car with 80 percent braking efficiency is 51.4 mi/h on high-friction wet concrete. Approximately 91 percent of all drivers who used this ramp were under this speed.

Clearly, the “margin of safety” does

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\(^1\) The concept of braking efficiency, as it is applied in this example, was defined recently by Ervin and Winkler in an NHTSA research contract report [9]. By their definition, a vehicle with 100 percent braking efficiency can exactly equal the “Ideal Braking Distance” of a standard or “mean passenger vehicle.” The “mean vehicle” is equipped with tires that have had their peak brake force coefficients [10, 11, 12] calibrated on specified standard pavements [13]. The “ideal braking distance” is intended to represent an upper performance boundary that is unlikely to be exceeded in practice.
depend on passenger car braking efficiency. However, the magnitude of the effect on the "margin of safety" is far less than that caused by low-friction wet pavements. For example, the maximum ramp speed for cars with the theoretical maximum 100 percent braking efficiency would drop to 45.7 mi/h if the pavement had low levels of wet friction (such as, \( \mu_{\text{peak}} = 0.47 \), or ASTM40 = 30). Over 34 percent of all drivers exceeded this speed on the exit ramp.

If cars were capable of having the theoretical maximum 100 percent braking efficiency, on low-friction wet pavements they would experience a large performance reduction as the tires wear down from highway use. For example, if the braking efficiency were to drop from 100 to 90 percent due to tire wear, the maximum ramp speed would be only 41.7 mi/h. Nearly two-thirds of all drivers who used the exit ramp exceeded this speed.

Discussion

The pilot study described above was conducted to demonstrate how indirect measures of safety performance can be applied to evaluate the relative safety benefits that might result if various elements of the total highway-driver-vehicle system were to be changed. The results suggest that worn tires and low-friction wet pavements are by far the most important factors in degrading vehicle braking performance. Published accident studies tend to support this conclusion.

Figures 4, 5, 6, and 7 summarize data from three different studies of pavement friction and wet-weather accident rates. [5, 6, 7] The studies all indicate that accident rates rise rapidly when pavement skid numbers fall below 30 to 35.

These published accident studies define pavement friction levels by using standard locked-wheel skid number methodology. Unfortunately, the skid number cannot be translated into peak tire traction coefficients, which are required by NHTSA's braking efficiency concept. Therefore, the published accident data can only be used to suggest trends between accident rates and vehicle braking efficiency. The trends suggest that accident data sensitive enough to detect differences in pavement skid numbers should also be sensitive to differences in necessary car braking efficiencies.

CONCLUSION AND RECOMMENDATIONS

Currently available evidence indicates that tire-pavement traction is the dominant factor in vehicle braking on public roads. More research is needed to establish the relative influence of vehicle, tire, and highway properties on vehicle handling and braking performance. A major part of these future research efforts should attempt to establish the types and severities of maneuvers that are performed by drivers on public roads.
Figure 5. Relationship found in Germany between the relative accident frequency on a wet road surface and the place in the frequency distribution of braking distances (and skidding resistances) on 32 test road sections [5].


Driver Capabilities in Vehicle Handling

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ABSTRACT

Many studies of accident data assign a large portion of culpability to the human part of the driver-vehicle-environment system. However, detailed and quantitative analyses of the driver's contribution to accident causation or accident avoidance are not generally available. Field accident data have not been able to provide sufficient insight to driver behavior. A possible supplement to field data is clinical data on driver behavior acquired from carefully planned experimental scenarios in a proving ground environment.

The considerations important to planning of clinical driver behavior studies are discussed, together with limitations of this approach. Recent studies conducted by industry and government are summarized. A study conducted by Calspan Corporation under General Motors sponsorship is reviewed in detail.

Clinical driver behavior studies will continue since there are few alternatives. However, the results should be compared with field experience and design practice to support their applicability. The clinical approach may be useful for evaluating advanced driver training.

INTRODUCTION

A casual review of the literature dealing with vehicle handling implies that most of the research has been directed at the vehicle while most of the problems have been blamed on the driver. Concern for the driver's role in safe and efficient operation of the vehicle was expressed by early workers in the field [1, 2] but systematic studies of driver behavior are a recent product of the rapidly expanding human factors engineering discipline. Accident investigation and causation analysis provides strong justification for a more systematic and quantitative understanding of the capabilities, limitations, and problems faced by the driver. These various studies, all ascribing a dominant causal role to the driver, were summarized in an earlier paper by Bundorf [3].

While the accident investigation community has directed attention to the driver, there is little specific information in the accident data that helps with conception or evaluation of countermeasures that address driver problems. The highly interactive nature of the vehicle and the driver makes it difficult to separate their respective contributions through analyses of field data. The exception is, of course, the area of driver impairment associated with drugs and alcohol. However, if all impaired drivers had an affinity for one type of car, we might still be wondering whether alcohol or handling was producing the problem; just as we might wonder whether youth, handling, or some other factor produces the high over-involvement observed with sports cars [4].

It can be argued that field accident data are the only dependable source for causation information and countermeasures evaluation. However, experience so far with achieving a useful understanding of the precrash situation from Multi-Disciplinary Accident Investigation (MDAI) data has been disappointing [5]. Particularly for driver-oriented problems, some alternative approach is clearly needed to at least supplement field accident data. The medical profession faces similar problems in developing methods for prevention of disease. Medical research proceeds through carefully controlled and duplicated experiments in a clinical environment. In recent years, industry and government have turned increasingly to this approach as a means for understanding and controlling the problem of motor vehicle accidents.

This paper will summarize and classify some of the past work of this nature and outline problems and limitations of clinical studies of driver behavior. A new study,
conducted by Calspan Corporation for General Motors (GM) will be described in detail.

BACKGROUND

Driver performance is a logical application for research in the man-machine interface. People trained in this discipline began to apply themselves to the driver in the 1960's. There is very little published work prior to that time. Studies of driver performance might be classified as follows:

- Anthropometry
- Strength
- Reaction time
- Transfer function analysis
- Maneuver level use
- Response to vehicle changes
- Accident avoidance behavior

Studies of driver anthropometry deal with the space occupied by the driver, entrance and egress, reach capabilities, and eye locations associated with direct and indirect vision. Large populations of subjects have been studied through the efforts of the Society of Automotive Engineers (SAE) [6]. A large body of literature has been published on the driver strength situation in an attempt to define the steering and brake force capabilities of the weakest and strongest portions of the population. This work includes a variety of test techniques and a wider variety of test results. The extremes of driver strength for motivated conditions in a vehicle are still very uncertain. Driver reaction times are easily measured in the laboratory; however, studies comparing anticipated and surprised reaction times for driving conditions show significant differences and wide subject variability [7]. Extensive and sophisticated work leading to a mathematical model of some aspects of the driving task has been published by Weir and McRuer [8]. This work is presently being extended to include emergency maneuvers and changes in driver characteristics with vehicle changes. Preferred levels of lateral and longitudinal maneuvering use must be identified for highway design and speed signing. This work is summarized in reference [9].

The driver's reaction to changes in vehicle characteristics has been studied by Mortimer and Olson [10] and Hoffman and Joubert [11, 12]. These data show surprising driver adaptability to changes in the sensitivity of steering and brake controls. The most difficult area of accident avoidance behavior has been studied in work published recently by Rundkvist [13] and Hayes [14].

This review of clinical studies of driver behavior mentions only a small portion of the best known research and contributors to the field. It is likely that published work of this nature does not represent the total effort.

PLANNING STUDIES OF DRIVER BEHAVIOR

The literature described previously indicates that the results of driver studies are significantly influenced by the methodology employed. This is a problem peculiar to testing of people that is much less evident in evaluation of hardware. Among the most significant factors that must be considered in planning driver research are the following:

- Vehicle configuration (simulators)
- Subject sample
- Subject instructions
- Tasks
- Motivation
- Learning
- Performance metric
- Real and perceived risk

Any test configuration from a laboratory buck to a full scale vehicle amounts to a simulation of the population of real vehicles. A compromise must be reached between the control and repeatability offered by the laboratory simulator [15] and the fidelity of the full scale vehicle. The variable response vehicle is an attempt to combine the advantages of the laboratory buck and a full scale vehicle [16, 17].

The subject sample would ideally represent the driving population to the extent possible. Economic considerations and other practical constraints make it difficult to test large populations and gain access to the extremes of the distribution of drivers.
Motivation and risk considerations must also be compromised in test planning. Driver performance as a function of motivation is thought to be represented by the characteristic described in figure 1. A driver will not approach ultimate capability for an easy task. A task that greatly exceeds driver capability will also result in a minimal effort. The area of interest usually lies between these extremes, but there is no systematic way to design tasks that produce this type of performance. Obviously, motivation must be achieved without employing significant real risk or even great perceived risk. Contests and rewards are used to artificially stimulate motivation with some degree of success.

Performance of people frequently changes as they are being tested. The influence of this learning is well documented in strength testing and similar phenomena have been observed in replications of driving tasks. It is usually necessary to prepare a subject to some degree for a particular test, but the influence of familiarization on results must be considered.

Driving tasks should simulate to the greatest extent possible, the real world situation. This is also a compromise. Most full scale work is done on courses marked with traffic cones. Visual cues for cone course driving are unreal. It is difficult to sustain motivation during extensive cone course testing. Replacing cones with rubber barrels or guardrails may produce changes in performance, but it also alters real risk.

The problems and compromises mentioned here would seem to limit the applicability of clinical testing of driver behavior. However, the problems of optimizing the system without these data or trying to derive them from field information are even more formidable. The limitations of clinical testing must be considered whenever particular data from unique studies are applied. Field data and vehicle design trends should also be checked for consistency with clinical results.

OBJECTIVES OF THE MAN-OFF-THE-STREET PROGRAM

General Motors has done extensive testing and analysis of the driver-vehicle interface situation for many years since there is an obvious need for this information in product development. Most of the past work, as described in the Background section, was directed at specific aspects of driver behavior and was accomplished with relatively limited subject populations. A logical extension of this work was a more comprehensive study with a large driver sample directed specifically at precrash or accident avoidance behavior. A program was organized with Calspan Corporation to measure the driving characteristics of the man-off-the-street (MOTS) in this context.

The basic objective of this program was to obtain a variety of measurements and observations of the behavior of typical drivers when motivated to drive aggressively over a road course that included a variety of maneuvers considered to be potentially associated with loss of control accidents. The interactive nature of drivers and vehicles was studied by testing with vehicles familiar to drivers, with vehicles unfamiliar to drivers, and also with a vehicle modified to have increased real and perceived maneuvering capability.

The program was expected to yield specific information on driver capabilities and
changes in their capabilities that might occur with changes in vehicle and road conditions. The results should also point to areas for driver improvement that might be addressed by an advanced driver training program. An obvious extension to this work would be to apply advanced driver training methodology already developed by General Motors [18] and measure its ability to modify driving behavior.

**METHODOLOGY**

The nature of the experiment will be outlined here very briefly. Further details on the work can be derived from the project report [19] available on request from Calspan Corporation.

**Vehicles**

The MOTS project was expected to encompass the full range of driving situations from normal, conservative driving through complete loss of control. It was therefore necessary to do this work in full scale vehicles rather than in laboratory simulators or a variable response vehicle with a limited range of validity. The 1972 Chevelle sedan with a most popular set of optional equipment was selected as a car familiar to many people. Two Chevelles identical except for color were selected. One car was left in a standard condition, while the other was modified to provide increased maneuvering capability that could be perceived by a driver and measured through objective tests. Modifications consisted of readily available equipment that could be easily applied to the vehicle. These include large, high performance tires, stiffer anti-roll bars, reduced steering ratio, and other minor adjustments. Except for the steering gear and tires, the modified parts were similar to those available in optional suspension packages.

The cars were evaluated subjectively to insure that differences were readily detectable. A series of control response and task performance tests were then performed to document in a quantitative way, the differences in maneuvering performance. These data are summarized in table 1. The properties apply to a nominal one to two passenger load condition as tested at GM. The properties for the MOTS work at Calspan were somewhat different due to the weight of instrumentation and observer, but differences should be similar.

**Subjects**

About 100 volunteer subjects were obtained, mostly from the Calspan staff. Three subject groups were formed from this population, including about 50 people that were judged to be familiar with the standard Chevelle vehicle and 25 people judged unfamiliar, with the rest applied to the modified (unfamiliar) car. Subject groups were formed so that their age and sex distribution approximated that of the New York State driver population as determined from license records. Age distribution is indicated in table 2.

Subject ages ranged from 17 to 77 years and 62 percent of the subjects were male. Difficulty was experienced in obtaining sufficient subjects in the oldest bracket. Logis-

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**Table 1. Standard and modified vehicle properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Standard vehicle</th>
<th>Modified vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll compliance</td>
<td>9.8°/g</td>
<td>5.3°/g</td>
</tr>
<tr>
<td>Lateral acceleration response time</td>
<td>0.46 s</td>
<td>0.40 s</td>
</tr>
<tr>
<td>Steering sensitivity—g's/100°</td>
<td>0.47</td>
<td>0.97</td>
</tr>
<tr>
<td>Maximum lateral acceleration steady state—constant radius</td>
<td>0.64 g</td>
<td>0.72 g</td>
</tr>
<tr>
<td>Lane change maneuver distance—45 mi/h</td>
<td>78.5 ft</td>
<td>66.1 ft</td>
</tr>
</tbody>
</table>

aData apply to 60 mi/h.

**Table 2. Subject age distribution**

<table>
<thead>
<tr>
<th>Age bracket (years)</th>
<th>Percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-19</td>
<td>8</td>
</tr>
<tr>
<td>20-24</td>
<td>12</td>
</tr>
<tr>
<td>25-40</td>
<td>45</td>
</tr>
<tr>
<td>25-90</td>
<td>31</td>
</tr>
<tr>
<td>60 and older</td>
<td>4</td>
</tr>
</tbody>
</table>
tical problems influenced the makeup of the group tested in the modified car and this group was limited to 15 subjects that were somewhat younger than the ideal sample population.

Motivation

Subjects were instructed to drive as if in a hurry, but the need for accuracy was also stressed in the instructions. Time from start to finish and an estimate of obstacles struck was provided at the end of each trial. Subjects were told that an award would be given for the best overall performance considering speed and accuracy for all trials. Details of the scoring system were not provided. Subjects were told to continue driving after striking an obstacle which tended to reduce the importance of the obstacles, but was necessary for completion of the experiment.

Learning

Subjects were given five trials through the 1.2-mile course. Familiarization with the vehicle and the course were minimized prior to testing through use of a map and one slow tour of the course.

Instructions

Subjects were free to select their own pace and strategy throughout the experiment under motivation for both speed and accuracy provided by the award system. No advice or special instructions were provided other than the minimum required for safe and orderly testing.

Tasks

Considerable effort was devoted to the development of tasks that fit the Calspan facility, were simulations of real situations, permitted a range of driving speeds, and were spaced for minimum task interaction. The course is described in figures 2 and 3. Tasks are listed in order of presentation on the driving course in table 3.

Performance Metric

The cars were instrumented for FM tape recording of speed, lateral acceleration, longitudinal acceleration, brake line pressure, steering wheel angle, and time. The observer marked a chart for obstacles struck during each trial. Many of the trials were filmed from a tower adjacent to the course. The observer also recorded lap times and some additional information on driver behavior.

Risk

The program was completed without any known trauma associated with the test or surprise obstacle task. One minor accident was experienced in the gravel section resulting in suspension damage to the modified car. The region around the course was kept free from substantial obstacles and the cars were frequently inspected and maintained. Tire wear was rapid and tires were changed frequently.

RESULTS

Data obtained from the MOTS project should be viewed as an indication of phenomena that may exist among real drivers on real roads. There is no way to be certain that volunteer drivers operating test vehicles on a reduced risk course perform in a realistic fashion. Some of the data show trends similar to field information and other data conflict with field information.
Figure 3. Driving course details.
Table 3. Driving tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-road recovery</td>
<td>Traversal of a 4-inch longitudinal curb</td>
</tr>
<tr>
<td>Large radius arcs</td>
<td>A u-turn of varying radii</td>
</tr>
<tr>
<td>Avoidance</td>
<td>A blocked lane with a shortened re-entry gate</td>
</tr>
<tr>
<td>Gravel turn</td>
<td>A u-turn of 90-ft radius with a rough gravel surface</td>
</tr>
<tr>
<td>Wet surface</td>
<td>A blocked lane avoidance requiring a maneuver over wet sealed asphalt</td>
</tr>
<tr>
<td>Ess turn</td>
<td>Joined 75-ft and 150-ft radii</td>
</tr>
<tr>
<td>Small arc</td>
<td>A u-turn of 150-ft radius</td>
</tr>
<tr>
<td>Surprise</td>
<td>Launching of a plastic barrel into the path of the car 100 ft from a trip</td>
</tr>
<tr>
<td></td>
<td>switch on straight road. (Used for some subjects)</td>
</tr>
<tr>
<td>Stop section</td>
<td>Braking to a marker cone in a 640-ft radius curve at the end of the course</td>
</tr>
</tbody>
</table>

Driver, vehicle, and road phenomena are interactive. The MOTS project was mainly a driver study, performed, in part, through manipulation of vehicle and road characteristics. The results will be discussed in that context.

Vehicle Effects on Driver Behavior

Characteristics that varied in the MOTS project were driver familiarity with the vehicles and vehicle maneuverability. There was very little difference in the performance of drivers familiar with the Chevelle and those considered to be familiar with significantly different cars. Average trial times were 129 seconds for familiar drivers and 130 seconds for unfamiliar. Differences in trial times were not statistically different.

There were 35 opportunities for obstacle contact during the five trials given each subject. Failure rate is defined as the number of recorded course violations divided by the 35 opportunities. The familiar drivers experienced a 7 percent failure rate and the unfamiliar drivers experienced an 8 percent rate.

This is a failure rate of about one for two miles of driving. Vehicle damage surveys imply a real road failure rate of about one for 12,000 miles. Unfamiliar drivers encountered greater difficulty with the wet maneuver, recording a 4 percent higher failure rate and over twice the percentage of loss of control events. Unfamiliar drivers approached this maneuver only 0.9 mi/h slower than familiar drivers. In this experiment, drivers approached the unfamiliar car with confidence and performed normally with it until adverse road conditions were encountered.

Modified vehicle data must be interpreted with the aforementioned reservations about the subject sample. The modified vehicle was different in several aspects of its performance and there is no way to determine which vehicle parameters influenced subject behavior. Subjects were probably unaware of its maximum lateral capability since none approached the 0.72 g steady state level and nearly all drove below the level of capability associated with the standard car. Subjects apparently responded to the perceived capability resulting from roll stiffness, response time, and steering sensitivity.

The modified vehicle was driven more aggressively than the standard vehicle, even when a comparable age group of standard vehicle drivers was formed for a more valid comparison. Increased aggressiveness was observed over all parts of the course. Trial times were similar for the first trial, but were reduced to a greater degree with the modified vehicle in the faster fourth and fifth trials.

Failure rates for the modified-vehicle group were similar to that of a comparable group of standard car drivers (10 percent versus 9 percent). Failures in the modified car happened at a higher speed than those of the standard car as shown in figure 4. Subjects who drove the modified car at speeds comparable to standard car subjects were more accurate with it. Subjects driving more aggressively produced failure rates similar to those of the standard car subjects. The effect of increased maneuvering capability seemed to depend on the driver and his response to these vehicle characteristics. The more capable vehicle contributed to accu-
racy when driven normally but, if driven more aggressively, a level of risk comparable to the typical vehicle was observed.

**Road Effects on Driver Behavior**

All drivers increased their speed as they became familiar with the road course. Ninety-eight percent of the fastest runs occurred during the fourth and fifth trials. The reduction in trial time averaged about 20 percent from the first trial to the fastest trial.

Failure rates for the large group of familiar drivers are noted for the various tasks in table 4.

The condition of changing road friction was involved with the highest failure rates, reaching 28 percent with the modified car. These data will be analyzed in more detail in the section to follow. Maneuvers involving transient turning associated with a blocked lane or change in road curvature produced more frequent failures than maneuvers involving steady cornering such as the various u-turns. The gravel turn appeared to intimidate drivers since first run lateral accelerations were about 13 percent lower than those for the small radius arc.

**Other Driver Phenomena**

Data from familiar and unfamiliar drivers were pooled to produce a large body of data that could be used to examine the influence of age and sex on driver performance. Table 5 shows that age and sex have a very significant influence on failure rates observed during the last two trials. Table 6 shows a more detailed analysis of age and sex differences for both failure rate and aggressiveness as measured by average trial time.

The pattern of these data is qualitatively similar to that observed in accident statistics. The problem with the young driver seems to manifest itself as an imbalance between skill and aggressiveness.

All of the steering motion data were not analyzed, data for 30 standard vehicle subjects were studied for the Avoidance Maneuver part of the course. The average of the maximum steering rates for successful runs was about 520 degrees/s. This steering rate was associated with an average peak maneuvering severity of about 0.46 g. The expert drivers used steering rates up to 800 degrees/s for maneuvers in the range of 0.6 g in this part of the course. Data for seven typical driver runs with course violations

### Table 4. Failure rates for driving tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>Percent failures (familiar group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet surface</td>
<td>16.0</td>
</tr>
<tr>
<td>Avoidance</td>
<td>10.4</td>
</tr>
<tr>
<td>Ess turn</td>
<td>7.2</td>
</tr>
<tr>
<td>Small arc</td>
<td>6.8</td>
</tr>
<tr>
<td>Off-road recovery</td>
<td>6.4</td>
</tr>
<tr>
<td>Large radius arc</td>
<td>2.0</td>
</tr>
<tr>
<td>Gravel turn</td>
<td>0.4</td>
</tr>
</tbody>
</table>

### Table 5. Familiar driver failure rates by sex and age (runs 4 and 5)

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Failure rate (percent)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females</td>
<td>4.1</td>
<td>420</td>
</tr>
<tr>
<td>Males</td>
<td>12.3</td>
<td>616</td>
</tr>
<tr>
<td>Difference</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>16-24 years</td>
<td>16.8</td>
<td>196</td>
</tr>
<tr>
<td>25-44 years</td>
<td>9.8</td>
<td>441</td>
</tr>
<tr>
<td>45 and over</td>
<td>4.0</td>
<td>399</td>
</tr>
</tbody>
</table>
Table 6. Failure rate and aggressiveness as a function of age and sex

<table>
<thead>
<tr>
<th>Drivers (years)</th>
<th>Failure rate (percent)</th>
<th>n₁ᵃ</th>
<th>Mean TIC (seconds)</th>
<th>n₂ᵇ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male: 16-24</td>
<td>23.2</td>
<td>112</td>
<td>117</td>
<td>16</td>
</tr>
<tr>
<td>25-44</td>
<td>13.9</td>
<td>273</td>
<td>115</td>
<td>39</td>
</tr>
<tr>
<td>45 and older</td>
<td>5.2</td>
<td>231</td>
<td>124</td>
<td>33</td>
</tr>
<tr>
<td>Female: 16-24</td>
<td>8.3</td>
<td>84</td>
<td>129</td>
<td>12</td>
</tr>
<tr>
<td>25-44</td>
<td>3.6</td>
<td>168</td>
<td>132</td>
<td>24</td>
</tr>
<tr>
<td>45 and older</td>
<td>2.4</td>
<td>168</td>
<td>148</td>
<td>24</td>
</tr>
</tbody>
</table>

ᵃn₁ = Number of exposures to tasks.
ᵇn₂ = Number of runs.

showed average peak rates of 850 degrees/s. Eleven observations of runs involving loss of control in other parts of the course showed steering rates in excess of 1,000 degrees/s. Course violations do not appear to be associated with a limited driver ability to steer at high velocities.

Most drivers were willing and able to use full throttle and nearly full vehicle brake capability for straight road maneuvering. Average longitudinal decelerations in the range of 0.56 g to 0.62 g were observed for braking maneuvers under these conditions. Drivers under real road conditions have been estimated to encounter this level of braking about 10 times per year [10]. While average lateral accelerations for these motivated and minimum risk conditions were somewhat higher than the 0.3 g levels observed in real roads, they were generally about half of vehicle steady state capability. Drivers seem very reluctant to subject themselves to lateral accelerations in excess of 0.5 g regardless of motivation or conditions.

In order to establish the maximum capabilities of the test vehicles on this course, two experienced GM test drivers were sent to Calspan during the test program for the purpose of establishing the best possible performance values. The drivers drove each car for up to seven trials until they felt that a best run had been achieved. Successful task speeds for the standard car are compared with the best speeds attained by subject drivers in table 7.

Trial time comparisons are summarized in table 8.

Table 7. Best speeds for various tasks with test drivers and subject drivers

<table>
<thead>
<tr>
<th>Task</th>
<th>Test drivers (mi/h)</th>
<th>Subject drivers (average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-road recovery</td>
<td>51</td>
<td>40</td>
</tr>
<tr>
<td>Large radius arcs</td>
<td>40</td>
<td>31</td>
</tr>
<tr>
<td>Gravel turn</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>Wet surface</td>
<td>44</td>
<td>35</td>
</tr>
<tr>
<td>Small arc</td>
<td>37</td>
<td>31</td>
</tr>
</tbody>
</table>

Table 8. Trial times for subjects and test drivers (fastest runs without failure)

<table>
<thead>
<tr>
<th>Subjects and Drivers</th>
<th>Mean trial time (s)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>All standard car subjects</td>
<td>125</td>
<td>75</td>
</tr>
<tr>
<td>All modified car subjects</td>
<td>114</td>
<td>14</td>
</tr>
<tr>
<td>Standard car subjects like modified car subjects for age and sex</td>
<td>122</td>
<td>15</td>
</tr>
<tr>
<td>Standard car test drivers</td>
<td>104</td>
<td>15</td>
</tr>
<tr>
<td>Modified car test drivers</td>
<td>98</td>
<td>2</td>
</tr>
</tbody>
</table>

Subject driver best runs averaged about 16 percent slower than vehicle capability based on trial times.

The wet task data were analyzed in more detail since it produced the most control difficulty. Forty-seven percent of the subjects were unsuccessful in at least one trial for this task. Half the runs attempted at
The surprise ejection of a plastic object into the vehicle path was applied to 34 subjects during the later stages of the project. This task was accomplished during a straight single lane portion of the course where speeds averaged about 55 mi/h. The task had fixed geometry so it was more difficult for the faster drivers. Only one driver avoided the obstacle. This was a female, driving 11 mi/h below the average speed, who initiated a steering input response after a 1.0-second reaction time. The mean reaction time of all drivers was 0.65 second, but several had reaction times in excess of 1.0 second. One driver exhibited no measurable reaction based on steering and braking records. About 75 percent of the drivers applied brakes initially and some of these then added some steering input. Twenty-seven percent of the subjects experienced some degree of control loss as a result of this task. This was judged by a spin or gross deviation from the intended path after striking the plastic obstacle. Measured reaction times varied from 0.35 second to 1.7 seconds, nearly a factor of five. The experimenters judged that the task should have been easily accomplished by a driver with average reaction times, driving at the average speed, if a steering input was appropriately applied. Most of the subject drivers did not adopt this strategy.

**POTENTIAL SIGNIFICANCE OF MOTS RESULTS**

A large amount of information on driver behavior for some vehicle and road conditions has been obtained in a clinical test. Although this test environment differed from real world driving, it may be useful to suggest some potential implications of this information to the possibilities for improving the performance of the driver-vehicle-road system.

MOTS data imply that there is little advantage to standardization of vehicle characteristics for reasons of familiarity. Drivers adapted quickly to the characteristics of the unfamiliar vehicle and the modified vehicle. Familiar drivers generally did no better than unfamiliar drivers.
Road configurations with consistent friction properties and geometries that minimize the need for transient maneuvering should be of benefit. Drivers may respond more prudently when roads are obviously degraded as in the case of the rough gravel surface. The wet road was apparently not sufficient warning to achieve a prudent level of maneuvering behavior.

MOTS data imply that a large improvement would result from imparting the skill and prudence of the older driver to the young driver. Self ratings of driving ability by MOTS subjects implied a positive and optimistic attitude toward the driving task. Forty-one percent rated themselves above average, while only one driver in 90 admitted to below average ability. Of the two driver age groups with the highest failure rates, 60 percent of the drivers rated themselves as above average. Better matching of prudence with skill is one potential benefit from an advanced training program where a driver experiences the limits of his skill in a safe environment.

Drivers are clearly not prepared to utilize the maximum lateral capability of present vehicles in a transient or steady state context. They do not quickly adapt to reduced friction conditions, the advantages of coordinated braking and steering, or methods for recovering from a skid. A number of drivers have very long reaction times that can only be compensated by elimination of surprise conditions through visual search and problem prediction procedures. Drivers are not prepared naturally to select the most effective control element for an emergency situation.

Most of these problems might be effectively treated with well-known advanced training procedures that are presently used to a very limited extent.

ACKNOWLEDGMENTS

The MOTS project was a large and ambitious program accomplished through the efforts of many people. Mr. Roy Rice of Calspan was the project engineer. Mr. Fred Dell’Amico assisted with data analysis and reporting. Mr. Keith McKenna of Engineering Staff was project monitor for General Motors.

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SECTION 4: TECHNICAL SEMINARS


An Estimation of the Complexity of the Control-Loop Environment—Driver-Vehicle Consequences for Research and Legislation

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ABSTRACT

The multitude of activities in the area of vehicle dynamics covering the sector of calculation as well as measurement technique can lead to the wrong conclusion, namely that today we would be able to measure and describe vehicle dynamics objectively. In truth the whole field is of such a huge size that we have just been able to measure and describe vehicle dynamics objectively.

A special consideration of the control-loop environment—driver-vehicle gives insight into the real relations.

The possibility of bad processing of information by the driver is much higher than for the vehicle and the part of the still improvable vehicle behaviour that will be utilized by the driver is very small. This leads to the realization that, by measures to the vehicle, only a few additional accidents can be avoided.

The small scope of significance of today's known test methods and the lack of knowledge about the relation between test results and safety lead to the conclusion that exhaustive statistical investigations of driver behaviour prior to accidents have to be undertaken and that, after accomplishing this, handling rules directed toward the specific objectives will be useful.

INTRODUCTION

For a number of years, public authorities and people in research and industry, have been trying, by means of tests and measurements, to prove and explain numerically the driving behaviour of automobiles. There is hope that a yardstick for the active safety of automobiles will be obtained in this way.

This is understandable because a great quantity of scientific works in the area of handling behaviour—done by industry as well as independent institutions—which are often very well done, leads us to expect that vehicle handling, at least to a great extent, can be scientifically explored.

The latest insights into our real lack of knowledge, particularly on the relationship to safety, show us more and more clearly that the state of our knowledge—compared with the total complex of vehicle...
dynamics—is by far smaller than we had formerly assumed.

Today we must state that we are in a phase of uncertainty on the correlations within the complex of vehicle dynamics and driving safety and on the importance of the single components of vehicle handling systems.

Since it will hardly be possible to get better yardsticks in the near future with the aid of scientifically well-grounded data, we are dependent on useful estimations to get at least an approximate idea of the relationships in this system.

Such estimations are tried subsequently, based on a consideration of the control-loop environment-driver-vehicle.

CONTROL-LOOP ENVIRONMENT- DRIVER-VEHICLE

Figure 1 shows the whole control loop together with all information paths in its principal function.

The basic elements of environmental information are indicated at the left side of figure 1. They consist mainly of optical and of acoustic information (wind, driving and engine noise, horn signals, and so forth).

They are received by the eyes and ears of the driver and pass through several stages in his brain: perception, processing, and evaluation lead to commands to move the arms, hands, legs, and feet.

Information passes in paths of different lengths from the short, unconscious, almost automatic reaction, to the long conscious action—then a decision filled with doubts and oscillations is made between different possibilities. Often an initial reaction that has taken the short path will be corrected by a different long-time action.

Just as different drivers have different kinds of processing, one driver has variable processing, influenced by alterations of his physical condition and his emotions (at the top in fig. 1) and by varying stress due to sensory impressions from the environment ("external influences on processing" in fig. 1).

Such influences may effect a switchover to reaction patterns of different quality, delineated by different planes for the information-flow in the brain of the driver.

For each driver these "planes" are differently programmed, that is, the processing patterns are different, particularly the areas that are impressed by specific experiences.

Similarly, the mechanism of switching over by interior and external influences varies within wide limits. This means that one input of information can result in a multiple and ambiguous scale of possible muscle reactions.

The wide range of variations also becomes evident from the extraordinarily good adaptability of man to different vehicle behaviours.

The vehicle behaviour per se, although complex enough, is extremely simple in comparison to human behavior, and the range of variations is only a fraction of that of a driver.

Inputs via the steering wheel, pedals, and levers result in definite vehicle motions. The influences from tires, loading, and maintenance conditions are fixed input data for the processing during one ride; road surface, weather conditions, and the state of vehicle motion are varying inputs with a very important effect on the vehicle reaction.

The control loop is closed in three ways.

The first and most direct way is by the motion of the vehicle that the driver senses through touch, balance, and hearing.

The motion of a vehicle is not perceived directly in an optical way. The vehicle's motion is only observed in relationship to the road and its borders and to other vehicles. That is the second most important closing path of the control loop.

The third way is the longest one. Other road users are influenced by the motion and by the signals of the vehicle and move in reaction to it. This "superposed" motion of other road users is mixed with their normal motion and the motion of one's own vehicle and comes this way to the eye of the driver.

The task of the whole control loop is to always keep sufficient distance from the edge of the road and other road users and not to obstruct them in doing the same.
Figure 1. Control loop: environment-driver-vehicle.
Traffic rules and traffic signs have to be observed. Safety is endangered if the functioning of the control loop, in this sense, is disturbed.

All efforts in active safety have to be directed toward improving functioning and making it insensitive to disturbances. Many measures in this direction may be comprehended immediately and conclusively without considering the closed loop environment—driver—vehicle one by one; for example, more room for traffic on the roads.

Many other measures are of a more complex nature, such as variations in vehicle behaviour. Furthermore, they influence other areas of the control loop and, therefore, must be judged more objectively than is usually necessary. The following consideration of the control loop in more detail may be helpful.

**QUALITY OF INFORMATION AND PROCESSING**

Only a part of the information that reaches the driver is useful.

Figure 2 shows roughly how the total information flow might be split up in useful, useless, and disturbing or misleading information.

First, the driver shall be considered. In an ideal case during the whole processing of the information all indifferent and disturbing information would be filtered out, the misleading information would be detected as such and also suppressed, and only correct and useful information would be used. Thus the appropriate reactions would come out via the short way and correct processing, evaluating, and action would be the result along the long, conscious way.

**Figure 2.** Control loop: environment-driver-vehicle with two extreme variants of information processing (I = ideal good; II = extremely bad).
SECTION 4: TECHNICAL SEMINARS

In reality we have to deal with poorer qualities of processing in a huge multitude of variations due to the changing condition of the driver, differing external influences, and also because of the many different kinds of drivers.

This begins with inexact perceptions, where bits of useful information are not observed and disturbing information is more easily received. During further processing on the short and long ways, useful information may go into a wrong channel and misleading information may take its place. Even after correct processing, wrong decisions may be made and incorrect actions may be carried out.

In the worst case, useful and misleading information change places, the perceived information is wrongly processed, the result is erroneously evaluated, and improper actions are performed. There is not much chance that the result will be accidentally correct. To be sure, this rarely happens, but we can see what innumerable possibilities of action—correct, less correct, or wrong—exist for the driver.

This also includes, just as an example, the not infrequent cases where drivers do not react at all when suddenly frightened by a situation that seems to be dangerous.

Compared with a driver, the behaviour of a vehicle is far more simple. The range of possible steering maneuvers, differing according to mode, intensity, and velocity of steering wheel and pedal actuations (multiplied by the number of the possible combinations of operating conditions) is enormous. The range of vehicle reactions is correspondingly manifold.

For instance, we must only think of the multitude of tires, road surfaces, and weather conditions.

It must be stated generally that for most vehicles the physical limits are fairly easily reached in many disciplines. Doubtless, some differences and imperfections still exist. But this is only a small fraction of the whole of all vehicle characteristics, and in almost every case, only the motions near the physical limit are affected. This can be expressed by the plate for the vehicle in figure 2.

It is reasonable to expect that vehicle behaviour can be improved by a better adaptation to man's ability. Unfortunately, it is a consequence of the physical laws that even optimal vehicle behaviour varies as the physical limit is approached. If, therefore, the driver has experience only in the normal driving area far from the physical limit, it is hardly possible to have him not be surprised by different vehicle behaviours. A vehicle that does not surprise the driver would therefore be a vehicle whose behaviour in the limit area is pulled down to the normal driving area. But such a behaviour certainly would have to be refused by subjective judgement and we must call it bad objectively too, because it would be very fatiguing for the driver and would have to be called unsafe for this reason.

Obviously today we do not even know all the components that are the basis for the often very perfect adaptation of today's vehicles to the human abilities. It so often happens that variations built during vehicle development from which an improvement must be expected in theory, in fact result in a deterioration of adaptation to man, to the great surprise of the engineers.

A part of this adaptation is also the quality that the car "forgives" drivers' mistakes, that is, the vehicle partially compensates for them.

During the further flow of information, the components of vehicle motion pass through different filters that belong to the vehicle (windows, seats, steering wheel, and so forth) and then go back to the driver who uses them for further actions and reactions. The quality of the filtering also plays an important role in good information transfer.

Finally, the quality of signalling to other road users must be mentioned. Here the driver's influence is more essential than the vehicle's equipment.

TEST METHODS AND CONTROL LOOP

Today we cannot make an objective statement on the significance of the test method for traffic safety because of the lack of data.
But we can get a clue to which part of safety can be covered in the best case by estimating that part of the control loop that is in operation during a test. That can, however, only be a rough estimation.

**Procedure 1, Open Loop, Objective Judgement**

This is a test procedure in which all driver influence is excluded and the control loop is open (fig. 3). From the environment, one or two road surface conditions and possibly the wind are taken into consideration.

A certain steering input is fed into the vehicle and the resulting vehicle motion is measured and evaluated. Vehicle load and sometimes tire pressure are varied. During the test only a small part of the whole vehicle is in operation.

If we compare this test with the whole control loop (fig. 1 and fig. 2) we realize how little such a test or even a couple of them can uncover even in the best test. Significance is even lower for the still more complex field of safety, because all maneuvers tested are only minimally relevant to the cause or avoidance of accidents.

**Procedure 2, Closed Loop, Objective Judgement**

In this test the driver must perform a certain maneuver and keep within a certain marked lane. The driver and his reactions are taken into consideration (fig. 4).

For the vehicle, we have the same preconditions as for procedure 1. The driver is usually experienced; however, only a small part of his whole processing apparatus, the "short", unconscious part, is in operation. A small part of the closed information flow is also working. Obviously such tests are much nearer to reality than tests without a driver, but they are often disliked for they are complicated and have bad reproducibility.

Relevance for safety is still very limited if we look at figures 1 and 2, particularly because the processing pattern in a real emergency situation is surely different from that operating in a test.

**Procedure 3, Closed Loop, Subjective Judgement**

This test method is used by automobile manufacturers during the development of their vehicles. It consists of extended test rides on test tracks in real traffic and covers an area much greater than that covered by single tests. Evaluation is done subjectively in almost all cases.

Almost all information is taken into consideration; the different processing patterns of many drivers are also considered. Practically, we have to take figure 1 or a good version of figure 2.

There is a much greater chance that hidden weak points can be detected that will only come out under a rare combination of conditions.

It can be assumed that by this method all disciplines that are important for driving are evaluated and improved. Only with regard to safety, we are unsure even with this procedure in answering the question how direct the relation to safety is in fact in the individual cases. In more than a few cases it is open whether safety is touched at all or if we are just cultivating an easy and comfortable driving.

**STATE OF KNOWLEDGE**

If we look at the last 20 years of vehicle development, we must acknowledge the continual progress of handling qualities. This statement is based on subjective experience according to procedure 3.

Today there are scarcely more than 10 test procedures of type 1 and 2 for single maneuvers.

Of the huge amount of possible combinations of maneuvers and operation conditions in real traffic, these test methods can cover only a very narrow part of the whole spectrum. We are far from being able to establish a general survey of the highly complex vehicle behaviour by analytical measuring methods, not to mention the far more complex control loop as a whole. The driver-vehicle-environment relationship was discussed earlier.
Figure 3. Parts of the control loop in operation during an example of an open-loop test.
So we are still obtaining—and with visible success—practically all our knowledge on vehicle handling by the comprehensive method 3. This method also leads—although we cannot prove it with figures—to the fact that we are near the physical limits of today’s technology and that marked differences are only present in very small areas.

As far as any clarification of the relation between vehicle handling and safety, it is not clear whether we are able to proceed much beyond the findings made possible by procedure 3.

Statistical data on driver behaviour prior to real accidents, which might help us in this direction, is not available today. How little hope exists of finding more reasonable material becomes clear immediately, if we try to formulate questions in the area of active safety for an accident investigation form.

After a few questions we are already at the end and we can predict that the answers that are expected and the quantitative accuracy will be unsatisfactory.

We have to admit that today we still do not have an objective yardstick for vehicle handling improvement and that we continue to obtain our knowledge on still unprovable areas by subjective judgements. Only indirectly can subjective estimations lead to assumptions on the value of objective test results concerning safety. However, we do not know to what extent an offered improvement is really utilized by the driver.

Also, our knowledge of objective data about the adaptability of drivers to differently behaving vehicles is extremely small.

**CONCLUSIONS**

By utilizing the control loop, which is in operation during driving in traffic, and by considering the related estimations, we can recognize the following facts:

- The control loop is of extreme complexity and ambiguity; the number of the possible combinations of circumstances that can lead to its failing is immensely high.
- The vehicle has a simple structure compared with the driver’s, but it is still very complicated and the number of possible operating conditions is very high.
- Only very small parts of the whole amount of handling disciplines are still unprovable, mostly in limit areas in which the normal driver has no experience.
- Measurement methods for individual handling disciplines cover only a narrow band, either of the wide not unprovable area or of the small still unprovable range.
- The relation between objective test results and traffic safety is unknown.

These facts result in the following consequences for industry research and legislation:

- The number of operating conditions of the control loop in practice is so immense that for development purposes procedure 3, which consists of extended rides in traffic in different regions and seasons, cannot be dispensed with.

For the legislator it is completely impossible to cover the whole of vehicle handling by objective tests.

- Normally it would be nonsense to immediately make a rule from a test that has been agreed upon in some association groups. There are always great difficulties to be expected with the test itself and the effect on safety cannot be predicted.

If the lawmaking process is not proceeding very carefully, negative effects are probable; the danger that well-balanced vehicle configurations could be made worse and that technological development might be frozen should not be underestimated.

- Due to the predominant importance of driver behaviour, efforts in research should be directed toward the areas of driver behaviour prior to accidents, and the frequency of typical driving situations prior to the accidents.

With such material available, a well-grounded study should follow on the question of which vehicle measures might lead to real improvements in safety. For such measures, regulations might be useful that pay attention to the maintenance of a good overall compromise.
In view of the difficult subject, it would be advisable to ask for the support of as many experts as possible, fixing no arbitrary final dates and using only the state of research as the guideline.

For more than 90 years it has been necessary to leave the development of vehicle dynamics solely to the initiative and responsibility of industry, which has done a good job of it. We, from Daimler-Benz, feel things should continue this way.

Review and Correlation of Driver/Vehicle Data

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ABSTRACT

The results of combining and evaluating driver/vehicle response and performance data from recent experimental studies are discussed and illustrated. Open-and closed-loop data are used to infer the behavior of drivers in various driving tasks and to determine the manner in which vehicle factors influence this behavior. Procedures are presented for establishing and predicting satisfactory or unsatisfactory vehicle performance regions and limits germane to driver/vehicle dynamic performance. Implications from the data are used to tentatively identify safety-relevant vehicle performance characteristics, requirements, and criteria to provide guidance for future test programs.

INTRODUCTION

This paper summarizes some of the highlights of a current program to review and correlate driver/vehicle response and performance data. The program is sponsored by the National Highway Traffic Safety Administration (NHTSA), and the Contract Technical Manager is Mr. Francis DiLorenzo [1].

In this work we are concentrating on the directional handling properties of automobiles in steering control tasks. The analysis and correlation activities consider data from several sources. Notable among these are the data bases from several recent experimental programs sponsored by NHTSA. One was conducted by Texas Transportation Institute under the direction of Mr. Gordon Hayes [2]. This work was summarized at the 1974 Experimental Safety Vehicle (ESV) Conference in London [3], and the results have also been reported to the Society of Automotive Engineers (SAE) in the United States. The second main source of data comes from a program accomplished by Systems Technology, Inc. [4]. This work was also outlined at the 1974 ESV Conference in a paper presented by Mr. Richard Klein [5]. The third project listed was accomplished by the Highway Safety Research Institute (HSRI) under Mr. Robert Ervin; it emphasized open loop maneuvers up to the limit of performance, with an automobile steering device [6]. Technical reports detailing the experimental procedures and results of all three programs are available from the National Technical Information Service [2, 4, 6].

The first two programs listed involved an extensive series of full scale experiments with instrumented vehicles, typical drivers, and a range of driving tasks. These tasks included regulation against a random directional disturbance, maneuvers such as a lane change, and the avoidance of obstacles appearing unexpectedly in the path of the vehicle. Measures of driver control behavior and vehicle motions were recorded on magnetic tape, and these data are being analyzed in the present Systems Technology, Inc. (STI) study.

It should be noted that, as part of this effort, we have conducted an extensive
review of the literature and the findings of researchers other than those whose data have been mentioned. This includes all the prior ESV and Research Safety Vehicle (RSV) work, as well as the work of other research organizations and manufacturers in the U.S. and abroad. Out of this have come a number of useful ideas and results, and we are trying to use them to the extent we can.

The overall objectives of this current work are summarized below. The first task has been to collect, review, analyze, and correlate the data. In the process, we have sought to develop an integrated and unified view of handling considerations for steering control. From this we are trying to derive answers to the third objective, which is to identify performance measures that are safety related. The final objective is to provide guidance for future research planning and to advise the NHTSA in areas related to handling requirements and considerations.

In this paper we will show a few highlights of the work to date and will emphasize some key factors and parameters in the interactions between the driver and the vehicle.

QUANTIFICATION OF VEHICLE DYNAMICS

For the first technical point, let us turn to the problem of describing the directional dynamics of the vehicle (see equation).

\[
\frac{r}{\delta_{sw}} = G_s \frac{r}{\delta_w} = \frac{G_s \delta_{w} (s + 1/T_r)}{[s^2 + 2\xi_1 \omega_1 s + \omega_1^2]}
\]

\[
= G_s \left( \frac{U_o}{\nu \ell} \right) \left( \frac{1}{T_r} \right) \times (s + 1/T_r)
\]

\[
\left[ s^2 + \left( 1 + \frac{1}{\nu \frac{1}{T_r}} \right)s + \frac{1}{\nu} + KU_o^2 \left( \frac{1}{T_r} \right)^2 \right]
\]

\[
= G_s \delta_{sw} (0) \frac{1}{T_e s + 1}
\]

where:

- \(T_r\) is the yaw time constant
- \(T_e\) is the effective time constant
- \(U_o\) is the forward speed
- \(\ell\) is the wheelbase, \(a + b\)
- \(\nu\) is the axle load ratio, \(bY_{\alpha_2}/aY_{\alpha_1}\)
- \(L_{zz}\) is approximately \(mab\)
- \(K = \frac{\nu - 1}{U_o \ell (1/T_r)}\) is the understeer/oversteer gradient

These dynamics are needed in order to correlate the performance data and to differentiate the types and sizes of cars. In our work, the transfer characteristics of the car are emphasized, modeled in the frequency or time domain. Another approach is to look at some output property such as the peak lateral acceleration \(a_y\) in a lane change, and we return to that later. It should be noted that the main interest in this paper is on nominal operating conditions with lateral accelerations up to about 0.5 \(g\), and we are not concerned here with limit performance or loss of control.

The equations summarize the transfer characteristics for steering control. As is often the case in vehicle handling, only a few parameters are needed to describe the important response properties of the car, and these are shown here. At the top is the yaw velocity response to steering wheel input transfer function for a two degree of freedom model. The parameters consist of a gain \((G_s N_5)\), a numerator yaw time constant \((T_r)\), and a damping ratio \((\xi_1)\) and natural frequency \((\omega_1)\) in the denominator or characteristic equation. Although this a simple expression, and one which can be used to quantify the dominant directional response properties, even more insight can be obtained by recognizing that the denominator terms are functions of the yaw time constant in the numerator.

This is shown in the second equation, where two additional parameters are introduced. One is the axle load ratio (\(\nu\)), which is the product of the effective rear tire side force coefficient \((Y_{\alpha_2})\)\(^1\) and the distance (b)

\(^1\)In the notation of SAE J670d, \(Y_\alpha\) is called \(C_\alpha\). [7].

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from the mass center to the rear axle, divided by the product of the corresponding values at the front \( aY_{\alpha_x} \). The other parameter \( K \) is the stability factor (oversteer/understeer gradient), which is positive for understeer and negative for oversteer. From this equation it can be seen that the yaw velocity to steer angle transfer function has three main parameters. The stability factor \( K \) can be determined from steady state tests [8] and it is related in turn to the yaw time constant and axle load ratio, as shown at the bottom. Since the covariation of \( \nu \) and \( T_r \) is known once \( K \) has been measured, only one parameter \( (\nu \text{ or } T_r) \) needs to be determined from suitable transient or frequency response data.

The third equation is an even simpler form that is useful in some cases. It contains only two parameters, the steady state gain \( G_f \) and an effective directional time constant \( T_e \). The gain can be determined from steady state tests, while \( T_e \) can be obtained directly from directional response data (as a phase lag or an equivalent time lag).

RESULTS FOR REGULATION TASKS

Having summarized those steering dynamics of the vehicle that are important in nominal driving situations, let us now consider some experimental results for the driver/vehicle system. A simple block diagram is shown in figure 1. Consider first what are often called regulation tasks, where the driver is steering the car in an effort to follow the desired path, in the presence of a disturbance.

In the STI experiments, response data were obtained for the driver/vehicle system while a simulated, random appearing, crosswind disturbance was acting on the car [5]. The resulting driver plus vehicle describing functions tell us a great deal about the driver’s behavior and the system performance. For example, we obtain, directly, measures of the system bandwidth and stability and can deduce measures of the driver’s anticipation (lead generation), gain, effective time delay, and so forth. The experimental data for the system [4] show that the driver adjusts his characteristics to maintain system bandwidth constant as vehicle dynamics are changed. However, the system stability, as measured by the phase margin, varies with vehicle dynamics.

Data showing the variation of phase margin with the effective time constant are given in figure 2. The vertical axis is the system phase margin in degrees. Larger values imply more driver/vehicle system damping, and better path following performance, both of which are desirable. These data for 16 driver subjects, male and female, four vehicle configurations, and several replications show a clear correlation between stability margin and the directional dynamics of the vehicle.

In addition, driver rating and performance data for the four configurations tested indicate that the two with effective time constants less than about 4 rad/s are poorer
than the two that respond more quickly. This is indicated on the figure as a region of transition.

RESULTS FOR MANEUVER TASKS

Turning next to driving tasks and situations involving maneuvers and other discrete responses, and referring to the block diagram (fig. 1), we are now dealing with various desired path inputs, rather than disturbances acting on the vehicle. In the data base being considered this includes single and double lane changes, turns and exits, slaloms, and obstacles appearing unexpectedly in the vehicle path. For such tasks, different kinds of response and performance measures are pertinent, although the important vehicle dynamic properties may be the same. The measures include ones which describe the form of the response such as reaction time, time to peak, and settling time; peak amplitude, ratio of peak amplitudes, and maximum rate; as well as time averages such as mean square, autocorrelation function, and energy spectrum. These kinds of measures can be applied to both the driver steering output and the vehicle motions.

A number of such measures are being extracted from the data for analysis and correlation [1]. Figure 3 illustrates the results with a plot of peak lateral acceleration (ay) vs the inverse effective yaw time constant. Combined data from both the STI and the TTI experiments are shown. Note that the TTI data for the unexpected "dropped box" are taken at 50 mi/h while the STI "unexpected obstacle" was presented at 30 mi/h, yet the trend is consistent. Furthermore, the STI obstacle appeared only rarely, and was truly an unexpected and surprising occurrence.2 The TTI dropped box, on the other hand, was one of several small flags which dropped in front of the car on every experimental trial, and the task was expected by, and familiar to, the driver.

2The STI data points shown are for "steer only" responses, and runs where the driver braked as well are not shown.

These data are for about 48 typical driver subjects, and a total of 8 different vehicle configurations in the combined results. The median value is shown on the plot, and the data points suggest the scatter among subjects. Despite the scatter and experimental differences, the trend of the data shows that higher accelerations are used with, and achieved by, the vehicles that respond more quickly. The median suggests that there is a transition to higher levels of maneuver activity in the region of 4 to 5 rad/s. Remarkably, this is very close to that shown previously as a transition region in regulation tasks (fig. 2).

COMBINED CONSIDERATIONS

Thus far, we have defined some key vehicle parameters and shown some examples of response and performance data. If we now consider the additional information from subjective rating data, the kind of relationship shown in figure 3 is obtained. The vertical axis is the steady state yaw velocity gain (multiplied by the wheelbase), while the horizontal axis is the yaw time constant. The optimum region is based on workload-related subjective ratings from an experienced test driver, subsequently validated for
Figure 4. Peak lateral acceleration in sudden maneuvers.
six boundary conditions by 16 subjects [4]. The region shown is formed by combining considerations of steering gain, and handling response, and performance in regulation and transient maneuver tasks. Note that, at 50 mi/h, the upper and lower horizontal segments of the boundary correspond approximately to neutral steer and 3.4 deg/g understeer, respectively.

The results in Figure 3 are tentative, and we are attempting to refine them as part of the current analysis and correlation effort. To date, there is some indication that the lower line may move down a little providing a larger optimum region. Note, also, that the right-hand edge corresponds to an inverse yaw time constant ranging from 3 to 4 rad/s, which is consistent with the transition region seen in figures 2 and 4 (after converting $T_e$ to $T_r$ for those vehicles).

In Figure 3 the iso-opinion contour has been plotted on coordinates of gain versus yaw time constant. This was appropriate, but some of the other vehicle parameters discussed in Figure 1 could have been chosen, as well. For example, the gain might have been replaced by the stability factor, $K$, or we could have normalized the parameters and the figure with forward speed. In short, possible alternative formats are still being considered. In any event, these kinds of composite plots serve to unify the results and display the correlations and interactions, which are otherwise obscure.

CONCLUDING REMARKS

In conclusion, we have tried to present the flavor of our work and to illustrate some of the kinds of results that are being obtained. As a final point, it should be noted that the complete results and recommendations from this applied research effort will be documented, and subsequently distributed if approved for release by the NHTSA.

REFERENCES

INFLUENCE OF TIRE PROPERTIES AND REAR AXLE COMPLIANCE STEER-ON POWER-OFF EFFECT IN CORNERING

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INTRODUCTION

During rapid cornering, a sudden reduction in speed might be necessary. In most cases, it would be sufficient to slightly release the accelerator pedal, that is, to change from engine driving force to engine braking force. As experience has shown, such a powering-off in cornering may result in sudden course deviations.

Due to the interaction of longitudinal and lateral vehicle dynamics quite a number of effects occur such as changed axle and tire load distribution, changes of the lateral forces and the self-aligning torque of the tires, as well as kinematic and elastic changes of the wheel position [1, 2]. Very often, the overall effect is an oversteering reaction, that is, a turning of the vehicle into the curve provoked primarily by the diminution of the rear axle lateral force.

EXAMINATION OF THE TIRE PROPERTIES

The point of departure is the dependence of the lateral force on the slip angle (fig. 4) and on the longitudinal force. The tires tested on the Porsche tire rig [6] exhibited behaviour already discussed in corresponding literature [7].

As far as transient side slip is concerned, Porsche has already carried out extensive measurements. There is no information available on transient dependence on the longitudinal force. The same applies to the overall transient behaviour during powering-off, as it concerns the side force behaviour with simultaneous change of the vertical load, the longitudinal force, and the slip angle.

So, tests were made on an appropriate tire rig in order to provide at least an approximate idea of what is going on. Due to the multitude of tire force functions that occur during normal operation and vary according to the respective chassis tuning, tire data, and driving conditions, a limited number of situations could only be simulated on the tire rig.

Based on previously effected driving tests and dynamics calculations, one input function each was preset for the change of longitudinal force and slip angle, whereas...
SECTION 4: TECHNICAL SEMINARS

Figure 1. Slip angle and lateral force of the outer rear wheel (quasi-steady-state principle graph).

Figure 2. Basic view of the elasto-kinematic toe changes.

NOTE. Before changing the longitudinal force:
- \( P_0 \) = Vertical load
- \( \alpha_0 \) = Slip angle
- \( S_0 \) = Lateral force

Upon changing the longitudinal force:
- \( \Delta P \) = Reduction of vertical load
- \( \Delta \alpha \) = Slip angle/toe-in increase
- \( \Delta S \) = Lateral force decrease and increase

NOTE. IP = Intersection point of the no load swivel axis and the road surface
- \( c_{\text{r1}} \) = No load negative offset
- \( r_{\text{n1}} \) = No load negative steering offset
- \( \Delta \phi \) = Toe change with braking force (and lateral force)
several input functions were provided for the vertical load.

On the longitudinal force curve, the tire rig does not allow quicker and yet reproducible changes. The functions were reproduced by means of electronic function generators and used to control the tire rig.

The test results can be summarized as follows:

- With constant vertical load and longitudinal force, the lateral force follows the slip angle with only slight time lag (fig. 5). This is a consequence of the low slip angle velocity [6].
- According to figure 6, the side force curve declines strongly with low constant vertical load and constant slip angle, due to the longitudinal force change, whereas with constant high vertical loads the lateral force curve rises slightly. It has been shown that the radial tire performance increasingly resembles the cross-ply tire behaviour [7].
- In the case of constant slip angle and constant longitudinal force, the lateral force decreases as a function of the vertical load, as expected (not illustrated).
- When superimposing the three transient input functions (fig. 7), one will clearly
forces. According to slip angle frequency investigations made by Porsche, this is also true of higher slip angle velocities (of the order of 1 degree/s), occurring with the elasto-kinematic wheel alignment.

- The hypothesis of activating part of the lateral force reserve of the highly loaded rear outer wheel by increasing the slip angle can be realized.
- Similar to the lateral force, the self-aligning torque was first examined, especially the particular factors by which it is influenced. The overall response can be seen in figure 8.

The strong decline of the self-aligning torque immediately upon initiation of the powering-off is caused by the change of longitudinal force and vertical load, whereas later on it is attributed to the increase of side slip. This reaction is desirable in the present context because the reduction of the self-aligning torque means the increase of the (elastic) toe-in and thus of the slip angle.

After the initially mentioned hypothesis has been basically confirmed by the tire rig measurements, the design of the test vehicle axle, illustrated in figure 3, shall be explained in detail.

DETAILS OF AXLE DESIGN

Let us start with the basic problem treated in this paper, that is, the toe-in change during powering-off. Figure 9 shows that during powering-off the instantaneous

see the strong influence exerted by the longitudinal force at low vertical loads, whereas with high vertical loads, the lateral force reduction is almost completely balanced by vertical load changes, and the lateral force increases by longitudinal force changes.

- When compared to figure 1, which shows a stationary process, figures 5 and 7 prove that the transient slip angle increases immediately result in increased side
Figure 9. Toe-in change with changing longitudinal forces.

center of the movement of the lower guide arm and the tie rod is situated outside the track. In addition, the upper four-joint linkage exerts a toe-in moment on the hub carrier, so that there are two factors that are responsible for keeping the wheel in toe-in position.

In this context, it is of special importance that the lever arm force value, influencing the toe-in change during powering-off with straight-ahead driving, differs in general from the one occurring in cornering. The reason for this phenomenon is the lateral displacement of the tire contact patch as well as changes of the pressure and shear force distribution. Further on it is of advantage that the toe-in change during braking (with the brake on the hub carrier) can be tuned independently (see fig. 9b).

This possibility is important because vehicle reactions to braking decelerations of varying degrees in cornering are basically different [5].

Further, this elastic wheel link system is characterized by a generally desirable understeering with lateral force increase. Figure 10a shows again the interaction of the lower arm elasticity and the upper arm toe-in moment.

Figure 10b shows that during powering-off the negative caster offset and thus the lateral force understeering might increase. It remains to be mentioned that the proposed wheel link system permits also an appro-
appropriate tuning of the antisquat/antidive properties, that is, the realisation of a progressively increasing antisquat effect during bounce and a progressively increasing antilift effect during rebound (fig. 11).

Based on the aforementioned considerations, a corresponding experimental axle was constructed, as shown in figure 12.

It was first submitted to bench tests with differing elastic and kinematic conditions in order to be tuned with the tire properties and to provide a basis for the interpretation of the driving tests (fig. 13).

The results can be summarized as follows:

- In the interest of dynamically efficient toe-in changes, the toe-in of the torsional rigidity of the rear wheel suspension must be inferior to that of today's suspensions. The realisation of this objective necessitates a thorough tuning in order to satisfy all handling requirements.
- In this framework there are certain limits to the tuning of the fictive swivel axis position and the toe-in changes.

Figure 10. Toe-in change with lateral force (a) increase of the negative caster offset upon changing from engine driving to engine braking force (b).

Figure 11. Basic view of the antisquat/antilift properties.
category with a modified front axle was chosen. The vehicle was equipped with the usual driving test instruments, including a slip angle and a toe-in measuring device. With a radius of 30 m, the initial lateral acceleration of all tests amounted to 8.3 m/s², which corresponded to about 90 to 95 percent of the maximum lateral acceleration that could be obtained. Upon powering-off, the steering wheel was maintained in the position corresponding to the stationary cornering condition.

During driving tests, extensive variations were carried out on the tire and rear axle adjustments. In the framework of this paper, we shall confine ourselves to two typical results.

Figure 14 shows two different wheel positions relative to the wheel suspension, with and without wheel spacer (25 mm thick) as well as the respective distances of the wheel centers a and b from the fictive swivel axis. Upon powering-off, the toe-in increase of the (smoothed) toe-in change curves is faster and more intense with the “negative” lever arm than with the lever arm b. The maximum value obtained of more than 15 feet corresponds to the test bench results. As the side force deflection steer was practically not changed by the wheel spacers, the differences of toe-in change time of up to 0.8 second upon powering-off, are to be attributed to the effects of the longitudinal force. The subsequent toe-in changes caused by the lateral force change are almost identical in both cases. This favourable toe-in change curve results in reproducible and distinctly improved road holding (fig. 15).

In general it can be said that the rear outer wheel permits toe-in increases up to about 20 to 30 feet which, according to the tire tests, results also in an increase of the lateral forces. An eventual change of the inner wheel toe-in is of very little influence. Here, the vertical load is of importance. Its effects can also be optimized within the possibilities of the present wheel suspension.

**DRIVING TEST RESULTS**

For testing of the experimental rear axle (fig. 12) European sedan of the upper
Figure 14. Toe-in time history of the outer rear wheel.

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**Figure Legends:**
- a = Lever arm without wheel spacer
- b = Lever arm with wheel spacer
- c = 25 mm (=1") wheel spacer

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**Notes:**
- Torsion is expressed as a function of time.
- Wheel spacer affects the overall movement and stability of the system.
- The graph illustrates the dynamic response of the system under different conditions.
the satisfactory tuning of the rear axle for behaviour under powering-off would be its tuning for defined braking in the curve.

REFERENCES


Driver Use of Indirect Vision Systems

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ABSTRACT

Driver behavior in obtaining information through rearview mirrors and head turns was analyzed for novice, young experienced, and mature drivers during daytime driving on a freeway route. No significantly different mirror sampling patterns were observed when the horizontal fields of view of the plane left side mirror and inside mirrors were increased by 25 percent. In a system with a convex mirror mounted on the right side, the mature driver utilized the convex mirror more frequently than the young experienced and novice drivers.

An analysis of recent data on the effect of training with a convex mirror on the right side by drivers who are uninitiated and by those who are experienced with convex mirrors will also be discussed.

INTRODUCTION

Although a driver's primary visual task is monitoring the forward scene, information that appears at the sides and to the rear of the vehicle is also needed to perform many maneuvers. The acquisition of indirect vision information involves both the type of mirror system and the driver's skill in using the mirror system. Several innovative rear vision systems have been investigated by Burger et al. [1]. They found that mirror systems with a large center plane mirror and corresponding field of view facilitated efficient gathering of rear scene information. When using small center-mounted plane mirrors, however, drivers made more frequent and longer glances to the mirror and direct glances to the rear scene.

Kaehn [2] has reviewed a series of experiments wherein drivers evaluated passenger cars equipped with periscopes and three types of outside convex mirror systems. One of the results of these studies was that an adjustable right outside convex mirror proved useful. Furthermore, previous research by Mourant and Rockwell [3] has indicated that novice drivers do not use mirror systems as frequently nor as efficiently as experienced drivers.

In order to determine the effect on mirror usage of all three of these parameters; namely, mirror size, driving experience, and the addition of a convex mirror, General Motors has supported a research program at Wayne State University for the past several years under the direction of Dr. R. Mourant. The results of the early phases of this research have been previously reported [4]. This review will summarize some of the latest findings of that research program and indicate the direction of future studies.

METHOD

Experimental Design

A repeated measures design on three types of drivers was followed. Three novice, three experienced, and three mature drivers drove four vehicle mirror systems once over a freeway route and once over a city route for a total of 72 runs (9 drivers × 4 vehicle mirror systems × 2 routes).

Types of Drivers. Drivers were classified as novice, experienced, and mature, based on their total miles driven. The drivers averaged 2 000, 71 000 and 250 000 total miles driven, respectively. The average ages of the

1 In the United States, plane (unit magnification) mirrors are required inside and on the driver's (left) side of passenger cars by Federal Motor Vehicle Safety Standards (FMVSS). Passenger side mirrors are not normally required. Furthermore, almost all of the mirrors installed on the passenger's (right) side are plane.

2 Parts of this review have been submitted to the Journal of Safety Research for publication.
EXPERIMENTAL SAFETY VEHICLES

Table 1. Horizontal fields of view of vehicle mirror systems

<table>
<thead>
<tr>
<th>System</th>
<th>Left side mirror</th>
<th>Inside mirror</th>
<th>Right side convex mirror</th>
<th>Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12.8</td>
<td>27</td>
<td>-</td>
<td>1973 Buick LeSabre four-door sedan</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>38</td>
<td>-</td>
<td>1973 Buick LeSabre four-door sedan</td>
</tr>
<tr>
<td>C</td>
<td>16</td>
<td>38</td>
<td>19</td>
<td>1973 Buick LeSabre four-door sedan</td>
</tr>
<tr>
<td>D</td>
<td>19</td>
<td>38</td>
<td>-</td>
<td>1971 Chevrolet Impala four-door sedan</td>
</tr>
</tbody>
</table>

*aMeasured as per SAE Recommended Practice J1050.

Data Collection Equipment

A closed circuit television system consisting of three television cameras, special

Figure 1. Freeway route.
effects electronics, an electronic counter, a video monitor, and a video tape recorder was installed in the rear passenger compartment of the test car (fig. 2).

The course forced the driver to execute four left merges and one right merge. The drivers also made right and left lane changes during the natural course of driving the route. Note that the left merges consist of moving the car from an entrance ramp to the right or low speed freeway lane while the right merge moves the car into the left or high speed freeway lane. Also, the accelerating lane for the right merge on this course is shorter than the accelerating lanes on the left merges. These differences could have an effect on the results.

The city route, which was 8 miles (12.8 km) long, included a business district, residential areas, and a warehousing district. The course forced the drivers to make four right turns and one left turn. However, left and right lane changes were made at the discretion of the driver.

Procedure

For each of the Systems B, C, and D, subjects were trained for a period totaling at least 2-1/2 hours of freeway driving. Thus, each subject had about 125 miles of driving experience in which to become familiar with the routes and cars prior to actual data collection. During training with System C, the experimenter instructed the subject to use the convex mirror as a "go or no-go" device; that is, if a subject did not see a vehicle in the convex mirror, then it was safe to proceed with the maneuver. However, if a vehicle was visible, the subject was to determine its position before completing the maneuver by looking in the inside mirror or by a direct look to the rear. Subjects were tested first with System A and then sequentially to System D first on the freeway and then on the city route.

One camera viewed the driver's eyes through a front surface mirror mounted on the instrument panel while a second camera

Figure 2. Television recording system.
viewed the road scene ahead of the vehicle and the third camera monitored the road scene behind the vehicle. The video display from each camera appeared simultaneously in three different sections of each television frame (fig. 3). Each frame was also numbered by the electronic counter. An experimenter seated out of view of the driver in the rear passenger compartment could monitor the scenes from all three cameras simultaneously as the information was being videotaped.

RESULTS AND DISCUSSION

During each data collection run, the subject driver acquired information under two different circumstances: when traveling straight ahead, and when merging into the lane and making left and right lane changes. The data collection time for each maneuver was initiated at 14 seconds prior to the execution of the maneuver. The execution time was defined to occur when the leading edge of the test vehicle crossed the lane marking.

Mirror Glance Durations

The glance duration is a characteristic of an individual’s visual processing system. The mean glance duration times for the novice, experienced, and mature groups were not statistically different for any of the maneuvers. The mean glance duration for different maneuvers, however, are statistically significant (at .05 level of confidence). Mean glance durations for the left merge maneuver were significantly longer than mean glance durations for the straight ahead driving and the right lane change.

The results are expressed in terms of total time per maneuver; that is, the product of mean frequency and the mean glance duration. Since mirror glance duration is not affected by the amount of driving experience, differences between driving groups are
mainly due to the number of mirror glances made. Mean mirror glance durations are given for each maneuver and are indicated by D.

Traveling Straight Ahead

If a driver glanced to a mirror and/or made a direct look to the rearward scene and then did not execute a maneuver (lane change or merge) within 14 seconds, the behavior was classified as traffic monitoring while driving straight ahead. In that classification none of the drivers ever made direct looks to the side or rear of the car. Direct looks to the side or rear were only made in connection with the execution of lane changes and merges.

Figures 4, 5, and 6 present the total time per run as a function of driver type for looks to the left side, inside and convex mirrors while driving straight ahead. The total time per run is the summation of all the glances during the run averaged over the three subjects in each driver type. The glance duration averaged over all drivers, D, is listed on the graph.

From figure 4 it is apparent that the mature drivers spent more time monitoring their left side mirrors for both the freeway and city routes than did the experienced and novice drivers. This result is in agreement with previous findings [3]. On the other hand, the novice drivers spent more time monitoring the inside mirror (fig. 5) on the freeways than did the experienced drivers. This occurred because one novice driver made an abnormally large number of glances to the inside mirror. Post-test questioning revealed that the driver was acting upon his driver training instructor’s suggestion that a good driver is always aware of traffic behind him. Since that novice driver averaged 146 glances per run and the mature drivers averaged 58 glances per run, we conclude that he was carrying the instructor’s comment to an extreme. For the convex mirror glances (fig. 6) the pattern was similar to that of the left outside mirror. Mature drivers spent more time per run sampling the convex mirror than did experienced and novice drivers.

These results suggest that mature drivers have more spare visual capacity than experienced and novice drivers. They use this capacity to sample their left outside and convex mirrors and thus become aware of
potential traffic hazards. The novice drivers, however, either have not been trained to use these mirrors and/or must simply spend more time sampling straight ahead in order to maintain their position on the road.

**Lane Change and Merge Manuevers**

On both the city and freeway routes the decision to execute maneuvers was made by the subject driver. The specific routes chosen forced drivers to execute some maneuvers. For the freeway route all driver types executed about the same number of maneuvers. However, for the city route mature drivers made more left and right lane changes than novice drivers.

In the 14-second period prior to executing a left lane change or left merge, a driver may acquire indirect information by: (a) glancing to the left side mirror, (b) glancing to the inside mirror, or (c) turning his head and making a direct look. The time drivers engaged in seeking information prior to executing the maneuvers is shown in figures 7, 8, and 9, respectively, as a function of driver type.

Figure 7 shows that for the freeway left merge and all left lane changes the mature drivers spend more time gathering information via the left side mirror than did the novice drivers. Thus, novice drivers’ reluctance to use the left side mirror while driving straight ahead was continued when they acquired information prior to left side maneuvers. As illustrated in figure 8, all driver types made infrequent use of the inside mirror in connection with left side maneuvers. Figure 9 shows that novice drivers spent more time making direct looks than did mature and experienced drivers, particularly for the freeway left merge and left lane change.

Taken together, figures 7, 8, and 9 indicate that mature and novice drivers employ different information gathering techniques just prior to maneuver execution. Mature drivers rely on the vehicle’s mirrors while novice drivers make direct looks to the vehicle’s left rear.

Figure 10 presents the total time (summed over left and inside mirror glances and direct looks) spent obtaining indirect vision information prior to a maneuver. For every type of maneuver, novice drivers spent more time gathering information than did experienced or mature drivers. Also, as
shown in figure 9, for the freeway left merge, novice drivers spent one second more per maneuver glancing to the side than did mature drivers.

Figures 11 through 14 present data for the maneuvers to the right side. Figure 11 shows the time spent glancing to the inside mirror prior to executing freeway right merges, freeway right lane changes and city right lane changes. For the freeway maneuvers, the mature drivers spent more time looking in the inside mirror than did the experienced and novice drivers. This may be due to mature drivers being more careful when making maneuvers to the right side. Also, all drivers spent more time viewing through the inside mirror than looking directly to the right or viewing through the outside convex mirror.

Figure 12 shows the time drivers spent making direct looks to acquire information for right side maneuvers. The results are similar to those for left side maneuvers (fig. 9) in that novice drivers spent more time on direct looks than did mature drivers.

Figure 13 shows convex mirror use prior to the right side maneuvers. For freeway right lane changes, both mature and experienced drivers made considerable use of the convex mirror. Although some of these glances may be due to a "curiosity" effect, the data presented are for the period just prior to a maneuver being executed. During this period a driver must determine whether or not it is safe to perform a maneuver. Thus, it is likely that the mature and experienced drivers considered the convex mirror to be a useful aid in connection with right side maneuvers. The novice drivers either were unable to use the convex mirror or they chose a sampling strategy that relied heavily on direct glances. Thus, as with left side maneuvers, different driver types
EXPERIMENTAL SAFETY VEHICLES

Figure 14. Total time for obtaining indirect vision information prior to a right side maneuver.

Figure 15. Mirror system differences for the freeway left lane change.

the experienced drivers. This may be due to mature drivers being cautious and novice drivers being inefficient samplers with respect to right side maneuvers.

Mirror System Differences

Figure 15 shows the average frequency and mean duration (in brackets) of left side mirror looks, inside mirror looks and direct looks for the freeway left lane change. Mirror Systems B and C had the same configuration for left side maneuvers, a large inside and large left outside mirror. Thus, the results should be similar and the data show that they are. System D resulted in less time being spent in sampling the left side mirror than Systems A, B, and C.

The result from System D was questioned because, if a larger mirror size indeed reduced mirror usage, we would have expected a reduction in mirror usage (from System A) for Systems B and C as well. This
did not occur. However, the reduction in time could have been caused by a learning effect since the car with System D was always the last vehicle driven by the test subjects.

A completely separate study was undertaken to determine whether the large left outside mirror indeed reduced the total information gathering time for left lane changes. The mirror usage behavior of 20 new subjects was measured over the same freeway course with left outside mirror providing a 20-degree horizontal field of view and a production outside mirror with a 15-degree field of view on a 1976 Chevrolet Nova.

Although the results from this study have not been thoroughly analyzed, preliminary results indicate that the mirror usage times were not smaller when the larger left outside mirror was used. The results of this separate study will be published at a later date.

Figure 16 shows comparisons for the freeway right lane change. Systems B and C were again physically identical except that System C had a fender mounted convex mirror. When the time spent sampling the convex mirror (System C) is added to that of the inside mirror, it can be seen that Systems A, B and D are virtually equivalent. When using System D, subjects spent about the same amount of time sampling the inside mirror as System C, but took more direct looks. There appears to be a trade-off between direct looks (head turns) in System D and convex mirror use (with much less head turn) in System C; and fewer head turns and more inside mirror looks with Systems A and B. It is interesting to note that total time needed to obtain information was about the same no matter which system was used.

Extended Study With Right Outside Convex Mirror

We are presently engaged in a study to investigate more thoroughly the behavior of

Figure 16. Mirror system differences for the freeway right lane change.

![Figure 16. Mirror system differences for the freeway right lane change.](image-url)
drivers when executing right lane changes and merges with a convex mirror. For this study, we have instrumented a car to give four simultaneous images of the traffic scene; the front scene, two rear scenes as seen from each side of the car, and the driver's head and eyes as before. In this instance, a driver is given a car with a right outside convex mirror mounted on the door. The driver's mirror behavior pattern is measured before the driver has any experience in driving the vehicle with the right outside convex mirror. Then at intervals of 200 miles of experience up to a total of 1,200 miles, the driver's mirror behavioral pattern is examined.

To date only two test subjects have been run, one who is a young experienced driver with no previous convex mirror experience, and another, a mature driver who has considerable driving experience in Europe with convex mirrors. Although more subjects need to be run to build an adequate data base on which to draw conclusions, we do see a consistent pattern developing.

The total time spent in obtaining information needed to execute a right lane change with the convex mirror appears to remain unchanged or reduced slightly compared to the time required with a conventional mirror system. However, the drivers have changed their mirror use behavior. Both drivers sample information from the door-mounted convex mirror as frequently as from the inside plane mirror. In one instance, the driver no longer relied on a head turn and in the other case, the amount of head turn was reduced considerably. Furthermore, an interesting pattern of a combination outside convex to inside mirror glances is developing which indicates that the drivers are acquiring considerably more information with this mirror use pattern than they would if the convex mirror were not used.

These conclusions are only preliminary. A confirmation of these observations and a detailed analysis of the pattern of mirror use must wait until the program is completed.

SUMMARY

To date, these studies have given us insight into the driver's behavior with mirror systems. We find that the driver likes to look in the direction that he wants to move the car; that increasing the size of the mirror does not necessarily reduce the information gathering time although he is obviously getting more information because of the larger field of view. We found also that the experienced and mature drivers have more efficient vision information gathering patterns and use their mirrors, whereas the novice driver uses the mirrors for maneuvers but does not depend strictly on the mirrors for making decisions. Finally, it appears that the convex mirror can be used for making lane changing and merging decisions by mature drivers and with some additional driving experience by experienced drivers; and indeed, it appears to improve the vision information gathering process of those drivers who are utilizing them.

The studies at Wayne State University will continue and the results of these research programs will be published on a timely basis.

REFERENCES

LILAC—Low Intensity Large Area City Light

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ABSTRACT

The paper describes means for controlling vehicle headlamp intensity to provide a 'town beam' for use in lighted streets. Two systems have been developed to meet the recommendations of the International Commission on Illumination (CIE) for "a town beam which is intermediate in intensity between that of the currently used low beam and side lights. Such a light should have a luminous intensity between 50 and 100 cd and should have an area similar to that of current headlights." One system is a manual one consisting of a relay and resistor, which was first proposed in the early 1960's. The other is a recent development of an automatic system, which controls headlamp intensity automatically to suit the ambient streetlighting. A full scale trial of 1,000 units is proposed for the winter of 1976-77.

INTRODUCTION

In Great Britain approximately 75 per cent of night accidents occur on streets having a system of fixed lighting and 90 per cent of pedestrian casualties at night occur in lighted streets. The fixed lighting can vary from, at one extreme, low-power sources, as found, for example, on roads in housing estates, to highly sophisticated installations on main traffic routes and in city centres.

When driving on poorly lit roads at night it is essential for drivers to use their low beam headlamps. However, when driving on the better lit roads is considered, the question of what is the best type of vehicle front lighting to use is not so easy to answer. Side (or clearance) lamps are inadequate to mark a vehicle and to indicate its movements; on the other hand, low beam headlamps used in such circumstances give little help to the driver and can cause glare to other road users.

There is general agreement in lighting circles that what is required for driving in well-lit areas at night is a 'city light,' having an intensity less than that of a normal low beam headlamp but higher than that of a sidelamp. At the 18th Sessional Meeting of the CIE in London in 1975, a joint committee concerned with visual signalling, road lighting and automobile lighting came to the following conclusion [1]: "It is recommended that a 'town beam' be introduced which is intermediate in intensity between that of the currently used low beam and side lights. Such a light should have a luminous intensity between 50 and 100 cd and should have an area similar to that of current headlights."

In this paper, two systems proposed by the Transport and Road Research Laboratory for realising such a 'town beam' will be described. They are known by the generic name of 'LILAC' (Low Intensity Large Area City Light).

MANUAL SYSTEM ("DIM-DIP")

This system was first proposed in the early 1960's [2]. It consisted of a relay and resistor (value about 1) (fig. 1) which, when introduced into the headlamp circuit (fig. 2), caused the intensity of the low beam headlamps to be reduced to about 10 per cent of the normal value. This reduction is equivalent to an intensity of about 100 cd in the 'straight ahead' direction. The decision to change from reduced intensity to normal intensity (or vice versa) was left to the driver to make. The system was tested in...
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of road. In such circumstances he would have insufficient light to see by and an accident could occur before he realised his error in not switching to normal intensity low beams. To remove the burden of decision making from the driver, the Transport and Road Research Laboratory (TRRL) decided to look into the possibility of developing a system that would automatically respond to variations in the quality of the street lighting. As preliminary tests appeared promising, a contract was entered into with the firm Joseph Lucas Ltd. The contract required the firm to “investigate the feasibility of a system for automatically controlling the intensity of vehicle headlamps.” The system would have to satisfy the following conditions:

1. It must respond to variations in the quality of the fixed street lighting but not to the light from the headlamps of other vehicles or to daylight (to enable the headlamps to be used, if necessary, as “running lights”).

2. The maximum reduction of the intensity of the low beam headlamps must not be less than 10 per cent of the normal full intensity value. This intensity reduction must take place slowly to eliminate the possibility of the system responding to the light from one or two isolated luminaires. The “dimmed” intensity should vary between 10 and 100 per cent of the normal full intensity value, depending on the quality of the ‘good’ street lighting.

3. On leaving a well-lit area and entering a poorly lit or unlit area the headlamps must brighten up at once.

4. The system must not cause the headlamps to brighten up in a well-lit area when encountering isolated unlit luminaires.

AUTOMATIC SYSTEM ("AUTODIM")

An objection to the manual system that was voiced when it was first proposed was that a driver might forget to switch from reduced to normal intensity low beam when entering a poorly lit or even an unlit stretch

Figure 1. Manual system installed in the vehicle.

Figure 2. Circuit diagram for fitting manual system.

a trial in London in 1966, using 800 vehicles [3] but, although there was an encouraging reduction in accidents, the trial was not large enough to produce a statistically significant result. However the trial did show that the system was reliable (no equipment failures were reported) and that the electrical load imposed by the system was not likely to drain the battery.

Design and Installation of Automatic System

An example of a prototype system is shown in figure 3. It consists of a photodiode detector connected by a flying lead to
a metal box that contains the control electronics. The detector is mounted at the top of the windscreen, behind the rear view mirror (fig. 4), within an area swept by the wipers. The metal box is mounted on any convenient metal surface in the vicinity of the dash. Installation in existing vehicles is simple, only four connections having to be made to the vehicle’s electrical system.

A block diagram of the automatic system is shown in figure 5. In order to satisfy the first condition of the automatic control system, a method of discriminating between the light emitted by fixed street lighting luminaires and that emitted by other light sources had to be devised. As the majority of light sources used in street lighting installations are discharge lamps that “flash” at a frequency (100 Hz in Europe) that is twice the frequency of the electricity supply, a solution was found by designing the system so that it only responded to light signals emitted at a frequency of 100 Hz.

Transducer. The transducer uses a silicon photodiode, connected in the short circuit mode, as detector. This mode gives a linear relationship between illuminance and diode current. An AC amplifier and 100 Hz filter remove the DC light component so that the peak-to-peak amplitude of the resultant 100 Hz sinewave can be used as a measure of street lighting quality. Full wave rectification and filtering then gives a DC signal that is proportional to the illuminance from the fixed street lighting.

Time constant and signal processing circuit. The third and fourth conditions ask for conflicting requirements in terms of response speed. Passing from good lighting to poor lighting requires a fast response whilst on the other hand there should be no response at all when a single unlit luminaire is encountered. The second condition can be easily satisfied. A compromise solution to the conflicting requirements of the third and fourth conditions has been effected in the
signal processing circuit by introducing a delay of approximately 2.5 seconds when a reduction in the signal from the transducer occurs. If, after this time, the transducer signal remains low (signifying a genuine reduction in lighting quality), then a fast "bright-up" response occurs. Conversely, if the transducer signal has recovered after the delay period (as in the case of a single unlit luminaire), then the processed signal is allowed to remain at the value that it had before the beginning of the reduction in the transducer signal.

"Loss of 100 Hz" detector. A delay of 2.5 seconds is unacceptable when passing on a high-speed road from a well-lit to an unlit section of road. To cater for this case the system includes a circuit that ensures that the headlamps will revert to their full brightness as soon as the 100 Hz signal is lost.

200 Hz wave generator and comparator. Headlamp intensity is varied in the automatic system by pulsing the headlamp filaments with a variable mark/space ratio 200 Hz waveform. The choice of 200 Hz was made to prevent any optical feedback taking...
place between the light emitted by the head-
lamps and the photodiode. The processed
signal from the time constant and signal
processing circuit provides one of the inputs
to a comparator; the signal from the 200 Hz
triangle wave generator provides the other
input. It is thus possible to generate levels
on the triangular waveform by means of the
processed signal voltage. By limiting the
range of the processed signal the switching
range can be limited to a control band
within which controlled headlamp intensity
is required. This method of operation is
shown in figure 6.

Trial of Automatic System

The contract requires 50 systems to be
provided for design proving, followed by the
supply of 1000 systems which are to be
used in a full-scale trial that will (1) test the
reliability of the system, (2) enable the
subjective opinions of users to be obtained
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and, if possible, (3) assess any safety benefits that might accrue from using the system. At the time this paper was prepared (July 1976) production of the 1,000 units was about to commence. It is intended to fit most of these units to Post Office vehicles based in the London area, fitting to take place during September and October 1976. As the Post Office vehicles work on a 'round the clock' basis this trial should provide a thorough test of the reliability and acceptability of the automatic system. If the trial is successful it is hoped to extend it through the winter of 1977-78 to include accident statistics.

CONCLUSIONS

This paper has described two systems that can be fitted without difficulty to a vehicle to produce a "city light." 1,000 units of the automatic version of 'LILAC' are about to undergo evaluation tests in city traffic conditions. If these tests are successful, it is hoped that the system will be generally adopted as it will provide the optimum vehicle front lighting system for all conditions of night driving, whether on well-lit roads, on poorly lit roads, or on unlit roads.

ACKNOWLEDGMENTS

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. Thanks are also due to Duncan Hodgson and his colleagues at the Lucas Group Research Centre for their work in developing the automatic system.

REFERENCES

SIDE IMPACT RESPONSE AND INJURY

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The University of Michigan

ABSTRACT

This paper presents results from a project studying the side impact response of anthropomorphic test devices and human cadavers. Using a baseline test configuration of a flat rigid wall for initial tests and a contoured, padded surface to simulate a vehicle side interior configuration for subsequent tests, a series of experiments was performed with:

- Unembalmed human cadavers with head, thorax, and pelvis accelerometer instrumentation
- Part 572 test device with head, thorax, and pelvis triaxial accelerometer instrumentation
- Transport and Road Research Laboratory (TRRL) side impact test device with head, thorax, and pelvis triaxial accelerometers as well as shoulder, rib, and pelvis load cells

Comparisons of both the kinematic responses and the accelerometer data of the three types of test subjects are made. In addition, a discussion of the injuries produced in the cadaver tests with respect to test device interpretation is included with emphasis on the development of improved test response specifications.

INTRODUCTION

The subject of side impact injury protection in automobile crashes has received relatively little emphasis when compared to the research conducted on frontal impact protection. This is mainly due to the high priority of protecting vehicle occupants in frontal type crashes. As this goal is approached, attention has been shifted to consideration of the side impact problem. Protection of vehicle occupants sitting on the near side of a vehicle subjected to a side impact presents several difficulties, the major ones being:

- Minimal crush distance to attenuate and control the forces of the crash
- Penetration of the occupant compartment space
- Partial ejection of the occupant through the side windows—thereby allowing interaction with outside objects
- Difficulty of adequate lateral restraint of the occupant by conventional restraint systems

The sequence of events that happen to a near side occupant in a side impact depend somewhat on the seating position relative to the point of impact and upon the geometry of the impacting structure. In the case of an unrestrained occupant seated near the point of impact, the initial acceleration of the vehicle due to the crash is not transmitted to the occupant—instead the vehicle undergoes a velocity change while the unrestrained occupant continues at the velocity he had in that direction at the start of the crash.
Eventually, the side structure of the vehicle (which may be moving toward the occupant due to intrusion) and the occupant meet in a second impact with a relative velocity which depends upon the crash velocity and the rate of intrusion. The forces generated by the impact of the occupant with the side structure depend on their relative velocity and the mechanical properties of both the occupant and the side structure. In many side impacts, the window glazing shatters upon the initial impact and is gone by the time the occupant reaches the side structure of the vehicle. This leads to additional concentration of the occupant impact loads into the thorax since the glazing no longer can serve as a load-bearing surface on the upper portions of the body. The shape of the interior surfaces of the side structure also influences the load distribution developed when the occupant’s body impacts the side structure.

The protection of occupants in side impacts depends primarily upon controlling the magnitude and distribution of impact forces applied to the occupant’s body as the vehicle side structure and the occupant collide. The design of the side structure interior surfaces to achieve this goal depends on a knowledge of the biomechanical characteristics of the human body under lateral impact—particularly of the shoulder, thorax, and pelvis—and the development of test devices based on such knowledge.

MATERIALS AND METHODS

The test subjects used in this study were unembalmed human cadavers, a Part 572 anthropometric test device, and a prototype side impact test device developed by Transport and Road Research Laboratory (TRRL).

Cadaver Test Subjects

The unembalmed human cadavers were stored under refrigeration (5° C) except when being surgically prepared and were allowed to reach room temperature (25° C) prior to testing. Testing took place typically 5 to 7 days post mortem, and the effects of rigor mortis were past at the time of testing. Instrumentation surgically attached to the cadavers included the following:

- An externally mounted array of uniaxial Endevco 2264-2000 piezo-resistive accelerometers on the right side of the head oriented one each in the anterior-posterior (A-P), superior-inferior (S-I) and left-right (L-R) directions
- An array of 10 uniaxial Endevco 2264-2000 accelerometers mounted on the thorax in a manner described in detail by Robbins, et al. [1], consisting of biaxial arrays on the first thoracic vertebra (T1) (A-P and S-I) and the twelfth vertebra (T12) (A-P and L-R) as well as various uniaxial mounts on individual ribs and the sternum
- An externally mounted triaxial array of uniaxial Endevco 2764-2000 accelerometers in the A-P, S-I and L-R directions on the rear of the pelvis in the mid-sagittal plane

All accelerometers were attached in a rigid manner to the bony structures indicated. In addition to the accelerometers, pressure transducers (Kulite miniature piezo-resistive units) were inserted into the trachea and aortic arch to measure airway and vascular system pressures. The vascular system of the cadavers was fluid-filled and the lungs were air-filled; both were pressurized to physiological levels prior to testing. The cadaver test subject data are listed in Table 1 for the

Table 1. Cadaver test subject data

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Age</th>
<th>Sex</th>
<th>Stature</th>
<th>Weight</th>
</tr>
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<td>60</td>
<td>M</td>
<td>181</td>
<td>102.1</td>
</tr>
<tr>
<td>009</td>
<td>75</td>
<td>F</td>
<td>156</td>
<td>44.1</td>
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<tr>
<td>010</td>
<td>84</td>
<td>M</td>
<td>162</td>
<td>87.8</td>
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<tr>
<td>011</td>
<td>69</td>
<td>M</td>
<td>170</td>
<td>74.9</td>
</tr>
<tr>
<td>029</td>
<td>67</td>
<td>M</td>
<td>167</td>
<td>62.5</td>
</tr>
<tr>
<td>039</td>
<td>72</td>
<td>M</td>
<td>187</td>
<td>73.9</td>
</tr>
<tr>
<td>042</td>
<td>58</td>
<td>F</td>
<td>178</td>
<td>64.5</td>
</tr>
</tbody>
</table>
seven cadavers used in this study. The cadavers were clothed in vinyl exercise suits to minimize moisture loss and then suited in cotton thermal underwear to provide an appropriate outer surface for testing.

Part 572 Test Subject

The Part 572 anthropometric test device used in the study was instrumented with triaxial arrays of uniaxial Endevco 2264-2000 accelerometers mounted internally in the required head, thorax, and pelvic locations. The dummy was suited in the same type of cotton thermal underwear as the cadavers.

TRRL Test Subject

The TRRL side impact test device was instrumented with triaxial arrays of uniaxial Endevco 2264-2000 accelerometers in the head, thorax, and pelvis in the same manner as the Part 572 dummy. In addition, this test device features load cells built into various of the side structures of the dummy. The load cells are contained in the shoulder, the four individual ribs which comprise the thorax, the iliac crest, and the hip. The details of this design can be found in the paper of Harris [2]. A notable feature of the device is the absence of arms—the shoulder load cells take their place. This dummy was also suited in cotton thermal underwear for the tests.

Test Methods

All tests in this study were performed at the Highway Safety Research Institute (HSRI) Impact Sled Facility. The sled is a deceleration sled which operates on the rebound principle. Since the tests were to simulate an unrestrained vehicle occupant in a side impact, the test technique utilized a test fixture consisting of a rigid bench seat mounted in a side impact configuration on the sled with a rigid wall structure representing the side of the vehicle at the left end of the seat. The test subject was placed a predetermined distance from the impact surface such that the subject was free to trans- late along the seat during the sled deceleration and impact the surface only after the sled deceleration had terminated. This technique produced an impact situation in which the test subject and the impact surface came together at the desired relative impact velocity while allowing the test subject decelerations to be determined solely by the interaction between the subject and the impact surface rather than the sled deceleration profile. Three test relative velocities were used—25, 33, and 43 km/h—designated low, medium, and high velocities, respectively. In addition, a special low velocity (16 km/h) test was performed on the TRRL dummy only.

The impact surface configurations consisted of a flat rigid wall and a contoured energy-absorbing structure. The flat wall buck configuration (shown in fig. 1) was constructed of one-inch plywood backed by

Figure 1. Test set up configuration for rigid wall impact tests.
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Channel Class 1000; thorax and pelvis accelerations - Channel Class 180; and load cells - Channel Class 600.

Test Subject Kinematics

During the phase of the test when the test subject is sliding towards the impact surface, all three types of test subjects behaved similarly and exhibited uniform translation of the body with no relative motion of body parts. As soon as impact with the side structure begins, each type of test subject starts to exhibit individual impact behavior unique to the structural characteristics of the subject. The differences were most marked in the rigid wall impact tests. In the case of the Part 572 dummy, the side of the torso contacts the wall and then deforms slightly due to the low compliance of the dummy internal structure. This is quite pronounced in the shoulder region where the shoulder linkage transmits the forces directly to the base of the neck and thereby starts the head to rotate toward the wall. The resulting lateral flexion of the neck rotates the head almost horizontally, but the shoulder structure does not let the head fully contact the wall—it barely grazes it at the higher test velocities. With the TRRL dummy, the lack of arms allows the head to be much closer to the wall and thus the head contacts the wall more directly, although only after lateral neck flexion on the order of 30 to 45 degrees occurs.

The cadaver subjects exhibited a completely different head-neck response in the rigid wall tests. The shoulder linkage of the cadaver displaced laterally with little apparent resistance and the head-neck system does not undergo appreciable lateral flexion. The result is that the head strikes the wall in an upright position and the loads are carried by the lower parietal and temporal bone regions.

For the case of the padded structure impacts, the differences in head-neck response diminished somewhat due to the spacing of the torso impact surface away from the wall. The highly compliant cadaver shoulder structure still reduces the lateral neck flexion and allows head contact with
the wall but the contact is more onto the parietal bone region. It should be noted that the shoulder bones were not broken or dislocated in any of the tests.

The general motions of the rest of the body below the shoulders were similar in all three types of test subjects. The pelvis region tended to rebound first followed by the thoracic region—leading to a marked tendency of the subject to rotate out of the seat in a counterclockwise manner.

Head Impact Response

The results of the head accelerometer peak readings are summarized in table 2. The lower acceleration values of the Part 572 dummy in all the tests are attributable to the lack of lateral shoulder compliance and its effect on head kinematics as discussed above. The lack of arms on the TRRL dummy allowed head impacts more like those produced with the cadavers to take place. Direct comparison of the A-P and S-I values between cadaver and dummies is questionable due to the external mounting of the accelerometers on the cadaver head. In those cases where skull fracture took place, it can be expected that high peak values may occur in various directions depending on fracture patterns.

Thorax Impact Response

The results of the thorax accelerometer peak readings are summarized in table 3. Due to the different accelerometer placement on the cadaver thorax, a direct comparison of transducers is not possible. The A-P and S-I values were taken from the biaxial accelerometer pair mounted on the first thoracic vertebra (T1) while the L-R values were taken from a uniaxial accelerometer mounted on the fourth rib on the right-hand side of the body (opposite the impacted side). Comparison of the L-R peaks in the rigid impacts shows that the values produced in the cadaver thorax were generally comparable to those obtained in the Part 572 dummy, while the TRRL dummy gave lower values. It is of interest to note that in the low velocity rigid test, the suggested tolerance

<table>
<thead>
<tr>
<th>Table 2. Head peak accelerations (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a. Rigid wall impact tests</strong></td>
</tr>
<tr>
<td>Low velocity</td>
</tr>
<tr>
<td><strong>Subject</strong></td>
</tr>
<tr>
<td>Test No.</td>
</tr>
<tr>
<td>A-P</td>
</tr>
<tr>
<td>S-I</td>
</tr>
<tr>
<td>L-R</td>
</tr>
<tr>
<td><strong>b. Padded side structure tests</strong></td>
</tr>
<tr>
<td>Low velocity</td>
</tr>
<tr>
<td><strong>Subject</strong></td>
</tr>
<tr>
<td>Test No.</td>
</tr>
<tr>
<td>A-P</td>
</tr>
<tr>
<td>S-I</td>
</tr>
<tr>
<td>L-R</td>
</tr>
</tbody>
</table>
Table 3. Thorax peak accelerations (g)

<table>
<thead>
<tr>
<th>a. Rigid wall impact tests</th>
<th>Low velocity</th>
<th>Medium velocity</th>
<th>High velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>CAD 572</td>
<td>TRRL CAD 572</td>
<td>TRRL CAD 572</td>
</tr>
<tr>
<td>Test No.</td>
<td>003 012 016</td>
<td>010 011 013 014</td>
<td>017 009 015</td>
</tr>
<tr>
<td>A-P</td>
<td>73 15 5</td>
<td>56 95 17 18</td>
<td>42 100 40</td>
</tr>
<tr>
<td>S-I</td>
<td>196 18 16</td>
<td>107 81 35 22</td>
<td>42 96 84</td>
</tr>
<tr>
<td>L-R</td>
<td>82 61 42</td>
<td>120 149 139 147</td>
<td>89 150 162</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b. Padded side structure tests</th>
<th>Low velocity</th>
<th>Medium velocity</th>
<th>High velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>CAD 572</td>
<td>TRRL CAD 572</td>
<td>TRRL CAD 572</td>
</tr>
<tr>
<td>Test No.</td>
<td>029 028 045</td>
<td>039 043 030 042</td>
<td>044 046</td>
</tr>
<tr>
<td>A-P</td>
<td>14 5 5</td>
<td>25 4 11</td>
<td>44 14 13</td>
</tr>
<tr>
<td>S-I</td>
<td>24 8 5</td>
<td>37 12 7</td>
<td>51 24 26</td>
</tr>
<tr>
<td>L-R</td>
<td>56 28 37</td>
<td>19 102 40</td>
<td>175 145 88</td>
</tr>
</tbody>
</table>

Table 4. Pelvis peak accelerations (g)

<table>
<thead>
<tr>
<th>a. Rigid wall impact tests</th>
<th>Low velocity</th>
<th>Medium velocity</th>
<th>High velocity</th>
</tr>
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<tr>
<td>Subject</td>
<td>CAD 572</td>
<td>TRRL CAD 572</td>
<td>TRRL CAD 572</td>
</tr>
<tr>
<td>Test No.</td>
<td>003 012 016</td>
<td>010 011 013 014</td>
<td>017 009 015</td>
</tr>
<tr>
<td>A-P</td>
<td>22 10 3</td>
<td>41 – 21 24</td>
<td>28 54 42</td>
</tr>
<tr>
<td>S-I</td>
<td>65 14 93</td>
<td>63 70 63 47</td>
<td>96 47 61</td>
</tr>
<tr>
<td>L-R</td>
<td>53 60 49</td>
<td>70 149 286 278</td>
<td>147 279 379</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b. Padded side structure tests</th>
<th>Low velocity</th>
<th>Medium velocity</th>
<th>High velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>CAD 572</td>
<td>TRRL CAD 572</td>
<td>TRRL CAD 572</td>
</tr>
<tr>
<td>Test No.</td>
<td>029 028 045</td>
<td>039 043 030 042</td>
<td>044 046</td>
</tr>
<tr>
<td>A-P</td>
<td>42 3 4</td>
<td>7 7 – 35 9</td>
<td>23</td>
</tr>
<tr>
<td>S-I</td>
<td>20 5 6</td>
<td>19 15 – 43 35</td>
<td>43</td>
</tr>
<tr>
<td>L-R</td>
<td>78 28 34</td>
<td>39 44 – 106 121</td>
<td>74</td>
</tr>
</tbody>
</table>
level of FMVSS 208 was exceeded by the cadaver and the Part 572 dummy and closely approached by the TRRL dummy, while in the padded low velocity test, only the cadaver exceeded the 45g level.

Pelvis Impact Response

The results of the pelvis accelerometer peak readings are summarized in table 4. The external placement of the accelerometers on the cadaver pelvis is most likely the cause of the large differences which appear in the A-P and S-I values when comparing the cadaver values to the dummy values. The L-R values are, for the most part, quite comparable in both the rigid wall and padded structure tests. The exception to this is the low velocity padded test.

TRRL Dummy Load Cell Response

The peak readings of the various load cells of the TRRL dummy are listed in table 5.

Table 5. TRRL dummy peak load cell values (kN)

<table>
<thead>
<tr>
<th></th>
<th>a. Rigid wall impact tests</th>
<th>b. Padded side structure tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test No.</td>
<td>109[^a] 016 017</td>
<td>030 044 046</td>
</tr>
<tr>
<td>Left shoulder</td>
<td>9.79 19.06 –</td>
<td>0.32 0.16 1.01</td>
</tr>
<tr>
<td>Left rib 1</td>
<td>0.36 0.70 1.91</td>
<td>3.10 2.09 4.49</td>
</tr>
<tr>
<td>Left rib 2</td>
<td>0.52 1.04 2.18</td>
<td>2.99 1.98 3.02</td>
</tr>
<tr>
<td>Left rib 3</td>
<td>0.28 0.44 1.05</td>
<td>1.84 0.47 2.41</td>
</tr>
<tr>
<td>Left rib 4</td>
<td>0.37 0.65 0.77</td>
<td>0.32 0.32 0.18</td>
</tr>
<tr>
<td>Left iliac</td>
<td>16.69 – –</td>
<td>1.28 – –</td>
</tr>
<tr>
<td>Left hip</td>
<td>1.17 5.22 4.70</td>
<td>10.07 2.71 10.85</td>
</tr>
</tbody>
</table>

[^a]Special low speed (16 km/h) test.

The missing data in the table are due to either malfunctioning transducers or overload conditions. In the rigid wall tests, some ringing of the rib load cells was noted. The padding configuration in the energy-absorbing side structure tests was such that the shoulder load cell did not come into full contact with the padding, thereby producing low readings. The special low speed (16 km/h) test was necessary due to load cell overload in the rigid wall tests at the medium velocity level.

Cadaver Injury Ratings

The injuries sustained by the cadavers in the various rigid wall impact tests are listed in table 6 along with the assessments of the Abbreviated Injury Scale (AIS) ratings of the injuries. The moderate injuries sustained in the 25-km/h impact escalate sharply at the 33-km/h level indicating that in rigid wall impacts the AIS 3 level is most likely reached in the 28 to 30 km/h velocity range. The severity of the injuries at the 43-km/h level point out the serious need to manage the occupant kinetic energy in impacts at velocities considerably lower than those associated with frontal crashes.

The results of the injuries sustained in the padded structure tests are given in table 7. Although the severity of the injuries was reduced at the high velocity in comparison to the rigid wall test, the padded structure did not change the injury level of the thorax at the medium velocity and actually raised it slightly in the low velocity test. The padded structure did help to reduce head injuries in the low and medium test velocities even though the head hit the wall in the medium velocity test.

Some insight into the factors affecting injury production in the padded side structures can be gained by examining the resulting deformation patterns in the energy-absorbing materials used in the structures. The Part 572 dummy consistently produced larger penetrations of the thorax padding and in the medium- and high-velocity tests most likely bottomed the foam out (that is, completely penetrated it)—yet the deformations were more localized. This
Table 6. Cadaver injury summary—rigid wall impact tests

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Body part</th>
<th>Injuries</th>
<th>AIS rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>003 25 km/h</td>
<td>Thorax</td>
<td>Left side—minor rib fracture directly under fourth rib accelerometer mount</td>
<td>2</td>
</tr>
<tr>
<td>010 33 km/h</td>
<td>Head</td>
<td>Superficial bruising of brain at the base of the frontal lobe</td>
<td>4/5</td>
</tr>
<tr>
<td></td>
<td>Thorax</td>
<td>Left side—fractures of ribs 1-8 in front and 3 and 4 in rear</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right side—fractures of ribs 1-5 in front</td>
<td></td>
</tr>
<tr>
<td>011 33 km/h</td>
<td>Head</td>
<td>Depressed fracture of the left side of the skull, free blood in the cavity right side: subarachnoid hemorrhage left side: frontal lobe hemorrhage</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Thorax</td>
<td>Left side—fractures of ribs 2, 3, 4, 5, 6, 7, and 9</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right side—fractures of ribs 2-6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spinal dislocation between C4/C5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Abdomen</td>
<td>Liver—small tear on surface</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spleen—crushed</td>
<td></td>
</tr>
<tr>
<td>009 43 km/h</td>
<td>Head</td>
<td>Left side—massive depressed skull fractures and extensive hemorrhaging in scalp, muscle, and dura mater</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Neck</td>
<td>Cervical spine fractures at C1 and dislocation between C2/C3</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Thorax</td>
<td>Left side—15 rib fractures in front and 11 rib fractures in rear</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Right side—13 rib fractures in front and 2 rib fractures in rear</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 cm tear of left lung with free blood</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 cm tear of pulmonary artery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Abdomen</td>
<td>Crushed left kidney</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Pelvis</td>
<td>Left side iliac crest crushed severely with soft tissue damage</td>
<td>5</td>
</tr>
</tbody>
</table>

was due to the rigidity of the arm structure which penetrated the foam at load levels lower than the more distributed loading on the side of the cadaver thorax. In fact, the TRRL dummy with no arms produced thorax padding similar to those of the cadavers.

An additional feature was noted in the deformations of the pelvis honeycomb padding. The cadaver tests tended to produce crushing distributed along the honeycomb in contrast to the more localized crushing associated with the pelvis and knees of the dummies. This behavior may be due to the more concentrated masses of the dummy pelvis and knee structures as opposed to the more evenly distributed soft tissue masses of the cadavers.

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Table 7. Cadaver injury summary—padded side structure tests

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Body part</th>
<th>Injuries</th>
<th>AIS rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>029</td>
<td>Thorax</td>
<td>Left side—4 rib fractures</td>
<td>3</td>
</tr>
<tr>
<td>039</td>
<td>Thorax</td>
<td>Left side—11 rib fractures, very slight surface hemorrhage on heart</td>
<td>4</td>
</tr>
<tr>
<td>042</td>
<td>Head</td>
<td>Left side—massive depressed skull fracture with fractures extending to the right side. Extensive hemorrhage over the right temporal and parietal lobes of the brain</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Thorax</td>
<td>Left side—12 rib fractures, Mid-shaft fracture of left humerus</td>
<td>4</td>
</tr>
</tbody>
</table>

SUMMARY AND CONCLUSIONS

A series of comparative side impact tests using unembalmed human cadavers, a Part 572 test device and the TRRL side impact test device has been presented in brief. The results of the program indicate the following:

- Significant differences in head-neck kinematics exist in the side impact behaviors of the three types of test subjects—the lack of lateral compliance of the shoulder structure in dummies contributes to this effect.
- The peak responses of the thorax accelerometers were similar in the three types of test subjects, but the resulting injuries in the limited cadaver test sample did not correlate well with suggested tolerance levels for lateral acceleration.
- The peak responses of the pelvis accelerometers were similar for the three types of test subjects.
- The differences between dummy and cadavers in lateral compliance of the shoulder and arm structures and in the distribution of masses in the lower body must be considered in the design of energy-absorbing side impact structures.

ACKNOWLEDGMENTS

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REFERENCES

Contribution to Defining a Tolerance Level for a Laterally Impacted Human Head

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ABSTRACT

The authors report on a series of head impacts carried out on fresh cadavers, the head being hit after a free fall. The heads were naked or protected.

The injury analysis compares the measurements and the usual protection criteria.

Similar tests were carried out on dummies’ heads to determine values for protection criteria of such impacts.

The problems raised by the interpretation of measurements when they are made directly upon the human subject’s head, are discussed.

METHODOLOGY

The series of tests carried out are all under conditions of free fall and come under three categories:

- Free fall of helmeted or nonhelmeted cadavers
- Free fall of Hybrid II anthropomorphic dummy head
- Free fall of light alloy metallic headform

In all the reported cases, the head, whether helmeted or not, struck a flat rigid surface. The height of the fall and the helmet differ; the desired point of impact of

Figure 1a. Compared falls of dummy head and cadavers.
the head was invariably the same and corresponded to the lower part of the parietal bone near the temporal bone on the human head (fig. 1a). The resulting impact was assimilated to a lateral impact where data concerning human tolerance are rare; it is generally assumed that the tolerance to the lateral impact of the head is lower than the tolerance to impact on the frontal bone; this has been verified with the level of the efforts needed to obtain fracture.

The helmets used are available on the French market. The cross-section of these helmets is shown in figure 1b. They were selected for their wide diffusion on the market and, in particular, for the presence of shock-absorbing material of relatively considerable thickness in the impact zone selected.

The “A” type helmet has 20 mm of expanded polystyrene with a density of 22 g/l near to the point of impact. The polystyrene extends to the entire upper section of the helmet. The external shell is in Acrylo-Butyl-tylene (A.B.S.).

Figure 1b. Cross section of tested helmets—Type B.
Local cuts in the helmets had to be made to enable accelerometers to be mounted, although no cuts were ever made in the impact zone.

The human subjects consisted of fresh cadavers, not embalmed, tested less than four days after death, having been preserved in a cold room between 0 and 2 degrees C. They were withdrawn from the cold room several hours before the tests.

The subjects were installed prone in a rigid metal cradle, with the head and top of the shoulders protruding. The head was held in alignment until impact with an appropriate device.

On impact, the head struck a flat rigid surface, while the motion of the cradle was dampened by a thick mattress of shock-absorbing material, the height of which was adjusted (as a result of preliminary tests) in such a way that the kinematics did not result in a neck motion of excessive amplitude.

The circulatory system was kept pressurized during the tests and for a few seconds after it by the method described in references [1] and [2]. The injected liquid, consisting of a mixture of formol water and India ink, made it possible, in the event of the bursting of a blood vessel even of minimum extent, to detect the spreading of the “blood” under microscopic examination of the brain fixed by the formol. In this way, a fine “read out” of the cerebral lesions that may occur was obtained, supplementing the conventional autopsy. In contrast to the procedure of [1], the perfusion liquid was injected directly into the aorta.

After the tests, the heads and necks were weighed; the sections retained were those used by L.B. Walker [3].

The anthropometric characteristics are grouped together in table 1.

Accelerometers were mounted on the heads of the subjects (fig. 2). These accelerometers were secured to metal plates screwed into the skull. On the right temple, on the side of the skull opposite the impact, a triaxial accelerometer was mounted. A bi-axial accelerometer was mounted on the forehead, giving a transverse component with relation to the head and a vertical component. On the occiput, a biaxial accelerometer was mounted resulting in a transverse component to the head and a longitudinal component.

It was not possible to mount the accelerometers in strictly the same position for each test with relation to conventional anatomical reference points [4] that situate the centre of gravity. The reasons for this can be ascribed to the extension of the frontal sinuses, anthropometrical differences in the heads, and so forth.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Age/sex</th>
<th>Circumference (mm)</th>
<th>Breadth (mm)</th>
<th>Length (mm)</th>
<th>Head and neck mass (kg)</th>
<th>Head mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>78 F</td>
<td>541</td>
<td>150</td>
<td>182</td>
<td>4.020</td>
<td>3.280</td>
</tr>
<tr>
<td>64</td>
<td>59 M</td>
<td>548</td>
<td>145</td>
<td>192</td>
<td>4.860</td>
<td>3.920</td>
</tr>
<tr>
<td>65</td>
<td>57 M</td>
<td>571</td>
<td>155</td>
<td>194</td>
<td>5.020</td>
<td>4.230</td>
</tr>
<tr>
<td>66</td>
<td>82 F</td>
<td>539</td>
<td>145</td>
<td>182</td>
<td>3.560</td>
<td>2.920</td>
</tr>
<tr>
<td>67</td>
<td>82 F</td>
<td>554</td>
<td>141</td>
<td>182</td>
<td>4.430</td>
<td>3.340</td>
</tr>
<tr>
<td>68</td>
<td>49 F</td>
<td>556</td>
<td>145</td>
<td>184</td>
<td>5.160</td>
<td>3.820</td>
</tr>
<tr>
<td>69</td>
<td>71 M</td>
<td>585</td>
<td>156</td>
<td>202</td>
<td>4.700</td>
<td>3.810</td>
</tr>
<tr>
<td>70</td>
<td>68 M</td>
<td>548</td>
<td>141</td>
<td>192</td>
<td>4.580</td>
<td>3.560</td>
</tr>
<tr>
<td>73</td>
<td>55 F</td>
<td>560</td>
<td>140</td>
<td>175</td>
<td>4.780</td>
<td>3.680</td>
</tr>
<tr>
<td>74</td>
<td>74 M</td>
<td>565</td>
<td>135</td>
<td>180</td>
<td>5.220</td>
<td>3.640</td>
</tr>
<tr>
<td>76</td>
<td>65 M</td>
<td>550</td>
<td>140</td>
<td>192</td>
<td>4.290</td>
<td>3.450</td>
</tr>
</tbody>
</table>
The position of the accelerometers was recorded for each test for subsequent use of the data.

The measuring systems as a whole comply with the requirements of Federal Motor Vehicle Safety Standards (FMVSS) 208/SAE J 211 b for the head.

Free falls of the head of the anthropomorphic dummy were induced in conjunction with tests of the human subjects wearing the same helmets and falling from the same height.

The head was that of a Hybrid II dummy equipped with instruments in accordance with the specifications of FMVSS 208/SAE J 211 b. The neck of the dummy is present and the unit weighs 5.304 kg without the helmet.

The purpose of these tests was to obtain values of the protection criteria derived from the measured acceleration such as the severity index SI [5] and the Head Injury Criterion (HIC) for head impacts of the dummy commonly used today, comparable to those undergone by human subjects.

We considered that the impacts of the head of the human subjects would be better reproduced by dropping the dummy's head alone than by dropping the complete dummy, owing to the considerable rigidity of the dummy's neck, compared to the neck of subjects under the test conditions. This point will be specified by subsequent tests.

Free falls of light alloy headforms supplement the previous tests. Light alloy headforms with low resonance are, in fact, commonly used in testing helmets; they have no surfacing as does a Hybrid II head and consequently have higher accelerations for the same impact, but the same weight.

Furthermore, by adjusting the distribution of the ballast, we have caused the centre of gravity of the unit to coincide with the position of the triaxial accelerometer used; the point of impact and the centre of gravity lie on the same vertical line.

The kinematics obtained, therefore, more closely approximate simple transverse motion; the offset of the sensor is small and the acceleration measured is exempt from causes of attenuation.

The dropping heights were 1.83 m in the first series and then 2.50 m in the second. 1.83 m corresponds to the falling height required for helmet tests under American legislation. 2.50 m corresponds to a higher severity that appeared necessary following the satisfactory results of the first series.

All the tests of human subjects and most of the other tests were filmed by Stalex cameras at 1000 frames per second.

RESULTS

Tests with Human Subjects

Anatomical-Pathological Results. The significance of the results achieved depends on
Figure 3. Test No. 69 (1776 B)—Dropping height: 1.83 m, with helmet, transversal section of the brain. Good injection of the capillaries in the white and in the grey matter. No rupture.

Figure 4. Test No. 65 (1774 B)—Dropping height: 1.83 m, with helmet. Hematoxylin-phloxin stain—capillary injection without damage to the vessels. Vascular cavities are filled with carbon particles. No lesion (field: 1.8 X 1.2 mm).
the validity of cerebral lesion risk evaluation for subjects submitted to experimentation. This evaluation is based on autopsy results (search for skull fractures and macroscopic lesions of cerebral tissue) and the search for microscopic lesions that would result from fine ruptures of capillaries with liquid extravasation in cerebral tissues. It is for these histological researches that the setting up of a mean vascular pressure and the recourse to carbon particles as lesion indicators show their usefulness.

**Histological Results.** Some accompanying figures make it possible to illustrate aspects which may be considered either normal (figs. 3 and 4) or pathologic (figs. 5-8). It must be made clear that it has been quite impossible, up to this date, to define with certainty the degree of severity which some subnormal aspects would show for actually injured people. The answer is obvious in the case of severe lesions that might be serious or fatal. This is the case of lesions observed on subject 76. It is difficult, however, to establish the severity of a minor injury (very limited effusion around a capillary rupture) since, owing to the fact that injured occupants fortunately survive minor cerebral lesions, it cannot be made clear which objective traces are associated with slight concussions with loss of consciousness not exceeding half an hour. There exists such a case in our sample; it is subject 64, for which we think that an AIS of 2 would be probable for a living subject (table 2). There is no blinking the fact that the evaluation of cerebral lesions observed on cadavers in terms of lesion severity for a living subject expressed according to an

![Figure 5. Test No. 76 (1767 B')—Dropping height: 2.50 m, without helmet. Pontine transversal section (millimetric scale)—fatal injuries: the India ink spot indicates a rupture of vessels in the right postero-lateral part of the brain stem. Between this lesion and the fourth ventricle, a grey zone of capillary injection without vascular rupture. The greatest part of the section in white corresponding to the injection at the arteriolar level only.](image-url)
Figure 6. Test No. 76 (1772 D)—Same section as figure 3 with higher magnification of the capillary injection (field = 3.3 × 2.2 mm).

Figure 7. Test No. 76 (1772 C)—Dark patch produced by the accumulation of India ink outside the ruptured vessels.
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Figure 8. Test No. 69 (1781 B)—Hematoxylin-phloxin stain. Carbon particles outside the vessels in a damaged zone (field 1.8 X 1.2 mm).

Table 2. Summary of cerebral examinations

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Dropping height</th>
<th>Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>1.83</td>
<td>No apparent lesion in the vertebro-basiliar area, although the injection was not perfect.</td>
</tr>
<tr>
<td>64</td>
<td>1.83</td>
<td>Minor lesions - AIS 2 probable for a living subject.</td>
</tr>
<tr>
<td>65</td>
<td>1.83</td>
<td>The former state of the brain is the cause of the minor damage observed.</td>
</tr>
<tr>
<td>66</td>
<td>1.83</td>
<td>No lesion.</td>
</tr>
<tr>
<td>67</td>
<td>1.83</td>
<td>Probably no lesion, but the injection was not perfect in the peripheric carotidian area.</td>
</tr>
<tr>
<td>69</td>
<td>2.50</td>
<td>No lesion with binocular lens examination. Two small &quot;bleedings&quot; of India ink in the brain stem.</td>
</tr>
<tr>
<td>70</td>
<td>2.50</td>
<td>No lesion.</td>
</tr>
<tr>
<td>73</td>
<td>2.50</td>
<td>No apparent lesion, although the injection was not perfect in the right antero-cerebral area.</td>
</tr>
<tr>
<td>74</td>
<td>2.50</td>
<td>Lesions of minor extent by volume, but severe due to their location at cerebral trunk level (probable coma).</td>
</tr>
<tr>
<td>68</td>
<td>no helmet)</td>
<td>Minor fracture of the skull (the failure of the injection into the deep brain structures does not allow the detection of possible cerebral lesions).</td>
</tr>
<tr>
<td>69</td>
<td>1.83</td>
<td>Minor fracture of the skull (the failure of the injection into the deep brain structures does not allow the detection of possible cerebral lesions).</td>
</tr>
<tr>
<td>76</td>
<td>no helmet)</td>
<td>Very large fracture of the skull and fatal cerebral lesions (rupture of the callus corpus and cerebral trunk lesion).</td>
</tr>
</tbody>
</table>

Note: Some subjects being quite old, one might think that their cerebral tolerance to impact has diminished though no objective data are available concerning arterial and capillary weakness caused by age.
AIS scale can be only very rough since the classification is based mainly on the duration of unconsciousness. There should be described the cerebral organic lesions connected with the various levels of unconsciousness, lesions likely to be observed on the cadaver. This work is still to be done, and animal experimentation might contribute to it.1

Interpretation of Histological Results. In the absence of vascular rupture, carbon particles are visible only in arterioles and capillaries (figs. 3 and 4). In case of a rupture occurring in meningeal vessels, the leak is easily visible, by macroscopy as well as by microscopy. Assuming that the rupture is intra-parenchymateous, the injected mixture percolates into Virchow-Robin sheaths and makes up a pigmented carbon casing around small arteries. One can see such aspects on figures 7 and 8.

When the lesion is severe, the blood vessel leakage may be seen by macroscopic means (figs. 5 and 9).

One can only be absolutely certain that no lesions have occurred, if the vascular injection technique has succeeded perfectly, which does not occur on every subject.

It can be concluded that with the helmets tested, dropped up to a height of 2.50 m, serious lesions were only revealed in a single case, number 74, out of the 9 subjects wearing helmets.

Without a helmet, one finds very severe injuries in test number 76: rupture of corpus collosum and important hemorrhages in the internal faces of the temporal structures (fig. 9) and in the brain-stem (fig. 5). Such

---

1 Such works are now underway in France on the behalf of the Committee of Common Market Constructors (CCMC).

Figure 9. Test No. 76 (1767 G)—One can see four lesions on this brain cut in coronal plane through the marmillary bodies. The main lesion is in the middle part of the corpus collosum; others are visible above the right marmillary body and in the grey matter of the parahippocampal gyrus on both sides.
injuries are considered as fatal. They are found in the deep structures, remote from the impact area on the skull.

In the other test without helmet (test number 68), the failure of the injection into the deep brain structures did not allow the detection of any possible cerebral lesion.

**Skull Fractures.** No skull fracture could be observed in all tests with helmeted subjects. In both tests performed without a helmet, a minor fracture happened at a drop height of 1.83 m (test number 68) and a very severe skull fracture at 2.50 m (test number 76).

**Synthesis of Anatomical-Pathological Results.** Synthesis of anatomical-pathological results is shortly presented in table 2.

**Results of Measurements.** A dropping height of 2.50 m only corresponds to an impact speed of about 25 km/h, but the variation in the speed of the head is higher in view of “bounce” which varies depending on the test. One can estimate the mean value at the head of ΔV as 30 km/h, in the vertical direction.

The results of measurements are shown in table 3.

The period during which speed variation is undergone is about 15 ms; the HIC values have been calculated for durations of from 4 to 6.5 ms. The SI and HIC values must be considered in function of the measuring point used to calculate them, which was indicated previously. The head rotations during impact change the accelerations measured on its periphery; this phenomenon is distinct for Gz accelerations (parallel to the vertical axis of the head) which are increased considerably when passing from the measuring point on the forehead to the measuring point on the right temple.

Having said this, a relatively low Gx-acceleration results in a relatively small rotation around the vertical axis of the head. For such tests, the SI and HIC values calculated are close to those which would have been attained from a measuring point coinciding with the centre of gravity of the head and close to those obtained on the head of a dummy subjected to the same kinematics.

Except for subject number 74, which we shall consider later, the heads of the helmeted subjects revealed $I$ values of about 1000 to 2500, accompanied with HIC values of 800 to 2100.

The highest values are for subject number 66, the head and neck combination of which was the lightest of all.

Subject number 74 underwent exceptional values (HIC > 2300). This is the only helmeted subject among our sample suffering notable lesions after the autopsy (AIS ≥ 3).

---

**Table 3. Summary of measurements on human subjects**

<table>
<thead>
<tr>
<th>Test No</th>
<th>Height of fall (m)</th>
<th>Helmet</th>
<th>Right side of head</th>
<th>Frontal Bone</th>
<th>Occipital Bone</th>
<th>2 frontal components</th>
<th>2 frontal comp. t + Gx component from occiput</th>
<th>2 occipital comp. + Gx component from frontal bone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Gx)</td>
<td>(Gy)</td>
<td>(Gz)</td>
<td>(Gx)</td>
<td>(Gy)</td>
<td>(Gz)</td>
</tr>
<tr>
<td>63</td>
<td>1.83</td>
<td>A</td>
<td>50</td>
<td>380</td>
<td>215</td>
<td>--</td>
<td>150</td>
<td>--</td>
</tr>
<tr>
<td>64</td>
<td>1.83</td>
<td>A</td>
<td>35</td>
<td>190</td>
<td>125</td>
<td>120</td>
<td>136</td>
<td>165</td>
</tr>
<tr>
<td>65</td>
<td>1.83</td>
<td>A</td>
<td>88</td>
<td>200</td>
<td>150</td>
<td>126</td>
<td>126</td>
<td>175</td>
</tr>
<tr>
<td>66</td>
<td>1.83</td>
<td>B</td>
<td>58</td>
<td>240</td>
<td>175</td>
<td>225</td>
<td>170</td>
<td>240</td>
</tr>
<tr>
<td>67</td>
<td>1.83</td>
<td>B</td>
<td>90</td>
<td>400</td>
<td>170</td>
<td>165</td>
<td>160</td>
<td>210</td>
</tr>
<tr>
<td>69</td>
<td>2.50</td>
<td>A</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>70</td>
<td>2.50</td>
<td>A</td>
<td>33</td>
<td>160</td>
<td>130</td>
<td>110</td>
<td>120</td>
<td>160</td>
</tr>
<tr>
<td>73</td>
<td>2.50</td>
<td>B</td>
<td>65</td>
<td>290</td>
<td>240</td>
<td>105</td>
<td>220</td>
<td>240</td>
</tr>
<tr>
<td>74</td>
<td>2.50</td>
<td>B</td>
<td>40</td>
<td>370</td>
<td>160</td>
<td>450</td>
<td>275</td>
<td>52</td>
</tr>
<tr>
<td>68</td>
<td>1.83</td>
<td>NO</td>
<td>&gt;500</td>
<td>&gt;500</td>
<td>&gt;500</td>
<td>&gt;7000</td>
<td>&gt;7000</td>
<td>&gt;7000</td>
</tr>
<tr>
<td>76</td>
<td>2.50</td>
<td>NO</td>
<td>&gt;500</td>
<td>&gt;500</td>
<td>&gt;500</td>
<td>&gt;6000</td>
<td>&gt;6000</td>
<td>&gt;6000</td>
</tr>
</tbody>
</table>

Rt: Maximum Resultant
The interpretation must allow for one particularity of the test: this is the subject the head of whom was inclined the most to the horizontal at the moment of impact (40°). Allowing for the technology of the helmet used (type B), the dampening of the impact in the vertical direction of the head has been insufficient. This explains the very high vertical acceleration values recorded and their importance compared to the transverse accelerations.

According to the method used to detect cerebral lesions, one has to consider that the head impact tolerance has been exceeded in this case, which differs from other cases of the sample by the paramount magnitude of Gz acceleration (370 g and 450 g measured by 2 transducers at different locations).

In this series of fairly lengthy lateral impacts (thanks to the dampening materials in the helmets), high SI and HIC values could be reached without noticing lesions; an HIC of 1.500 was exceeded twice.

Without a helmet, fractures of the skull occurred in the two tests carried out, together with very high HIC values.

Tests with the Head of a Dummy

These have enabled us to draw up table 4. These results express lower accelerations than during comparable tests with human subjects. The kinematics of the sensors is, however, not exactly the same. For example, if we consider the previous test number 66 with its counterpart above (Helmet B, 1.83 m), the vertical rebound velocity observed on the films in the alignment of the accelerometers is about 2.5 m/s for subject number 66 (frontal sensors) and 1.5 m/s for the Hybrid II head. One should allow for the difference in the weights in order to explain this lower rebound speed.

These results, therefore, do not reveal a lower tolerance as measured on the dummy, (but the test imposed on this dummy head was less severe for the cases reported here.) For all other types of test imposed on a human subject and an anthropomorphical dummy under identical conditions, the conclusions concerning the comparison of severities might be different.

Tests with the Metal Heads

Comparable falls give the following results for the “B” helmets (table 5).

Changing from the head of Hybrid II to the metal head results in an increase in the acceleration levels measured. This evidence is confirmed by the results of tests made with other types of helmets, not published here.

Note — These three types of impacts leave a lasting print on the dampening material of the helmet, evidencing the violence of the impact. An example of this can be seen on the section of “B” helmet shown on figure 1b.

DISCUSSION

It has been shown in the foregoing that SI and HIC values going over 2100 could be supported without indication of notable lesions—even microscopic ones. This has been established for impacts on the side of the head with a helmet which avoids excessive pressions.

Table 4. Results of tests with a dummy head

<table>
<thead>
<tr>
<th>Helmet</th>
<th>Peak accelerations (g)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gx (AP)</td>
<td>Gy (RL)</td>
<td>Gz (SI)</td>
<td>R</td>
<td>Gadd index</td>
</tr>
<tr>
<td>A ........... 1.83m</td>
<td>12</td>
<td>132</td>
<td>63</td>
<td>135</td>
<td>800</td>
</tr>
<tr>
<td>A (modified) 2.50m</td>
<td>31</td>
<td>196</td>
<td>53</td>
<td>211</td>
<td>1873</td>
</tr>
<tr>
<td>B ........... 1.83m</td>
<td>19</td>
<td>118</td>
<td>71</td>
<td>138</td>
<td>791</td>
</tr>
<tr>
<td>B (modified) 2.50m</td>
<td>9</td>
<td>140</td>
<td>97</td>
<td>170</td>
<td>1453</td>
</tr>
</tbody>
</table>
These impacts last about 15 ms and the corresponding HIC have been calculated on a 4 to 6.5 ms time interval.

Validity and range of application must be pointed out.

On concern of lesions detection, one can be certain of the absence of fracture and of gross trauma. There is either no microscopic injuries when injection was able to include the entire cranial territory and that there was no lesion before.

The study of table 2 shows that few risks are taken when supposing the absence of lesions other than minor ones.

The results of the range of application can be discussed in terms of the role of the helmet on the impact duration and the impacted area on the head.

A padded helmet protects against fracture like a padded steering wheel hub, like a padding for B-pillar, like a laminated windshield and any device which increases the impact duration. One can use the indicated tolerance levels in case of head impact against each of such pieces, against dashboards, in case of a pedestrian head hitting a hood, so far as impact duration exceeds a sufficient value such as 12 ms; the impact of a head which hits at 22 km/h a B-pillar covered by a 40 mm padding exceeds 20 ms; the impact of a pedestrian head at 32 km/h against a hood may be 15 ms long.

Rather than impact duration, it would be more practical to use a minimum HIC computation duration, such as 4 ms from our tests.

In the case of impacts of helmeted subjects against a flat and rigid surface, the durations of calculation intervals are shorter, comprised between 4 and 6.5 ms. This interval briefness can be explained by the relative purity of the impact without rotation, thus without deceleration of the head before impact. We think, however, that these results may be extended to longer HIC calculation intervals. To support this statement, the most essential results concerning a series of tests carried out with fresh cadavers have been already published [2]. These works showed the absence of severe brain tissue lesions and of fractures for HIC reaching about 2200 on human subjects (with or without head impacts); the length of the intervals for which the HIC are calculated vary between 14 and 54 ms.

In some tests, further to the failure of experimental restraint systems, some subjects were submitted to very severe head impacts causing very serious injuries. The corresponding HIC's were about 1700, 2000 and 3500 for human subjects, for time intervals of 44, 21 and 10 ms.

Figure 10 shows a synthesis of available results that must include most of the accidents involving pedestrians, cyclists and motorcyclists and the occupants of vehicles involved in head-on or lateral crashes.

Considering these results one can conclude that, to our present state of knowledge, a HIC of 1500 can be reckoned a satisfactory performance criterion ensuring head protection in case of a frontal or lateral impact.

**CONCLUSION**

On the basis of these first results obtained from human subjects experiments, it appears that certain current helmets protect against skull fracture and cerebral lesions in impacts on the lateral head, face up, to at least 2.5 m dropping height.

The main fact lies in the level of probable
head tolerances in terms of SI and HIC. In fact, for HIC above 2100 on human subjects, the following statements have been allowed:

- Absence of fractures and severe cerebral lesions and, more generally, of any macroscopical lesion
- Absence of microscopical lesions such as arterioles or cerebral capillaries rupture in all correctly injected territories

The test conditions are applicable in any situation when the impact duration is over approximately 12 ms, which, in fact, covers the impact conditions most frequently observed in real crash conditions.

These results, which confirm those obtained from belt restraint tests with or without head impact [2, 7] lead us to propose a HIC of 1500 as a protection criterion in a frontal or lateral head impact during tests conducted with Hybrid II dummies.

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Influence of Intrusion In Side Impact

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Organisme National de Securite Routiere Laboratoire des Chocs et de Biomecanique

ABSTRACT

The results of the bidisciplinary accident investigation indicate that the frequency of side impact accidents is high (20 percent of car accidents) and especially that they are more serious than other accidents.

The first part of the study shows that the severity of injuries increases with intrusion, especially for occupants seated on the impacted side.

In the second part, the results of car-to-car side impact crashes, with and without intrusion, are analysed. It is shown that nonintrusion, because of stiffened side steel plates, decreases the accelerations and forces exerted on struck car dummies, while not appreciably increasing those applied on the restrained dummies in striking cars.

This leads us to think that it is possible to reduce the severity of side impact accidents by preventing intrusion.

Since early 1970, the Impact Research Laboratory of the French National Highway Safety Organisation has been carrying out a bidisciplinary investigation on highway accidents occurring in the Lyon area. [1] In 1972, a second team was set up at Salon-de-Provence (near Marseille), to work in cooperation with the local hospital.

STUDY OF SIDE IMPACT ACCIDENTS

The 743 cases investigated by these teams gave the distribution according the different types of impact indicated in table 1. The high frequency of lateral impacts tallies with other results published, particularly in Europe and Australia. [2, 3]

Figure 1 enables one to compare the severity of injuries (AIS) [4] in all accidents with that of the side impacts. It will be noticed that if the variations have a generally comparable shape, slight differences exist, such as:

- The variation curve relation to lateral impact cases is above the curve of all types of accidents for AIS values from 2 to 4.
- The severity of side impact accidents is higher than that of other accidents. Thus we find no injuries in 21.67 percent of

1 Research reported in this paper is being carried out under the sponsorship of the Ministere de l'Equipement et du Logement—Direction des Routes et de la Circulation Routiere—Paris (France).
Table 1. Test results—parameters recorded on the cars

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Impact speed (km/h)</th>
<th>Impacted area displacement (cm)</th>
<th>Deformation or intrusion$^a$ (cm)</th>
<th>Impact duration (ms)</th>
<th>Average resultant acceleration (g)</th>
<th>Maximum resultant acceleration (g)</th>
<th>Belt forces shoulder anchorage (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Striking car</td>
<td>51</td>
<td>0</td>
<td>25</td>
<td>110</td>
<td>9</td>
<td>29.5</td>
<td>5 250</td>
</tr>
<tr>
<td>Struck car (without shield)</td>
<td>0</td>
<td>–</td>
<td>30</td>
<td>110</td>
<td>12.5</td>
<td>37</td>
<td>–</td>
</tr>
<tr>
<td>2. Striking car</td>
<td>54</td>
<td>–10</td>
<td>24</td>
<td>100.3</td>
<td>11.2</td>
<td>25</td>
<td>7 500</td>
</tr>
<tr>
<td>Struck car (with the shield)</td>
<td>0</td>
<td>–</td>
<td>0</td>
<td>100.3</td>
<td>13.5</td>
<td>35</td>
<td>–</td>
</tr>
<tr>
<td>3. Striking car</td>
<td>42</td>
<td>–</td>
<td>15</td>
<td>93.2</td>
<td>7.6</td>
<td>14</td>
<td>3 500</td>
</tr>
<tr>
<td>Struck car (without shield)</td>
<td>42</td>
<td>–10</td>
<td>31</td>
<td>93.2</td>
<td>7.9</td>
<td>14</td>
<td>–</td>
</tr>
<tr>
<td>4. Striking car</td>
<td>39</td>
<td>–</td>
<td>20</td>
<td>130</td>
<td>5.5</td>
<td>18</td>
<td>–</td>
</tr>
<tr>
<td>Struck car (with the shield)</td>
<td>39</td>
<td>+25</td>
<td>0</td>
<td>130</td>
<td>8.5</td>
<td>29.5</td>
<td>–</td>
</tr>
<tr>
<td>5. Striking car</td>
<td>51</td>
<td>–</td>
<td>16</td>
<td>120</td>
<td>8.1</td>
<td>16</td>
<td>4 800</td>
</tr>
<tr>
<td>Struck car (without shield)</td>
<td>51</td>
<td>+20</td>
<td>35</td>
<td>120</td>
<td>8.3</td>
<td>25</td>
<td>–</td>
</tr>
<tr>
<td>6. Striking car</td>
<td>51</td>
<td>–</td>
<td>15</td>
<td>130</td>
<td>6.5</td>
<td>30</td>
<td>4 900</td>
</tr>
<tr>
<td>Struck car (with the shield)</td>
<td>51</td>
<td>–15</td>
<td>0</td>
<td>130</td>
<td>11.5</td>
<td>47</td>
<td>–</td>
</tr>
</tbody>
</table>

$^a$Deformation of the striking car—intrusion of the struck car.

NOTE. + indicates that the impacted area was displaced to the front of the struck car.
- indicates the opposite.

Figure 1. Severity of side impacts compared with all accidents.

The lateral impacts, whereas there are injuries in 31.6 percent of them. Also, lateral impacts caused 12.50 percent of the fatalities in this type of accident, whereas the overall figure for fatalities in all accidents is only 5.7 percent.

MAIN FEATURES OF THESE ACCIDENTS

The vehicles included in this study met three criteria:

- The main forces bearing on the vehicle during impact had to be more transversal than longitudinal (impact directions 02, 03, 04 and 08, 09, 10). [5]
- The impacted area had to be the lateral structure of the car.
- Only car-to-car accidents were considered.
For this study, 66 accidents were selected according to the criteria defined above. The struck vehicles were divided as follows: 55 passenger cars, seven trucks, and four vans. In 32 of the vehicles concerned, the driver was alone; in the other 34 cases, there were at least two people in each vehicle. Distribution of seating was as follows:

- Front left—66 people
- Front right—33 people
- Rear left—10 people
- Rear right—11 people

for a total of 120 occupants. Only eight drivers and two front-seat passengers were wearing belts during the accidents.

Thirty-three vehicles were struck on the right flank, 33 on the left. Impact directions were as follows:

- 2 o’clock—5 vehicles (right side)
- 3 o’clock—28 vehicles (impact—33 vehicles)
- 4 o’clock—0 vehicle (33 vehicles)
- 8 o’clock—3 vehicles (left side)
- 9 o’clock—24 vehicles (impact—33 vehicles)
- 10 o’clock—6 vehicles (33 vehicles)

Figure 2 illustrates the distribution of points of impact. 4 areas were considered:

- First zone—from the front to the A pillar
- Second zone—from A pillar to B pillar (or the front half of the body for two-door vehicles)
- Third zone—from B pillar to C pillar (or the rear half of the body for two-door vehicles)
- Fourth zone—to the rear of C pillar

The figure shows that the front half was clearly more involved than the rear. The passenger compartment area was involved in 55 impacts out of 66, particularly the front half.

**INJURY TYPOLOGY**

Figure 3 compares the frequency of injuries of each body segment in lateral impacts with that of accidents as a whole. Significant differences can be noticed for the pelvis and the vertebral column, which are more frequently involved in side impacts. On the other hand, lower limbs are affected much less frequently.

**INFLUENCE OF INTRUSION**

A previous study [6] demonstrated that there exists an increasing relation between the intensity of distortion of struck vehicles and the seriousness of the injuries incurred by the occupant. To study the influence of intrusion, we must consider separately the occupants on the impact side (who are close to the buckled wall) and those on the other side.

Influence of Intrusion on the Occupants on the Impact Side

Figure 4 gives the severity (AIS) in connection with Vehicle Interior Deformation Index (VIDI) column 7 value [7], significant parameter of intrusion. This graph shows that severity increases with intrusion.

Figure 5 indicates that:

- Up to a VIDI 2, none of the occupants were seriously injured. (AIS 3)
- From a VIDI 2 on, the risk of death became greater and increased with the VIDI values.
Figure 3. Frequency of injured body segments.

- From a VIDI 3 on, all occupants were injured.

The interaction of occupants in lateral impact may have two consequences:

- To increase the seriousness of injuries for the occupant on the side of impact caused

Figure 4. Correlation between intrusion and severity of injuries.

Figure 5. Distribution of severity of injuries versus intrusion.

- Occupant with a neighbour
- Occupant without a neighbour
SECTION 4: TECHNICAL SEMINARS

by the projection of the occupant next to him.

- To lessen the seriousness of injuries for the occupant seated opposite the impact because his neighbor will receive the brunt of the impact.

Influence of Intrusion on Occupants Seated on the Side Opposite the Impact

When the occupant is alone, the distortion resulting from intrusion seldom touches him. When there are two occupants, those seated on the opposite side of impact are protected by their neighbor (fig. 6).

CAR-TO-CAR EXPERIMENTAL CRASHES

A previous study [6] demonstrated experimentally that the violence of a lateral impact depended on the struck area, especially when the point of impact was located on the passenger side of the car. The distortion caused by intrusion was deeper and the severity of injuries increased with intrusion. Also, the severity of injuries to the passenger seated on the impacted side was higher.

In this accident configuration, it was difficult to distinguish the part of intrusion or of kinetic energy in the severity of injuries. To complete this preliminary study, we had to examine the effects of stiffening the sides of the struck vehicle and analyse the influence of this stiffening on the occupants of the striking car.

Crash Methodology

In order to compare the influence of intrusion, two types of tests were carried out. Half of the tests were conducted on standard model cars. Similar tests (of speed and impacted areas) were made preventing intrusion, enabling us to study its influence.

Test Device—the Steel Shield. The struck vehicle was a standard model. On its left flank a rectangular shield was attached to the car at six points and placed 1.2 inches (3 cm) from the outer face of the left side. This shield covered the area between A pillar and C pillar (fig. 7). It is composed of a 2-mm thick steel sheet, made rigid by a mechanically soldered structure of square tubes. Its sizes are 2 m X 0.65 m. Otherwise, the vehicle is not modified and the original doors are kept.

Test Conditions. In each case, the test was made the first time using standard model cars, then repeated with the protection shield. The trajectory of the striking vehicle was supposed to pass through point H of the driver of the struck vehicle. Three types of tests were conducted:

- The struck vehicle was stationary whereas the striking vehicle impacted it at 40 km/h.
- Each vehicle was moving at 40 km/h at the moment of impact.
- Each vehicle was moving at 50 km/h at the moment of impact.

For all the tests, dummies were placed in the drivers' seats in the struck cars and two...
dummies in the front seats of the striking cars. All the dummies were 50-percentile ONSER models, secured by 3-point safety belts.

In the course of each test, the following measurements were recorded:

- In the striking car:
  - Acceleration in three directions on the floor
  - Strain near the three fixture points of the belt securing the front passenger
  - Accelerations of the head and thorax on the front passenger dummy
- In the struck car:
  - Acceleration in three directions on the floor
  - Accelerations of the head and thorax on the driver dummy
  - Transversal and longitudinal accelerations of the pelvis
  - Compressive force on the clavicle

Four high speed cameras on the ground and one overhead filmed the trajectories of the vehicles. Two car-borne cameras (one on each vehicle) were used to study the kinematics of the struck car dummy.

Six tests (three with a shield, and three without) were conducted following the procedures defined above.

Test Results

The results of these crashes are listed in tables 1 and 2. The chest acceleration charts of the struck car driver dummy will be found in figure 8.
### Table 2. Test results—parameters recorded on the dummies

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Impact speed</th>
<th>Head</th>
<th>Chest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(km/h)</td>
<td>Maximum resultant acceleration</td>
<td>Maximum resultant acceleration</td>
</tr>
<tr>
<td></td>
<td>(g)</td>
<td>HIC</td>
<td>(g)</td>
</tr>
<tr>
<td>1. Striking car</td>
<td>51</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Struck car (without shield)</td>
<td>0</td>
<td>65.5</td>
<td>209</td>
</tr>
<tr>
<td>2. Striking car</td>
<td>54</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Struck car (with the shield)</td>
<td>0</td>
<td>a146</td>
<td>a654</td>
</tr>
<tr>
<td>3. Striking car</td>
<td>42</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Struck car (without shield)</td>
<td>42</td>
<td>80.5</td>
<td>425</td>
</tr>
<tr>
<td>4. Striking car</td>
<td>39</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Struck car (with the shield)</td>
<td>39</td>
<td>60</td>
<td>125</td>
</tr>
<tr>
<td>5. Striking car</td>
<td>51</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Struck car (without shield)</td>
<td>51</td>
<td>135.6</td>
<td>790</td>
</tr>
<tr>
<td>6. Striking car</td>
<td>51</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Struck car (with the shield)</td>
<td>51</td>
<td>60.5</td>
<td>158</td>
</tr>
</tbody>
</table>

*aThese high values are associated with a head impact against the B pillar.
NOTE. Struck car data recorded on the driver dummy (impacted side); striking cars, on right front passenger dummy.

**Striking Car Results.** The deformations were not extensive even when the shield was impacted. The passenger compartment was never distorted (figs. 9 and 10). Decelerations recorded on the floor were low and the shield did not change either the shape of the trace or the maximal value. The maximal and average resultant values were, in all cases, clearly lower than those recorded during frontal crashes.

**Struck Car Results.** Intrusion increases with speed when the impacted car is not fitted with a shield; for a similar speed it is quite the same if the struck car is stationary or moving (fig. 11). The shield prevents intrusion even in case of highest speeds (54 km/h) (fig. 12). Accelerations recorded on the floor increase when the shield is there but average resultant values are still low: 13.5 g during the crash conducted at 54 km/h.

In tests conducted with two standard cars, the intrusion enables a joined motion of both cars. On the other hand, the shield
Figure 8. Chest resultant accelerations (struck car driver) for tests 1-4.

Figure 9. Striking car—test No. 5 (without the shield).
allows the swipe of the striking front-end car on the protected side of the struck car and the break-out of both vehicles. At the finish of impact, the stiff shield pushed the struck car away, releasing its elastic energy.

Results on the Driver Dummy in the Struck Car. The analysis of high speed films established that without a shield, in every case, left front door distortions impacted the dummy before it started to move.

Head accelerations and HIC values decreased when the shield was used, as in tests 3, 4, and 5, 6. For the two other tests (1 and 2) the HIC values was higher in the test with the shield but the analysis of the films showed a direct impact of the dummy's head against the B pillar. All HIC values were lower than 1000.

Chest accelerations and SI values were also lessened when the shield was used. During the two tests in which both cars were moving, the presence of the shield divided roughly by two the maximal values of chest accelerations. In all the tests conducted with a shield, these values were lower than the values for chest tolerance, whereas in two of the three tests without the shield, the maximal chest acceleration values were higher than the tolerance limits.
Figure 11. Struck car—test No. 5.

Figure 12. Struck car—test No. 6.
SECTION 4: TECHNICAL SEMINARS

Clavicle of the dummy in the struck car were measured in four out of six crashes. The highest maximal value was obtained for test No. 5. The value was much higher than those for tests with the shield, but it remained below the suggested tolerance value of 5 kN [9]. This value, determined with another dummy model, can be used only as a reference. Transversal pelvis maximal accelerations were very low during tests with the shield and should correspond to very tolerable compressive loads.

As for the chest accelerations, the maximal values of transversal pelvis accelerations were reduced to half when the shield was used. However, the value obtained from test No. 5 (two cars moving at 51 mi/h without shields) was high (23 g) and if we suppose that one-third of the load due to dummy weight was balanced by the impact of the pelvis against the inner door, the compressive load associated with this acceleration value is higher than the suggested tolerance limits of the pelvis, which is 5 kN [10].

DISCUSSION OF TEST RESULTS

The tests conducted with the shield show that preventing intrusion increased the maximal values of accelerations undergone by the struck car more than those recorded on the striking car. The average values of these accelerations were always low because of the translation motion of the struck car during the impact. This motion allowed long stopping distances and lengthened the duration of the impact. This statement agrees with the conclusions of Severy et al. [11]. The struck car stiffness increased the decelerations of the striking car occupants and at the same time the loads exerted on them by the 3-point seatbelt.

The recorded values were still below what is thought to be the permissible limits. In the struck car, the shield appeared to lessen the accelerations and the loads undergone by the occupant. All injury criteria of the dummies seated on the impact side of the struck car had values below human tolerance limits, even for the more serious impact that was conducted at 54 km/h against a stationary car. This speed was much higher than the one proposed for future standard crash test in side impacts [10]. Without the shield, the distortion caused by intrusion hit the occupant seated on the impacted side. That is why loads, accelerations, and injury criteria were higher than those recorded with the shield and generally higher than the proposed tolerance values for frontal impacts; moreover, human tolerance to side impacts is probably lower than to frontal impact [12].

CONCLUSIONS

The severity of side impact accidents is higher than the severity of other accidents. The analysis of side impact accidents shows that the severity of injury to the occupants on the impacted side is higher than that of the opposite side occupants.

The severity of injuries is higher when the intrusion hits the occupant directly. Tests conducted with standard cars show that intrusion directly impacts the occupant before he starts to move. This direct hit, occurring at a speed close to the impact speed, explains the bad effect of intrusion. Avoiding intrusion (tests with the shield) decreases the risk of severe injuries at speeds up to 50 km/h.

It would seem that the control of intrusion so as not to hit the occupant would be an important countermeasure in the protection of occupants involved in side impact accidents.

Control of lateral intrusion can be obtained by putting stiff side structures at the same height as the stiff frontal area.

Inside lateral padding can increase the occupants' protection by damping the occupant as he hits the inside structure.

Stiffening of the struck car does not decrease the protection of the striking car occupants; the use of conventional safety belts would be sufficient to enhance their safety.

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Columbus Laboratories

ABSTRACT

The objective of the study described in this paper is to experimentally assess the pedestrian injury reduction potential of the front end of the Calspan RSV. A series of 16 experimental pedestrian impacts were conducted using an experimental set up and procedure developed in an earlier program. The test series consisted of impacts with two representative U.S. production vehicles (a 1974 Impala and a 1974 Vega) and the Calspan RSV—performance with both adult and 6-year-old child dummies was evaluated over a 20-25 mi/h speed range. Preliminary results indicate that acceleration levels of the head, chest, pelvis, and knee for both the adult and child dummies are significantly reduced (on the order of 50 percent) in impacts with the RSV. Major gains are indicated in reducing the acceleration of the pelvis and leg areas due to the inherent compliance of the RSV bumper. Based on the tentative results of this study, it appears that the injury attenuation performance of the RSV might increase the permissible impact velocity for a given level of injury by as much as 5 to 10 mi/h.

INTRODUCTION

One of the design objectives of the U.S. Research Safety Vehicle (RSV) program is
the development of pedestrian injury reduction features for the front end of small vehicles. The purpose of the program described in this paper is to experimentally compare the pedestrian injury performance of the Calspan RSV with that of two representative production vehicles. This program, consisting of a series of 16 experimental pedestrian impacts, was conducted as part of an ongoing National Highway Traffic Safety Administration (NHTSA) contract entitled “Pedestrian Impacts: Baseline and Preliminary Concepts Evaluation.” The experimental set up and procedures used were largely developed in prior studies dating back to 1972. As a result, the methodology is of a proven quantity and baseline data from previous tests are directly useable in making comparisons. It should be noted that although the experimental portion of the investigation of the Calspan RSV is complete, the data reduction and analysis is still in progress and the results presented herein should be considered preliminary. It should also be noted that a similar experiment and analysis sequence will be conducted on the Minicar RSV as soon as pertinent vehicle components can be obtained.

Pending further analysis, it appears that the Calspan RSV offers significant potential for improvements in pedestrian impact protection. For some parameters, the acceleration levels measured for RSV impacts involving adult and child dummies were less than half those obtained with representative production vehicles.

EXPERIMENTAL APPROACH

The experimental technique developed to investigate pedestrian/vehicle impact severity resulting from both current production (baseline) vehicles and potential injury minimization concepts (in this instance the Calspan RSV) is illustrated in figure 1. A 24-inch HYGE crash simulator is used as a velocity generator to propel the vehicle(s) mounted on the sled into the standing pedestrians. To enhance A to B comparisons and/or improve test economics, the high payload capacity of the 24-inch HYGE can be capitalized on by conducting two separate vehicle/pedestrian impacts simultaneously. The HYGE can, of course, be programmed for any desired sled impact velocity and, by adjusting the brake system on the sled, representative actual vehicle braking rates can be obtained. While either (a) specially developed standing 50th-percentile adult and 6-year-old child dummies or (b) unembalmed cadavers may be used as pedestrian surrogates, only the dummies were utilized in this particular study. Figure 2 illustrates the typical dummy position and stance. The initial set up conditions used in this program involve positioning the surrogate with a minimum of 80 percent of the body weight on the leg nearest the vehicle. This position is representative of a walking mode and may be either lateral (walking across path of the vehicle) or frontal (facing the vehicle). The dummies are essentially free-standing objects held in position by joint muscle tone settings on the order of 1 to 2 g’s. This overall approach then, provides for representative vehicle/pedestrian orientation, excellent test repeatability, realistic ground reaction forces, and representative impact dynamics ranging from the initial contact, followed by upper body contact with the hood/windshield and finally ground contact as the dummy leaves the vehicle.

Because the ground contact environment in real world accidents is a very uncontrollable and widely scoped parameter, emphasis in this study has been placed on attenuating the pedestrian/vehicle contact phase only.
Impala representing a full-size vehicle, and four with a 1974 Chevrolet Vega representing a compact vehicle, were conducted. The test vehicles impacted the pedestrian at two speeds, 20 and 25 mi/h, and with a normal (that is, .5 g) braking rate. In this series, all impacts with the Impala and Vega were conducted with the dummy in the frontal stance.

**RSV TEST VEHICLE DESCRIPTION**

The test buck was constructed from components provided by Chrysler Corporation and by Calspan Corporation. Due to the unavailability from the source of a complete front end "assembly," some adaptive modifications were required in the hood and cowling areas. The hood provided was fabricated of aluminum in the standard Simca configuration and, therefore, deviated somewhat from that which may be on the RSV. Based on discussions with Chrysler personnel, a representative modification was made to the hood and a cowling was added. An additional modification was the addition of a simulated engine valve cover beneath the hood to provide representative hood bottoming conditions.

**DATA ACQUISITION REQUIREMENTS**

The primary data acquisition requirements were as follows:

- Adult dummy accelerometer channels

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Speed (mi/h)</th>
<th>Vehicle A</th>
<th>Dummy</th>
<th>Stance</th>
<th>Vehicle B</th>
<th>Dummy</th>
<th>Stance</th>
</tr>
</thead>
<tbody>
<tr>
<td>S11</td>
<td>20</td>
<td>RSV</td>
<td>Child</td>
<td>Frontal</td>
<td>Impala</td>
<td>Adult</td>
<td>Frontal</td>
</tr>
<tr>
<td>S12</td>
<td>20</td>
<td>RSV</td>
<td>Adult</td>
<td>Frontal</td>
<td>Impala</td>
<td>Child</td>
<td>Frontal</td>
</tr>
<tr>
<td>S13</td>
<td>25</td>
<td>RSV</td>
<td>Adult</td>
<td>Frontal</td>
<td>Impala</td>
<td>Child</td>
<td>Frontal</td>
</tr>
<tr>
<td>S14</td>
<td>25</td>
<td>RSV</td>
<td>Child</td>
<td>Frontal</td>
<td>Impala</td>
<td>Adult</td>
<td>Frontal</td>
</tr>
<tr>
<td>S15</td>
<td>20</td>
<td>RSV</td>
<td>Child</td>
<td>Lateral</td>
<td>Vega</td>
<td>Adult</td>
<td>Frontal</td>
</tr>
<tr>
<td>S16</td>
<td>20</td>
<td>RSV</td>
<td>Adult</td>
<td>Lateral</td>
<td>Vega</td>
<td>Child</td>
<td>Frontal</td>
</tr>
<tr>
<td>S17</td>
<td>25</td>
<td>RSV</td>
<td>Adult</td>
<td>Lateral</td>
<td>Vega</td>
<td>Child</td>
<td>Frontal</td>
</tr>
<tr>
<td>S18</td>
<td>25</td>
<td>RSV</td>
<td>Child</td>
<td>Lateral</td>
<td>Vega</td>
<td>Adult</td>
<td>Frontal</td>
</tr>
</tbody>
</table>

*Frontal stance—dummy faces the vehicle head on. Lateral stance—dummy is positioned as though walking across the street in front of the vehicle.*
### SECTION 4: TECHNICAL SEMINARS

<table>
<thead>
<tr>
<th>Location</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>9</td>
</tr>
<tr>
<td>Chest</td>
<td>3</td>
</tr>
<tr>
<td>Pelvis</td>
<td>3</td>
</tr>
<tr>
<td>Knee</td>
<td>3</td>
</tr>
<tr>
<td>Foot</td>
<td>3</td>
</tr>
</tbody>
</table>

- Bumper displacement/time at RSV center-line (impact point)
- High-speed camera coverage—four on-board and three off-board
- Graph check (Polaroid) sequence camera—two oblique shots, both off-board

### EXPERIMENTAL RESULTS

The gross trajectories of the adult and 6-year-old child during the impact sequence are shown for two of the tests in figures 3 and 4. From these figures it can be seen that the adult is impacted initially well below the center of gravity, rotates forward onto the

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**Figure 3.** Impact sequence for experiment S16: RSV/adult—Vega/6-year-old—20 mi/h.
Figure 4. Impact sequence for experiment-S18: RSV/6-year-old Vega/adult—25 mi/h.

Figure 5. Adult peak resultant head acceleration versus vehicle velocity.
SECTION 4: TECHNICAL SEMINARS

Figure 6. Adult Gadd severity index versus vehicle velocity.

hood, and rides with the vehicle for some period of time. The child is impacted initially much higher on the body, very close to the center of gravity, and is essentially propelled forward of the vehicle. These basic motions are true in general for all three vehicles investigated.

It has been necessary due to time limitations to concentrate this discussion primarily on resultant acceleration values for the vehicle impact portion of the event. The complete analysis is still in progress and will, of course, be reported more fully at a later date. It is anticipated that this future effort will include a quantitative motion analysis of the high-speed film to measure (1) impact penetrations of the body and (2) exit/rebound body velocity and orientation for use in inferring ground impact severity for the adult dummy.

Shown in the following figures are peak resultant head, chest, pelvis, and knee accelerations and head severity indices during vehicle contact plotted as a function of vehicle velocity at impact. Data are indicated for three vehicles, an Impala, a Vega, and the RSV, and for both lateral and frontal impact stances of the dummies. In reviewing the trend lines in figures 5 to 9, which pertain to the adult, it is clear that significant reductions in acceleration levels were obtained with the RSV as compared to the baseline vehicles particularly in the head and knee area and to some extent in the pelvic region. The peak head acceleration, figure 5, is greatly reduced with the RSV impacts, especially in the frontal impact stance. As expected, the head impact with the hood is the most severe part of the vehicle impact phase and produces the greatest injury. This is shown in figure 6 where the Gadd severity index values range upward to 4 000. It is to be noted that for the four RSV/adult experiments the range is from 300 to 1 500. The adult chest accelerations (see fig. 7) change very little with the three vehicles and the levels are reasonably low.

It is anticipated that a noticeable reduc-
Figure 7. Adult peak resultant chest acceleration versus vehicle velocity.

Figure 8. Adult peak resultant pelvis acceleration versus vehicle velocity.

which suggested that 40-50 g’s is an injury threshold. Thus it is possible that the RSV as shown in figure 8 would produce only minimal pelvic injuries during vehicle contact in the speed range up to approximately 22 mi/h. Similarly it is expected that significant reductions in vehicle contact induced leg

injury severity (see fig. 9) would result if bumpers were softened as in the RSV. Again, utilizing results from the earlier investigation of cadaver impacts the acceleration levels recorded in the knee for the RSV impacts are below that of potential or preliminary indicators of the tolerance level.

One general comment on the effect of initial stance should be made. It is apparent that this effect, frontal or lateral, is most pronounced for the head/hood impacts and in general more severe for the frontal than the lateral. It is suggested that this difference be investigated further as the results may be strongly influenced by the shoulder and neck design of current dummies.

Figures 10 to 14 indicate the peak resultant accelerations and severity indices for the experiments conducted with the 6-year-old child dummy. Here too it is apparent that the acceleration levels are generally lower for the RSV tests than that of the baseline impacts. In regard to child head accelerations, the values recorded (see fig. 10) were quite similar to the baseline vehicles and quite severe above 20 mi/h. While the RSV/child frontal stance acceleration levels are much lower than those measured with the Vega/frontal stance impacts, this drastic reduction in acceleration levels must be tempered when the resulting severity index values are compared as shown in figure 11. As indicated in figure 11, all of the child dummy Gadd severity indices were above 1000 for speeds above 20 mi/h. As noted previously, the area of the vehicle where the child head impacts occur is one that required some modification in adapting the

Figure 9. Adult peak resultant knee acceleration versus vehicle velocity.
RSV parts furnished to the subject. Experimental set up performances of an unmodified RSV may be somewhat different.

Based on the subject experiments the most potential benefit for the child is (as indicated by figs. 12-14) in the chest, pelvis, and knee areas. The chest acceleration levels in figure 12, for example, suggest that a 5 mi/h improvement in tolerance may be possible with the RSV. The child pelvis accelerations, figure 13, were considerably reduced for the RSV as compared to the Vega impacts. The child knee accelerations,
and the ground contact acceleration levels are that the ground impact for the 6-year-old dummy is very severe and quite similar for both the RSV and the production vehicles.

CONCLUSIONS

Based on preliminary analysis of the results of this project task aimed at comparing the pedestrian injury performance of the Calspan RSV to two baseline vehicles, four major tentative conclusions can be drawn at this time.

Adult Pedestrian Protection

- The RSV (as tested) produced (a) much lower peak acceleration and severity index levels (that is, reductions on the order of 50 percent) for the head and knee and (b) comparable to 50 percent improvement for the chest and pelvis values.
- Based on the slope of the severity/impact velocity trend lines, it is possible that the level of attenuation provided by the RSV could increase the tolerable impact velocity by a very noteworthy 5 to 10 mi/h.

Child Pedestrian Protection

- In terms of accelerations of the chest, pelvis, and knee for the vehicle impact portion of the total event, the RSV produced reductions of up to 75 percent.
- Initial review of the ground impact severity measures indicates that these values are very similar for the RSV and the baseline vehicles.

Additional data, conclusions, and findings for this study will be included in the final report for the ongoing major project, of which this study was one task.
Research and Development Towards Improved Protection for Pedestrians Struck by Cars

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ABSTRACT

In Great Britain in 1974, approximately 40 per cent of all fatal road casualties were pedestrians. Accidents between cars and pedestrians accounted for approximately 70 per cent of all these casualties and this paper considers features of car front end design that may reduce the frequency and severity of injury.

Results of car impact tests on pedestrian dummies representing adults and 6-year-old children are given, and these data are related to information obtained from accident investigations.

It is concluded that wherever possible, a pedestrian should be projected to come to rest on the bonnet rather than knocked down in front of the car or thrown over the bonnet or roof to the ground.

A low-mounted, energy-absorbing bumper and an energy-absorbing bonnet leading edge with crush characteristics matched to appropriate human tolerance levels, could accelerate a pedestrian to the velocity of the impacting car with less injury from the initial impact than occurring with existing designs.

Fatal and other head injuries from vehicle impact may be reduced by ensuring head impact with the bonnet rather than the windscreen surround. Preliminary design parameters for providing these features are discussed.

INTRODUCTION

In Great Britain in 1974, 2,642 pedestrians were killed and 21,029 were seriously injured in road accidents [1]. These represent nearly 40 per cent of all the fatalities and 25 per cent of all the seriously injured casualties. This paper examines how changes in car design may reduce the number and severity of pedestrian injuries.

Summaries are given of relevant United Kingdom national accident statistics and more detailed accident injury data. Car-to-dummy pedestrian impact test results are discussed and tentative conclusions are drawn in relation to the pedestrian injury potential of various car frontal layouts.

This work forms part of the United Kingdom programme on pedestrian protection and is aimed at drawing together other results from accident investigations, detailed impact testing, and computer simulation of this impact problem.

ACCIDENT STATISTICS IN GREAT BRITAIN

Vehicles

The vehicles involved in single vehicle accidents with pedestrians may be broadly divided into the three groups, as shown in table 1.

<table>
<thead>
<tr>
<th>Vehicles</th>
<th>Pedestrian casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatal</td>
</tr>
<tr>
<td>Two wheeled</td>
<td>6</td>
</tr>
<tr>
<td>Public service and goods</td>
<td>22</td>
</tr>
<tr>
<td>Cars and taxis</td>
<td>65</td>
</tr>
</tbody>
</table>

Source: National data obtained from police.

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Generally, the shapes of the vehicles in any group are so different from those in other groups that different solutions for reducing pedestrian injury will be required for each type of vehicle.

This paper considers only the design of cars causing, as shown in table 1, approximately 70 per cent of the serious and fatal pedestrian casualties.

Pedestrians

In Great Britain there are two distinct age groups of pedestrians at risk. Adults 60 years old and over account for approximately 50 per cent of the fatally injured pedestrians, and children 14 years and under comprise 50 per cent of the seriously injured cases. [2]

Any change in vehicle design must, therefore, consider the requirements of both the child and the adult pedestrian.

ACCIDENT INVESTIGATION

Accident studies [3] have shown that in 70 per cent of a sample of 171 pedestrian casualties, the first direct contact was to the front face of the vehicle.

The most frequent areas of contact in a sample of 152 pedestrians with injuries more severe than minor, were the bumper and leading edge of the bonnet with, in many cases, other injuries resulting from subsequent impacts to the bonnet top, windscreen surround, and the ground (report in preparation). Table 2 summarises the regions of the body most frequently injured in this sample and gives the locations on the vehicle which were judged to have caused the injury.

The head is reported as the area of the body most likely to sustain life-threatening injury [3]. In 60 per cent of these cases, the injury was attributed to vehicle impact and the remainder to contact with the ground.

In the same sample, 50 per cent of the cases who sustained a severe injury, AIS 3 or worse, to any part of the body, were reported to have suffered a vehicle impact of not more than 40 km/h.

<table>
<thead>
<tr>
<th>Cause of injury</th>
<th>Body region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Head</td>
</tr>
<tr>
<td>Roof</td>
<td>2</td>
</tr>
<tr>
<td>Windscreen glass</td>
<td>6</td>
</tr>
<tr>
<td>Windscreen surround</td>
<td>8</td>
</tr>
<tr>
<td>Bonnet top</td>
<td>5</td>
</tr>
<tr>
<td>Bonnet front edge</td>
<td>–</td>
</tr>
<tr>
<td>Scuttle</td>
<td>4</td>
</tr>
<tr>
<td>Wing side</td>
<td>2</td>
</tr>
<tr>
<td>Wing front</td>
<td>–</td>
</tr>
<tr>
<td>Radiator grill</td>
<td>1</td>
</tr>
<tr>
<td>Bumper</td>
<td>–</td>
</tr>
<tr>
<td>Run over</td>
<td>–</td>
</tr>
<tr>
<td>Ground</td>
<td>27</td>
</tr>
<tr>
<td>Other structures or</td>
<td>56</td>
</tr>
<tr>
<td>not known</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>111</td>
</tr>
</tbody>
</table>
CAR TO PEDESTRIAN DUMMY

IMPACT TESTS

Full scale tests have been conducted to investigate the problems of pedestrian accidents. Child and adult pedestrian dummies were struck by different models of standard production cars at impact speeds up to 40 km/h and the resulting trajectories of the dummies studied with the aid of high speed cine photography.

Experimental front end configurations were fitted to cars to study the requirements for obtaining a more controllable dummy trajectory.

Different heights of the bumper and bonnet leading edge were investigated and also the horizontal projection of the bumper in front of the bonnet. Energy-absorbing bumpers and leading edges of the bonnet were fitted to limit the magnitude of the impact forces resulting from primary collisions.

The energy-absorbing structures consisted of thin aluminium alloy sections filled with rigid polyurethane foam with a density of 25 kg/m³. The designs used had a constant collapse force of approximately 5 kN and a maximum available crush depth of 150 mm. In order to reduce injury attributed to striking the ground, devices have been developed to retain a pedestrian on the bonnet of a car. The same device also helps to lift a child onto the bonnet. [4]

ANTHROPOMORPHIC DUMMIES

The adult dummies used were of a robust construction to withstand repeated violent impact and represented a 50th-percentile adult, being based on an RAE-type VB dummy. Two smaller dummies represented a 6-year-old child; the youngest age group that is normally seen unaccompanied on the road. One child dummy was of TRRL manufacture and the other was a Sierra Sammy of American origin.

The dummies were supported in standing positions by an easily dislodged prop. The

<table>
<thead>
<tr>
<th>Car</th>
<th>Vehicle details</th>
<th>Dummy trajectory onto bonnet¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bonnet leading edge height (mm)</td>
<td>Height at top of bumper (mm)</td>
</tr>
<tr>
<td>British Leyland Marina</td>
<td>790</td>
<td>510</td>
</tr>
<tr>
<td>British Leyland 1800</td>
<td>750</td>
<td>450</td>
</tr>
<tr>
<td>British Leyland 1300</td>
<td>750</td>
<td>380</td>
</tr>
<tr>
<td>British Leyland Clubman</td>
<td>740</td>
<td>470</td>
</tr>
</tbody>
</table>

¹Trajectory code: 1—Knocked to the ground under bumper  
2—Carried on front, then slumped to the ground  
3—Knocked forward to the ground
joints of the adult and the TRRL child dummy were fitted with weak shear pins and the hip and knee joints of the Sierra Sammy dummy were torque loaded to resist collapse when propped.

In later tests, to obtain a more flexible dummy, all of the body and limb joints were completely free and the dummy was supported from an overhead catch that was electrically released by the approaching car just prior to impact.

RESULTS

The test details and a brief description of dummy trajectories resulting from the initial impact are summarised in tables 3 to 7. In these tests, the car was braked at about 0.5 g, just after impact; this often caused the dummy to be thrown off the bonnet to the ground.

Plots of the adult dummy trajectory with respect to bonnet leading edge height and vehicle impact velocity are shown in figure 1.

Figure 2 shows plots of the ratio of head impact velocity to vehicle impact velocity in terms of the bonnet leading edge height for the tests at 20 to 30 km/h. The head velocities used are the average over approximately the last 0.5 metre travelled before head impact. Figure 3 shows, for different bonnet heights, the distance from the bonnet leading edge to the first point of adult dummy head impact onto the bonnet for

Table 4. Details of experimental car (rigid car front) impacts into child dummies

<table>
<thead>
<tr>
<th>Design feature</th>
<th>Vehicle details (mm)</th>
<th>Impact speed (km/h)</th>
<th>Dummy trajectorya</th>
<th>Point of head impact on car or distance from bonnet leading edge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bonnet</td>
<td>Bumper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Height at leading edge</td>
<td>Length</td>
<td>Height of top face</td>
<td>Projection in front of bonnet</td>
</tr>
<tr>
<td></td>
<td>650</td>
<td>1 130</td>
<td>430</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>2</td>
<td>700</td>
<td></td>
</tr>
<tr>
<td>Low bonnet leading edge</td>
<td>720</td>
<td>1 130</td>
<td>420</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>4</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>1</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>2</td>
<td>550</td>
<td></td>
</tr>
<tr>
<td>Sloping bonnet front</td>
<td>Lower front face of bonnet 30° to vertical.</td>
<td>400</td>
<td>50</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Bonnet top 940 mm above ground.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Joining contour 1.05 m radius.</td>
<td>20</td>
<td>1</td>
<td>100 mm aft curved front.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23</td>
<td>5</td>
<td>200 mm aft curved front.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

aTrajectory Code: 1—Rotated to lie horizontally on bonnet. 2—Rotated on bonnet, legs rising to vertical. 3—Rotated towards bonnet then collapsed to ground. 4—Rotated to lie on front portion of bonnet. 5—Rotated onto bonnet, legs rising to 45° above horizontal. 6—Rotated over bonnet and wing to ground.
Table 5. Details of standard production car impacts into adult dummies

<table>
<thead>
<tr>
<th>Vehicle details (mm)</th>
<th>Car</th>
<th>Bonnet</th>
<th>Bumper</th>
<th>Impact speed (km/h)</th>
<th>Dummy trajectory&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Point of head impact on car or distance from bonnet leading edge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Height at leading edge</td>
<td>Length</td>
<td>Height at top face</td>
<td>Projection in front of bonnet</td>
<td></td>
</tr>
<tr>
<td>British Leyland</td>
<td>Marina 790</td>
<td>790</td>
<td>1 180</td>
<td>510</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marina 750</td>
<td>750</td>
<td>1 060</td>
<td>450</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>British Leyland</td>
<td>1300</td>
<td>750</td>
<td>930</td>
<td>380</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>British Leyland</td>
<td>Clubman 750</td>
<td>750</td>
<td>850</td>
<td>470</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>British Leyland</td>
<td>Clubman Mini 800</td>
<td>800</td>
<td>1 170</td>
<td>470</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>British Leyland</td>
<td>1100</td>
<td>720</td>
<td>700</td>
<td>335</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>British Leyland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Trajectory Code:
1—Knocked to ground under bumper
2—Rotated onto bonnet, feet just leaving ground
3—Knocked to ground in front of car
4—Leaned towards bonnet then collapsed to ground
5—Rotated to lie horizontally on bonnet
6—Rotated onto bonnet legs rising to vertical
7—Rotated over bonnet and wing to ground
8—Pushed along in an upright stance then fell to the ground

Tests with a vehicle impact speed of approximately 24 km/h.

COMMENTS ON RESULTS

Tests on Child Dummies

Trajectory. The child dummy was always knocked to the ground when struck by a conventional car having a bonnet leading edge height of 740 mm or greater (table 3). In most cases, after the initial impact, the dummy was carried on the front face of the bonnet for a short distance before being thrown to the ground. A high-mounted bumper (the top face 450 mm or more above ground level) deflected the dummy to the ground below the front of the car at impact speeds of 9 km/h or less. In these
Table 6. Details of experimental car impacts into adult dummies (rigid car front)

<table>
<thead>
<tr>
<th>Design feature</th>
<th>Vehicle details (mm)</th>
<th>Impact speed (km/h)</th>
<th>Dummy trajectory a</th>
<th>Point of head impact on car or distance from bonnet leading edge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bonnet</td>
<td>Bumper</td>
<td>Projection in front of bonnet</td>
<td></td>
</tr>
<tr>
<td>Extended bumper</td>
<td>750</td>
<td>930</td>
<td>380</td>
<td>230</td>
</tr>
<tr>
<td>Rounded bonnet front</td>
<td>Lower front face mounted vertically, Bonnet 760 mm above ground, Joining contour 1.05-m</td>
<td>380</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Sloping bonnet front</td>
<td>Lower front face 30° to vertical, Bonnet 940 mm above ground, Joining contour 1.05-m radius</td>
<td>400</td>
<td>50</td>
<td>13</td>
</tr>
<tr>
<td>Extra low bonnet leading edge</td>
<td>650</td>
<td>1130</td>
<td>430</td>
<td>150</td>
</tr>
<tr>
<td>Low leading edge of bonnet</td>
<td>720</td>
<td>1130</td>
<td>420</td>
<td>125</td>
</tr>
<tr>
<td>Raised bonnet</td>
<td>790</td>
<td>1130</td>
<td>420</td>
<td>125</td>
</tr>
</tbody>
</table>

a Trajectory Code: 1—Rotated to lie slumped over front and top of bonnet  
2—Rotated to lie horizontally on bonnet  
3—Rotated over bonnet and wing to ground  
4—Rotated onto bonnet, legs rising to 45° above the horizontal  
5—Rotated to lie slumped over front face  
6—Rotated onto bonnet, legs rising to vertical

Tests the brakes were applied just after impact to give a deceleration of approximately 0.5 g.

If the brake application had been delayed, the dummy would, in some instances, have been run over.

Experimental bonnet designs with a sloping front or low leading edge (720 mm above the ground or less) projected the dummy on to the front portion of the bonnet at impact speeds above 16 km/h (table 4). In these tests the legs of the dummy rose to a horizontal position at impact speeds of 16 to 25 km/h, before falling back to the ground. Over 25 km/h the legs rotated over the dummy’s head.

Child Head Impact. The headform did not strike the bonnet top in any test where the height of the bonnet leading edge was more
Table 7. Details of impacts into an adult dummy by an experimental car with an energy-absorbing front

<table>
<thead>
<tr>
<th>Design features</th>
<th>Vehicle Details (mm)</th>
<th>Impact speed (km/h)</th>
<th>Dummy trajectory(^a)</th>
<th>Point of head impact on car or distance from bonnet leading edge (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bonnet</td>
<td>Bumper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Height at leading edge</td>
<td>Length</td>
<td>Height to top face</td>
<td>Projection in front of bonnet</td>
</tr>
<tr>
<td>Energy-absorbing bonnet front</td>
<td>800</td>
<td>1 280</td>
<td>390</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy-absorbing bumper and bonnet front</td>
<td>700</td>
<td>1 280</td>
<td>375</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

\(^a\)Trajectory code: 1—Rotated to lie horizontally on bonnet  
2—Slumped on bonnet  
3—Rotated onto bonnet, legs rising to 45° above horizontal  
4—Rotated over bonnet and wing to the ground  
5—Rotated on to bonnet, legs rising to vertical

Figure 1. Adult dummy trajectory/bonnet leading edge height and vehicle impact speed (rigid car front).

than 740 mm above the ground. There was occasional low-velocity contact with the front of the vehicle as the dummy fell to the ground.

Figure 2. Ratio of head impact speed to vehicle impact speed/bonnet leading edge height (test speeds 20 to 30 km/h).
from 650 mm to 800 mm and impact speeds up to 24 km/h. At higher speeds the legs were thrown into the air over the bonnet. At impact speeds less than 14 km/h the dummy was knocked to the ground when struck by a car having a bonnet leading edge height of more than 725 mm and was deflected below the front of the car in the tests where the bumper top face was 470 mm or more above the ground and the impact speed was 8 km/h or less. The repeatability of the results from tests of this type is indicated in figure 1 by the amount of overlap of the different dummy trajectories.

Tests on experimental front ends showed that the impact velocity at which the legs were thrown into the air over the bonnet was reduced to about 20 km/h for sloping and rounded bonnet fronts and increased to almost 30 km/h for front ends with energy-absorbing structures. With these units, the apparent severity of impact was reduced and the dummy damaged less frequently, particularly at the femur. In the 40 km/h tests the bumper crushed 100 mm and the bonnet leading edge 130 mm.

**Adult Dummy Tests**

**Trajectory.** Tests with standard and experimental nonyielding vehicle front ends (fig. 1) showed that, when impacted, an adult dummy was nearly always projected on to the bonnet top. The final attitude obtained appeared from the cine records to be a function of the velocity imparted to the dummy’s legs by the car bumper. A high velocity propelled the legs high over the body of the dummy, sometimes continuing over the wing to the ground. In these tests the dummy’s legs rose to the horizontal position for bonnet leading edge heights

![Figure 3. Distance from bonnet leading edge to head impact point/bonnet height (test speed 24 km/h).](image-url)

Head to ground impact appeared to be most severe when friction stopped the feet from sliding along the ground and the dummy was thrown head first to the ground. In actual accidents some pedestrians who are walking or running may have one or both feet off the ground at the moment of impact. The child dummy head always made contact with the top of the bonnet when the leading edge was less than 720 mm above the ground. This contact occurred between 300 mm and 700 mm from the leading edge of the bonnet and in the case of sloping fronts between 100 and 200 mm from the top of that face.
impact velocity increased as the bonnet leading edge height was raised with the exception of the 650-mm high bonnet leading edge (fig. 2).

Cars fitted with energy-absorbing front ends gave less variable results ranging between 0.8 and 1.3 times the vehicle impact speed. There was no obvious head impact velocity change with respect to bonnet height.

DISCUSSION

In an accident a pedestrian may be knocked forward to the ground, projected onto the bonnet, or thrown over the wing or roof to the ground. Tests show that the factors determining the path taken are the height of the pedestrian, the speed of impact, the contour of the leading edge of the bonnet, the position of the bumper, and the braking of the car. Table 2 shows that the leading sources of injury are the car bumper wing and bonnet, headlamps, winds-creen surround, and the ground.

The probable effects of changes of design on these main sources of injury are discussed in the following.

Bumper

The main considerations are height, shape, and stiffness. To reduce the severity of leg injury, a car bumper should avoid direct contact with the less easily healed parts of the lower limbs, that is the femur and knee and rather should strike near the centre of the tibia and fibula well above the ankle joint. Research on the height of pedestrians involved in road accidents in Great Britain [2] showed that in 60 per cent of the cases the knee was 380 mm or more above the ground. Tests in Great Britain [5] have shown that lowering the bumper reduces the severity of the bumper to leg impact force and also reduces the bending moment across the knee.

Results of track tests at TRRL show that a high bumper (450 mm or above) usually knocks a pedestrian dummy to the ground, particularly one representing a small child. It lands beneath the front of the vehicle after low-speed impact but forward of the car at higher speeds when the car is braked. These factors all favour a bumper mounted as low as practicable, which is approximately 375 mm from the ground to the top of the bumper in the semi-laden condition.

The shape of the bumper will also influence its injury potential. A broad flat faced or slightly rounded energy-absorbing surface with rounded top and bottom edges reduces the bumper to leg forces, thereby the maximum bending stresses and crushing stresses. It also reduces the leg rebound velocity. Provisional estimates suggest that such a low-mounted bumper might reduce 2 000 serious pedestrian injuries annually in the United Kingdom to ones of lesser severity.

Further results are required before the optimum crushing strength and maximum permitted deformation of a bumper can be determined.

Bonnet Leading Edge

This structure accelerates most of either an adult or a child pedestrian to the speed of the car, but in so doing should cause as little injury as possible. This may best be achieved if it is made of an energy-absorbing material with crush characteristics that match adult pelvic and child thoracic tolerance loads.

A high fronted bonnet may knock a pedestrian under the front of a car at low speeds and throw a child forward to the ground at most accident speeds with a high risk of injurious head impact on the ground. A low fronted bonnet reduces these risks but the possibility of head impact with the windscreen surround is increased, particularly for the adult and this is one of the most frequent causes of fatal injury.

Bonnet Top and Wing

The collapse characteristics of the top of the bonnet and wing should give a constant reactive force to vertical impacts, designed to produce acceptable decelerations at the
head and thorax. Traditionally rigid areas such as the windscreen scuttle should be made flexible. Hidden components should be terminated well below bonnet level to allow depth for deformation. Examples are the engine and fittings, front suspension and the side walls of the engine compartment. An increased bonnet length (1 100 mm or more) reduces the risk of the head striking the windscreen surround.

**Windscreen Surround**

Some protection for the head from an impact with this structure may be provided by a windscreen lower edge that is recessed below a deformable bonnet and also by a crushable covering for the header rail. Protection to the side pillars must be of limited thickness or blind areas for the driver will result. Generally, because high velocity impact speeds result in high head to vehicle impact speeds (fig. 2), more satisfactory results may be obtained by reducing the frequency of head impact to windscreen surround by the use of longer and higher bonnets as previously noted.

**Protection from Subsequent Impact With the Ground**

The features already discussed aim to reduce injury from vehicle impact and this has been shown by accident investigation to be the major source of injury. There is, however, little merit in designing a car to reduce injury from vehicle impact if the pedestrian is subsequently fatally injured by contact with the ground. To reduce injury from ground impact a simple device may be needed to restrain a pedestrian from falling from the vehicle onto the road. A prototype has been developed for this purpose at TRRL which also helps to lift a child pedestrian onto a car bonnet at speeds up to 16 km/h. It is triggered by an impact to the front of the vehicle and when deployed it prevents a pedestrian that has been projected onto the bonnet from subsequently being thrown forward to the road.

**CONCLUSIONS**

Pedestrian accident injury may be reduced by cars that are designed to satisfy the following conditions:

- The severity of primary impact is reduced by matching the collapse characteristics of the front of the car to the appropriate human tolerance loads.
- An adult pedestrian should be picked up and retained on the bonnet over as wide a range of impact speeds as possible without being projected over the roof or wings to the ground.
- A child should be picked up onto the bonnet or bonnet front rather than knocked forward to the ground.
- The head should impact a suitably designed energy absorbing bonnet top rather than the more rigid windscreen surround. Some features of vehicle design that contribute to these conditions are:
  - A low-mounted energy absorbing bumper with a yield of at least 100 mm, which also ameliorates lower limb injury, moving the impact to below the adult knee
  - An energy-absorbing bonnet leading edge with a yield of at least 150 mm and preferably much more.
  - Bonnet and wings with controlled vertical collapse characteristics.

The height of the leading edge of the bonnet has conflicting requirements; it needs a low bonnet front for projecting a child onto the bonnet and a high bonnet front for reducing the frequency of adult head impact with the windscreen surround. A long bonnet also reduces this latter possibility.

The research programme is continuing to develop these basic design requirements into practical solutions to reduce the toll of pedestrian injuries.

**ACKNOWLEDGMENTS**

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REFERENCES


Computer Simulation of the Pedestrian Impact—Development of the Contact Model

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INTRODUCTION

With an increasing number of European countries introducing compulsory seatbelt use, the relative importance of vehicle occupant protection will change. Mackay [1] and Finch [2] have predicted that the effect of compulsory use on United Kingdom road-user fatalities will be as shown in table 1. The pedestrian will, therefore, become the largest single group of fatalities.

Under these conditions, the pedestrian will be morally entitled to at least more consideration from the legislators and better protection from vehicles. Forthcoming changes in the financing of the United Kingdom’s medical costs may also have an accelerating effect in this context. Currently, all accident medical costs are, in general, borne by the taxpayer; however, for financial reasons the Government of the United Kingdom is proposing that, in future, these should fall upon the motor insurers. This may bring commercial pressure to reduce injuries in addition to the present humanitarian reasons.

Obviously two courses of action can be taken to reduce pedestrian injuries. First, to segregate pedestrians from other traffic, and second, to design vehicles to minimize the injuries to all classes of pedestrians. As a vehicle manufacturer, the only direct contribution that Leyland Cars can make is to study the vehicle-pedestrian impact problem and introduce pro-pedestrian vehicle designs

Table 1. Possible effect of compulsory seatbelt use on United Kingdom traffic fatalities

<table>
<thead>
<tr>
<th></th>
<th>1972</th>
<th>With belts compulsory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car occupants (%)</td>
<td>39</td>
<td>26</td>
</tr>
<tr>
<td>Motorcyclists and others (%)</td>
<td>21</td>
<td>26</td>
</tr>
<tr>
<td>Pedestrians (%)</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Number</td>
<td>7,788</td>
<td>6,453</td>
</tr>
</tbody>
</table>
when the cost, and perhaps styling restrictions, will be accepted by the car-buying public. Indirectly, however, such studies should lead to better legislation that considers the implications on all aspects of vehicle performance, not only the immediate objective. [2]

STUDIES OF PEDESTRIAN IMPACT STATISTICS

Various researchers have analysed accident statistics [3-11] and, in general, most of their findings very roughly correlate with each other. Most are agreed that: the bumper height of 16 to 20 inches results in a maximum number of people receiving serious knee injuries; children receive less severe injuries than adults (at least from the vehicle); the severity of the injuries increases rapidly for speeds above 20 mi/h; the windshield frame is responsible for the majority of vehicle-inflicted serious head injuries; and head injuries are the largest single cause of death.

On the effect of vehicle shape, however, the researchers draw very different conclusions. For example, McLean [8] found that 4.6 per cent of all pedestrians involved in collisions with Cadillacs (high square front) were killed, whilst 3.8 per cent were killed when impacted by Volkswagens (low sloping front). On the other hand, Hall et al [4] found that the comparable figures were 2.8 per cent for Falcons and 9.4 per cent for Volkswagens. Not only are the fatality rates for Volkswagens very different, but opposite conclusions could be drawn from the two studies. McLean states that his results are to some extent supported by a smaller study conducted by the Cornell Aeronautical Laboratory [11]. Whereas Hall claims his are supported by the results of Robertson [10].

Similarly, there is also conflict as to whether the road or the vehicle is responsible for the majority of the fatalities. Ashton [7] reports that the vehicle is the most likely cause of death, whilst the results of Calkowski et al [11] show that the ground is equally as likely to be the cause.

Statistical analyses, therefore, produce little guidance for the design of the least aggressive vehicle front-end shape. Such inconclusiveness is not surprising because of the large number of unrecorded and unknown variables involved in real pedestrian impacts. Computer simulations by MacLaughlin [12] and Segal [13] have shown that the pedestrian trajectory is very sensitive to both initial victim attitude and vehicle profile. From the foregoing, it is obvious that to determine the effects of vehicle front-end shape either experimental or computer simulations are necessary.

COMPUTER SIMULATIONS

Owing to the large number of variables in the experimental simulation of pedestrian impacts, the results of such tests can be very difficult to interpret, especially when the number of tests is small. Some of the variables are not easily controlled, and nominally identical tests can result in quite different behaviour, different enough to mask the effects of some deliberate parameter changes. The main advantages of computer simulation in this context are its exact repeatability, and the speed at which the complete results of a parametric study are obtained.

The method of investigation chosen by Leyland Cars is to conduct initial studies using computer simulation, and then to finalise with experimental tests when trends and parameter importance have been established.

For some years Leyland Cars has been successfully using simulation techniques to study and optimise the crash test performance of vehicle structures. [14 and 15] This work has more recently been extended to include the occupant performance with the Calspan Corporation 3D Crash Victim Simulation Program. [16 and 17] The 3D program was chosen for its performance, documentation, extensive validation in the occupant mode, and the fact that it was already in use elsewhere in the motor industry. It has proved to be an extremely useful design aid in Leyland Cars’ Experimental Safety Vehicle (ESV) programme, and is now in routine use for new vehicle model development.
CALSPAN 3-D CRASH VICTIM SIMULATION PROGRAM (VERSION II)

The Version II victim model consists of 15 rigid body segments representing the head, neck, three torso segments, eight arm and leg segments, and feet. These are connected by 14 joints. All joints are of the ball-and-socket type except the elbows and knees which are pinned. The torques acting at the joints consist of viscous, coulomb friction, and linear spring components, with nonlinear spring torques acting as joint stops. For the ball and socket joints, uncoupled torsional and flexural torques are considered as functions of the torsion and flexure at the joint, whereas for the pinned joints only flexural spring torques are produced.

The victim contact surface model is defined by an ellipsoidal contact surface corresponding to each body segment. Contact forces can be generated between ellipsoids, or between ellipsoids and vehicle panels, and are calculated as a function of penetration of the surfaces, with sliding friction forces generated to oppose the relative motion.

The vehicle contact surface model consists of up to 20 rectangular plane panels. The panel stiffnesses are entered into the program as tabular or analytical data. Multiple panel loadings are allowed for, dissipating energy on each loading.

For use in its occupant mode a comprehensive choice of belt and airbag restraint options are provided.

Program output is both by printout of simulation parameters and by post-processor plotting of the dummy kinematics at selected time frames. An example of such a plot is shown in figure 1. In addition, a post-processor program has been written to calculate the relevant injury criteria and plot-selected parameters on a time abscissa.

Figure 1. Kinematic plot of pedestrian mode.
LIMITATIONS OF CONTACT MODEL FOR PEDESTRIAN SIMULATION

It should be noted that the following discussion specifically applies to the Version II program. Since Version II the program has been considerably improved by Calspan and the new Version III [8] is more generalised from a mathematical point of view; however, most of the following limitations in the contact panel modelling still exist.

When the program was first used in the pedestrian mode several limitations became apparent. The most serious of these was the inability of the contact model to generate forces when vehicle contact panels were penetrated by relatively large dummy segments.

Figure 2 shows a vehicle contact panel penetrated by a segment ellipsoid. The force is applied normal to the plane through the centre of the intersection ellipse. However, if the centre of the intersection ellipse is outside the plane boundary, as can be the case with small contact panels, no force is generated; this condition is shown in figure 3. Due to the continuously changing orientation and position of segments relative to the panels, the position of the intersection ellipse centre is also changing. Therefore, effective contact with a panel can be instantaneously lost or gained, giving unrealistic sudden changes in the contact force.

A consequence of this limitation is the failure of the contact model to accommodate panel edge or corner contact conditions. Figure 4 illustrates the case of an unregistered edge contact. Here the centre of the intersection ellipse is also outside the plane boundary with the result that no force is generated for this contact condition. However, an edge contact condition that will generate a force can exist (fig. 5), although, in this case, it is computed as a full plane contact because the penetration is always determined at the tangency point rather than at the actual edge of the contact panel.

Another limitation of the contact model concerns its behaviour with large penetrations. When the penetration exceeds the extremity of the segment (complete penetration in fig. 2) the force is instantaneously set to zero, and if the penetration reduces to less than complete penetration the full force is instantaneously re-applied. In a similar manner, where a segment approaches and contacts the panel from the reverse side large initial deflections and forces are generated that reduce as the segment continues to penetrate.

As shown in figure 2, the force, although being calculated from the maximum penetration, is in fact applied to the segment at the centre of the intersection ellipse. The choice of the point of application of the contact force = \( f \) (penetration)
force must be rather arbitrary where a distributed force system is simplified to a single force.

However, the Calspan model seems to have been formulated for segments that are considered soft in relation to the contact surface. In many practical applications this is not the case, especially when it is remembered that the long dummy segments are nonhomogeneous and are, in fact, usually considerably stiffer on their "ends" than in a direction normal to their long axes. For these reasons the authors believe that, in general, it is better to apply the force to the segment surface at the point of maximum penetration. The difference between the points of application for the two methods is only significant with elongated segments such as the arms or legs. With the segment orientation and the degree of penetration shown in figure 6, the point of maximum penetration and the point of force application using the Calspan method can be at opposite ends of the segment; clearly this is not representative of the actual condition. The technique used in the Calspan Version III [18] program of positioning the contact force by a factor that determines its position between the limits of the point of maximum penetration and the centre of the intersection ellipse, appears to be an approximate yet effective refinement.

**LEYLAND CARS' CONTACT MODEL**

To develop a model that will enable the realistic simulation of small panels, automatically implies that the modelling must accommodate both corner and edge contacts. In the Leyland Cars' contact model, there are five contact conditions: full plane contact, edge, corner, no contact, and invalid contact that will be described later.

For the edge contact, as shown in figure 4, the force is calculated from the "real" panel penetration at the edge. In the case of a corner contact, the force is similarly calculated, but this time it is from the length of a normal erected at the corner to the point at which it cuts the ellipsoid surface. In all cases, the force is applied in a direction normal to the panel at the point of maximum penetration.

An iterative technique is used to calculate the penetration and type of contact; this basically consists of selecting a point in the three-dimensional "shadow" space behind the panel and establishing whether an ellipsoid passing through this point must be expanded or contracted to achieve surface contact. Using this result, the next point in the panel "shadow" can be selected and the
process repeated until a point (if any) is found that lies on the surface of the original ellipsoid and corresponds with maximum penetration. An optimising technique is used to minimise the number of points that are selected for trial. By this method the program calculates both the penetration and type of panel contact in the same process. In order to minimise computation time, at the next integration interval a continuance of the same type of contact is initially assumed. This assumption is then checked and if it is found to be valid the penetration is calculated directly, but if it is not valid the iterative procedure is entered. The iterative method is thereby only used when a change in the contact condition is encountered.

A consequence of accommodating edge contacts is the instantaneous development of a large penetration when a segment approaches a panel as shown in figure 7. Here it can be seen that the direction of the motion and the angle of the segment are such as the panel touches the "back" of the segment an unrealistic instantaneous penetration is generated. To overcome this problem the concept of a terminator plane was established. Light shining from behind and normal to the panel will illuminate one half of the ellipsoidal segment, the other half being in shadow. The transition zone is termed the terminator plane. A panel will "see" only the illuminated half of an approaching segment and can only develop forces from an initial contact in the illuminated zone. Initial contacts in the invalid (shadow) zone will not produce forces. However, if, after an initial contact in the illuminated zone, the penetration increases to such an extent that the panel moves into the shadow zone, it remains a force-producing penetration.

As in the original Version II program, the contact force is considered to be a function of the penetration. For panels with a constant stiffness over their entire areas, this method probably over-estimates the edge or corner contact forces. A better method might be to calculate the force from some function of the area or volume of contact in addition to the penetration. Experimental measurement of such a complex relationship would be very difficult, and, in any case, probably vary with the shape of the test impactor. Bearing in mind this difficulty, the variation of stiffness over the surface of a real panel, and the limited number of panels that can be used to represent a vehicle, the assumption of force being proportional to penetration is justified on the grounds of sufficient accuracy and simplicity.

The program makes no correction to the contact panel force-deflection characteristics in order to allow for the dynamic strain and inertia effects. Leyland Cars has found that the dynamic characteristics vary considerably for the different panels, constructions and materials. It is much simpler to input the dynamic data as measured on standard impact testing equipment.

As shown in figure 8, when idealizing a vehicle outline into the rectangular contact panels it frequently happens that two or

Figure 7. Initial edge contact on the 'back' of a segment.

Figure 8. Idealization of bonnet.
three panels must be used to represent a single curved vehicle panel. If a dummy segment slides over the coincident edges of these panels then the accommodation of edge contacts means that two panels would be penetrated, both producing forces proportional to their penetrations. Obviously this would be unrepresentative of the actual bonnet force, so to overcome this, contact surfaces representing a single continuous vehicle panel are defined as such in the input data, and the panel that has the maximum penetration is the only one to generate a force on the segment. In this way a smooth force transition is achieved although the direction of the force application is changed by an amount determined by the flatness of the vehicle surface.

A similar condition of double force application can occur where two adjacent ellipsoidal dummy segments overlap and occupy the same space. An example of this is the folded knee penetration into a contact panel. The two segments will both generate forces dependent upon their individual penetrations. To avoid this erroneous double force generation, the user can specify that the segment with the largest penetration is the only one of the pair to generate a force on particular panels.

The period of interest in pedestrian impacts is of much longer duration than that of occupant impacts (2 seconds as opposed to 0.25 second). Computer processing time is therefore an important parameter in determining the cost-effectiveness of pedestrian computer simulation. With pedestrian simulations the actual impact of dummy segments with their allowable contact panels occur only over a small fraction of the total simulation period. Furthermore, after a little experience, these contact periods can be pre-identified. A facility has therefore been included in the program to limit the calculation of specified segment-panel contacts to specified time periods. This considerably reduces the processing time to about 40 minutes (IBM 370/158) for a typically complex pedestrian simulation. The Version III program would also reduce the processing time by virtue of its improved integrator performance.

The contact panels of the original occupant model were all fixed relative to the vehicle reference system. To enable the simulation of pedestrian impacts it was necessary to program the option of specifying selected panels fixed in ground reference. At the same time the maximum number of allowed segment-panel contacts was increased from 20 to 30.

The appendix gives further details of the revised contact model and a program flow diagram.

OTHER CHANGES TO THE PROGRAM

The dummies used in pedestrian impacts frequently have shear pins located at the knee joint and sometimes in the hip joint to ensure that the dummy will stand erect without external support. Changes were made to the joint modelling to incorporate the effects of such shear pins.

The majority of experimental pedestrian impacts in the United Kingdom are conducted using the Ogle Occupant Protection Assessment Test (OPAT) anthropometric dummy. Because of this, a contract to measure its physical parameters was placed with the Motor Industry Research Association by the Transport and Road Research Laboratory. Whilst this paper will not report the findings of these tests, it is relevant to note that the characteristics of the OPAT are considerably different from those of the Sierra 292-1050 as measured by Calspan, and that many of the joint stiffness characteristics are decidedly nonsymmetrical.

To accept the OPAT data without severe loss of accuracy, the joint modelling technique also had to be changed. Briefly, these changes consisted of representing the normal range of joint motion by a fifth order polynomial power series, and the joint stop by a quadratic function.

FUTURE CHANGES TO THE CONTACT MODEL

The revised contact model, through incorporating edge contacts, has produced another problem, the solution of which is currently being implemented.
Only when the approach angle is greater than the friction angle will the panel be penetrated. As the segment moves away from the panel, the panel will recover towards its original size, reaching its full size when the segment is completely out of contact. If, during the course of a continuous segment-panel contact, the approach angle changes from being less than to greater than the friction angle, the penetration will be calculated as usual but operating from the reduced panel size.

**PEDESTRIAN SIMULATION VALIDATION AND CONTACT MODEL PERFORMANCE**

To aid validation of the pedestrian simulation model, experimental tests were completed using a Pedestrian Impact facility developed at Rolls Royce Motors under sponsorship of the Transport and Road Research Laboratory. A vehicle profile representative of the Leyland Cars’ SRV2 Marina (reported on at the fifth International ESV Conference) was mounted on the rig’s trolley and subjected to a controlled deceleration after the initial impact with an Ogle OPAT anthropometric dummy. Impact speeds of 10 and 15 mi/h with the dummy were conducted and data recordings from the dummy’s comprehensive instrumentation were made throughout the impact sequences. In addition to cine coverage, still photographs were taken with a motorised camera.

A full validation study has not, as yet, been completed as the new contact model does not include the ‘crumpling edge’ modifications outlined in the previous section. Furthermore, the data for the OPAT dummy, although incorporated in the program, has not been fully checked out and it is anticipated that further refinements may be required to the joint modelling to accurately represent the dummy parameters. However, initial simulation runs were completed using both the Leyland Cars’ contact model and the original Calspan contact model.

A comparison of the dummy trajectory during the primary impact sequences (up to
and including head to bonnet contact) was considered to be a fundamental criterion on the computer simulation validity.

The Leyland Cars' contact model simulation results indicate a good general agreement with the test results, as shown by a comparison of the photographs in figures 11 to 14. The soft bumper was fully deflected and the dummy rolled about the leading edge of the bonnet profile. Note that rebound resulting from initial leg contact was rather excessive, probably due to underestimation of the energy absorption properties of the dummy segments as these values were obtained from static tests. A comparison of the head and chest accelerations is given in table 2. It should be noted that the mock bonnet profile was constructed from mild steel plate plus the high peak acceleration on the head.

The Calspan contact model simulation of this same test set-up highlights some of the problems the authors have encountered with the original model. Figure 15 shows a comparison of the two contact models early in the impact event. Owing to the relatively small bumper contact surface no lower leg-bumper contact forces are generated (centre of intersection ellipse outside plane boundary). This results in unimpeded vehicle motion "through" the dummy. Similarly bonnet contact forces with the upper leg are not generated until the upper leg has been penetrated by the bonnet, resulting in an instantaneous large penetration and force in the vertical direction when the conditions of the contact model are satisfied. These erroneous contacts are subsequently reflected in the resultant trajectory of the dummy.

Figure 11. Comparison of Leyland Cars simulation and experiment at 40 milliseconds after impact.

Figure 12. Comparison of Leyland Cars simulation and experiment at 150 milliseconds after impact.
Figure 13. Comparison of Leyland Cars simulation and experiment at 260 milliseconds after impact.

Figure 14. Comparison of Leyland Cars simulation and experiment at 370 milliseconds after impact.

Table 2. Comparison of experimental and simulated results

<table>
<thead>
<tr>
<th>Acceleration</th>
<th>Experimental</th>
<th>Simulation (Leyland Cars' model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head peak acceleration (g)</td>
<td>181</td>
<td>225</td>
</tr>
<tr>
<td>Time to peak (s)</td>
<td>0.339</td>
<td>0.322</td>
</tr>
<tr>
<td>Chest peak acceleration (g)</td>
<td>16.1</td>
<td>17.9</td>
</tr>
<tr>
<td>Time to peak</td>
<td>0.338</td>
<td>0.328</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENT

The authors wish to express their thanks to Rolls Royce Motors for conducting the experimental tests and providing the necessary results.

REFERENCES


APPENDIX. A MATHEMATICAL ANALYSIS OF THE NEW SEGMENT—PANEL CONTACT MODEL

An outline of the mathematics for a new dummy segment, panel contact model for CALSPAN Version II (3D Computer Simulation of a Motor Vehicle Crash Victim; CALSPAN Corporation (formerly, Cornell Aeronautical Laboratory, Inc.) is now given.
There are three cartesian coordinate axis systems, the inertial, that of the vehicle and that of the dummy segment (ellipsoid) referred to here by suffixes i, v, and s, respectively. The transpose of a vector or matrix will be denoted by t. Given a nx1 vector x, \( \| x \|_2^2 = \sum_{j=1}^{n} x_j^2 \).

The following are readily available in the package:

- \( \mathbf{x}_i \) A vector in the inertial system representing the displacement of the centre of gravity of the ellipsoid from the vehicle origin
- \( \mathbf{y}_s \) A vector in the segment system representing the displacement from the centre of gravity of the dummy segment to the centre of the ellipsoid
$P_v$ and $P_s$ Orthogonal matrices which on pre-multiplying a vector in the inertial system give vectors in the vehicle and segment systems respectively.

$D_s$ A diagonal matrix whose elements are in the inverse of the semi-axis of the ellipsoid.

$n_1, n_2, n_3$ Orthonormal vectors ($n_i^t n_i = 1$, $n_i^t n_j = 0$, $i \neq j$) in the vehicle axis system: $n_1^t r = p_1$ defines the plane in which the panel lies $n_1^t r = p_2$, $n_2^t r = p_2 + d_2$, $n_3^t r = p_3$ and $n_3^t r = p_3 + d_3$ define the edges of the panel.

The equation of the terminator plane $n^t r = p$ (a plane that separates what can be seen from that which cannot be seen of the ellipsoid, when viewed in the direction of the normal of the vehicle panel plane $n_1$) is first determined. Consider $\| Ax - b \|_2$ where $A$ is a $m \times n$ matrix, let the gradient vector of $\| Ax - b \|_2$ be the $n \times 1$ vector $g$ whose $i$th component is $\frac{\partial}{\partial x_i} \| Ax - b \|_2$. Let $v$ be the displacement from the centre of the ellipsoid to the ellipsoid in the segment reference. It follows that $\| D_s v \|_2^2 = 1$ and the gradient of $\| D_s v \|_2^2$ is $g = 2D_s^2 v$. For $v$ to be a point in the terminator plane $g^t P_s P_s^t v = 0 = v^t (D_s^2 P_s P_s^t v)$ and hence the terminator plane passes through the centre of the ellipsoid. Thus the terminator normal $n$ is such that $v^t (P_s P_s^t n) = 0$. Since the dimension of the space spanned by $v$ is two, we may take $n$ (normal not necessarily unit length) to be $n = P_v P_s D_s^2 P_s^t n_1$ and hence $p = n^t P_v (P_s y_s + z_i)$ where $n$ denotes a unit vector, since the terminator plane passes through the centre of the ellipsoid.

The determination of the maximum penetration of the panel through the ellipsoid is now considered. The penetration is computed as the displacement from the panel in a direction opposite to that of the normal of the panel, to where a parallel panel just touches the ellipsoid, the force associated with the penetration being applied at this point.

A point $r$ on a panel parallel to the original panel but displaced in a direction to that of the normal of the panel is given by

$$r = \begin{bmatrix} d_2 u_1 - l_1 n_2 \frac{d_3}{u_2 - l_2} n_3 - n_1 \\ p_2 - \frac{l_1 d_2}{u_1 - l_1} n_2 + \frac{p_3 - l_2 d_3}{u_2 - l_2} n_3 \\ p_1 + l_3 n_1 \end{bmatrix} x$$

where the parametrisation $x$ satisfies $l \leq x \leq u$. For convenience $r$ will be written $r = Mx + h$. In the segment reference the displacement from the centre of the ellipsoid to the parallel panel is thus $P_s P_v^t (Mx + h) - (y_s + P_s z_i)$. Consider $\| Ax - b \|_2^2$ where $A = D_s P_s P_v^t M$ and $b = D_s (y_s + P_s (z_i - P_v^t h))$, and denote by $\bar{x}$ the vector which minimizes $\| Ax - b \|_2$. Let $v$ be the displacement from the centre of the ellipsoid to the ellipsoid in the segment reference. It follows that $g = 2D_s^2 v$. For $v$ to be a point in the terminator plane $g^t P_s P_s^t v = 0 = v^t (D_s^2 P_s P_s^t v)$ and hence the terminator plane passes through the centre of the ellipsoid. Thus the terminator normal $n$ is such that $v^t (P_s P_s^t n) = 0$. Since the dimension of the space spanned by $v$ is two, we may take $n$ (normal not necessarily unit length) to be $n = P_v P_s D_s^2 P_s^t n_1$ and hence $p = n^t P_v (P_s y_s + z_i)$ where $n$ denotes a unit vector, since the terminator plane passes through the centre of the ellipsoid.

The equation of the terminator plane $n^t r = p$ (a plane that separates what can be seen from that which cannot be seen of the ellipsoid, when viewed in the direction of the normal of the vehicle panel plane $n_1$) is first determined. Consider $\| Ax - b \|_2$ where $A$ is a $m \times n$ matrix, let the gradient vector of $\| Ax - b \|_2$ be the $n \times 1$ vector $g$ whose $i$th component is $\frac{\partial}{\partial x_i} \| Ax - b \|_2 = 1$ subject to $l \leq x \leq u$ and $x_a$ is a maximum. If $\| Ax - b \|_2^2 > 1$ then all $r$ lie outside the ellipsoid. If $\| Ax - b \|_2^2 = 1$, then $x_3 - l_3$ gives the maximum penetration. An outline of the computation of $\bar{x}$ is now given.

Consider minimizing $\| Ax - b \|_2$ subject to $l \leq x \leq u$ where $A$ is a $m \times n$ matrix of full rank. The solution may be computed iteratively via a sequence of feasible points $x^r$ that is $l \leq x^r \leq u$. [19, 21 and 23] Thus consider $x^r$ (possibly permuted) to be partitioned $[x_1^r \, x_2^r]$ where $x_1^r$ is a $(n-k) \times 1$ vector and that $\| Ax - b \|_2^2$ is a minimum with $x_2^r = d$ a known vector. There exist orthonormal $m \times m$ matrices $Q (Q^t Q = I, the identity matrix) such that $Q (A \mid b)$ is of the form

$$[R_{11} R_{12} \mid b_1]$$

where $R_{11}$ is a nonsingular $k \times k$ matrix (usually upper triangular). For a minimum of $\| Ax - b \|_2^2$ it follows that $R_{11} x_1^r = b_1 - R_{12} x_2^r$ and hence $x_1^r$ could be computed by back substitution since $x_2^r = d$ is known. The gradient vector $g$ is such that

$$g^t = 2 \begin{bmatrix} R_{11}^t (R_{12} x_2^r - b_2) \end{bmatrix}$$

If, for all $k + 1 \leq i \leq n$, either

$$x_i = l_i \text{ and } g_i > 0 \text{ or } x_i = u_i \text{ and } g_i < 0,$$

then $\| Ax - b \|_2^2$ cannot be reduced. However, if (3) is not satisfied when $i = p$, then $\| Ax - b \|_2^2$ may be reduced by varying the previously fixed variable $x_p$. Let $x = x^r + \delta x$
minimize $\| Ax - b \|_2^2$ with $x_2 = d + \alpha e_{p-k}$ where $e_{p-k}$ is the $(p-k)$th column of a $(n-k)x(n-k)$ identity matrix. If $s$ is the $k\times 1$ vector such that $R_{11}s = -R_{12}e_{p-k}$ then $\delta x = s$ and

$$
\| Ax - b \|_2^2 = a^2 \| R_{22}e_{p-k} \|_2^2 + ag_p (4)
$$

$$
\delta g = 2\alpha \begin{bmatrix} 0 \\ R_{22}^T R_{22} e_{p-k} \end{bmatrix}, \text{ where } g = g^r + \delta g \ (5)
$$

If it is required that $\| Ax - b \|_2^2 = 1$, then (4) may be solved for $\alpha$, the maximum value of $\alpha$ when $p = 3$ (assuming the last component is not permuted) being required for the maximum penetration calculation. Also from (4) we may determine the reduction in $\| Ax - b \|_2^2$ as $\alpha$ is varied, thus we may choose the $p$ so that of all $k + 1 \leq i \leq n$, which do not satisfy (3), $i = p$ gives the maximum reduction of $\| Ax - b \|_2^2$ subject to feasibility of the $p$th variable [ref. 19] and thus optimise on the constraint to be freed.

In varying the $p$th constraint subject to feasibility of the $p$th variable, it is possible that $x_1 = x_1^r + \alpha s$ may not satisfy the constraints; when this occurs $x = x^r + \mu \delta x$ is used where $0 \leq \mu < 1$ is a maximum subject to the feasibility of $x$. Assume the $j$th constraint is invoked, $1 \leq j \leq k$. The partition $x_1$ may be permuted so that $j$th variable is in the $k$th position ($j$th variable replaces $k$th and $(i + 1)$th replaces $i$th, $i = j, j + 1, \ldots , k - 1$) and the corresponding permutation of the columns of (1), may be premultiplied by orthonormal matrices to recover the form (1) with $k$ reduced by 1 (ref 23) and then we may continue to vary the $p$th constraint.

If $\alpha$ is varied so as to minimize $\| Ax - b \|_2^2$ and the resulting $x$ is feasible, then the partition $x_2$ may be permuted so that the $(p-k)$th variable is the first position ($p$th variable of $x$ replaced $(k+1)$th and $i$th replaces $(i+1)$th, $i = k + 1, k + 2, \ldots , p - 1$) and the corresponding permutation of columns of (1) may be premultiplied by an orthonormal matrix to recover the form (1) with $k$ increased by 1. Thus, the existence of the form (1) has been established.

For the computation of $\bar{x}$ for the maximum penetration, $\| Ax - b \|_2^2$ is reduced subject to feasibility until a point is reached such that $\| Ax - b \|_2^2 < 1$. Then steps (i) and (ii) are performed repeatedly until $\| Ax - b \|_2^2 = 1$ with $\| Ax - b \|_2^2$ a minimum with $x_3$ fixed which is the required solution, where step (i) is vary $x_3$ so that $\| Ax - b \|_2^2 = 1$ and $x_3$ is a maximum and step (ii) is with $x_3$ fixed $\| Ax - b \|_2^2$ is minimized.

From one time step to the next constraints satisfied as equalities will usually be the same and this may be used to advantage as follows. For the partitioning at the solution of the previous time step, reduce $A \mid b$ to the form (1). If $\| Ax - b \|_2^2 = 1$ for the previous time step then $x_3$ is varied according to (4) so that $\| Ax - b \|_2^2 = 1$ for the current time step. Then for the current time step, $x_1$ is computed ($\| Ax - b \|_2^2 \geq 1$ for previous time step) by solving $R_{11}x_1 = b_1 - R_{12}x_2$. If the solution is feasible and of the same type, that is $\| Ax - b \|_2^2$ is still greater than 1 or equal to 1 as in previous time step, the solution is accepted; otherwise recourse is made to an iterative solution.

It is straightforward, and on current computers desirable, to implicitly deal with the permutations of $x$ and the columns of the form (1) by using a $n\times 1$ array $c$ in such a way that the variables $x_{cj}$, $j = 1, 2, \ldots , k$ correspond with the permuted variables ($x_1$)j and the variables $x_{cj}$, $j = k + 1, \ldots , n$ correspond with the permuted variables ($x_2$)j-k. Thus columns $c_j$, $j = 1, 2, \ldots , k$ of $A$ are pre-multiplied by orthogonal matrices to obtain the upper triangular matrix of form (1).

Two methods were used for the orthonormal reduction of $(A \mid b)$: they were the modified root free Givens method [refs. 20 and 22] and Householder transformation (ref 24). When $A$ is initially triangularised, Gentleman's [ref. 20] scheme is directly applicable to the updates to $A$ as a variable is freed or fixed.
Is this a specified contact period?

Yes

Single step algorithm

Is assumption of same contact type as previous step valid?

Yes

Compute penetration

No

Iterative algorithm

Iterate to determine type of contact and penetration

Is penetration >0?

Yes

Check contact conditions flags of previous time step

No contact

Invalid contact

Contact

Determines which side of terminator plane

Valid

Compute forces

Compute forces
Dummy Measurement as a Scale for Occupant Protection

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INTRODUCTION

The objective of all measures taken to increase the mitigation of injuries in road traffic is to arrive at a minimum risk of bodily injury for all road users—motor vehicle occupants, pedestrians, and cyclists—during an accident. Understandably, it does not suffice to retrospectively evaluate the effectiveness of a safety measure, that is, on the basis of the accident analysis. It is necessary to determine the possible benefit of a safety measure during the development stage of a vehicle. This must be done on the basis of objective data. The dummy is used during a simulated accident to measure the mechanical loads—such as accelerations and forces—in order to provide information on the possible risk of injury a human would incur if he were exposed to the same accident loads. This underlines the necessity of research work in biomechanics.

On the one hand, dummies must be developed that can supply reliable, reproducible data without being destroyed; on the other hand, knowledge must be developed that allows correlation between dummy measurement and human injuries, dummy response must validly represent medically defined injuries of the human road user.

This paper deals essentially with the present state of development of dummies using the extensive experience gained by Volkswagen to submit recommendations.

THE DUMMY IN USE

The use of dummies in automotive research and development work can be seen primarily in the performance evaluation of the interaction of the vehicle and the restraint system. The dummy is a measurement device that represents vehicle occupants and pedestrians. It should allow repeatable testing, simulation of human kinematic response (to some degree), easy instrument installation, and resistance to damage. With the present state of biomechanical knowledge, the question arises whether the dummy defined in Part 572 can still be used as the scale for occupant and pedestrian protection. It may be necessary to have a new approach to the evaluation of vehicles in crash events.

Of the dummies used today only two types are specified precisely: The dummy used for the seatbelt tests in accordance with the ECE-Regulation No. 16, and the dummy used for the evaluation of passive restraints in accordance with 49 CFR, Part 572. The differences in design and the purpose of these dummies are shown in figure 1.

Figure 1. Dummy measurements.

US—Part 572 (Hybrid II-dummy)

- Head:
  - HIC ≤ 1000

- Chest:
  - SI ≤ 1000
  - $a_{pe} ≤ 60$ g ($t > 3$ ms)

- Femur:
  - $F < 1700$ lb
  - (2250 lb)

ECE—No. 16 (TNO-dummy)

- Chest:
  - Forward movement $s = 200 \div 300$ mm

- Pelvis:
  - Forward movement $s = 100 \div 200$ mm
All other dummies, for example, one, three and six-year-old child dummies, 5 percent female, 95 percent male, and other types of 50 percent male dummies—such as the Opat dummy—are specified only in terms of dimensions and not in terms of performance under impact conditions. The dummies are used in the simulation of frontal, side, rear, rollover, pedestrian, and cycle accidents.

BIOMECHANICS

Although this paper deals only with dummy representation of motor vehicle occupants, it should be mentioned that because of different load applications in pedestrian accidents, different protection criteria may be required for motor vehicle occupants and pedestrians.

Figure 2. Injury pattern to restrained and unrestrained vehicle occupants.

The analysis of real accidents supplies information on the frequency of accident injuries to the various parts of the body of motor vehicle occupants. Figure 2 shows the results of two accident analyses [1, 2]. The schematic shows the injury frequencies for nonbelted and belted motor vehicle occupants.

With these frequencies and with the information about kind and severity of these injuries, a ranking order of the degree of hazardousness of different injuries can be prepared. On the basis of such a ranking order, a decision can be made about what biomechanical problems must be given priority to better adapt the technology of occupant restraint to the human being.

Development of Protection Criteria

The most prominent objective of biomechanical research is to prepare protection criteria. Protective criteria are to be understood as upper limits of mechanical loads measured on the dummy, such as accelerations and forces. Compliance with such criteria is meant to insure that a humanly tolerable degree of injury is not exceeded with equivalent input loads.

Injury criteria can be derived from human load tolerances, taking into account a safety margin that has yet to be established. On the other hand, injury criteria must be translated into protection criteria. The effects of sex, age, anthropometrics, and mass distribution of the human must be accounted for.

Suggested Priorities for the Definition of Protection Criteria

In 1974, the Volkswagenwerk AG contracted for a literature study entitled “Biomechanical Load Data” with the Institute for Automotive Technology of the Berlin University [3]. The objective of this study was to define the present state of knowledge in biomechanics. The Department of Transportation of the German Federal Republic published an extensive study on this subject in 1976 [4].

Working Group 4 of the European Experimental Vehicles Committee (EEVC) published a report in 1976 [5] that tries to define load limits, injury criteria, and protection criteria on the basis of present day knowledge. On the basis of this work, as well as on the basis of our own experience in biomechanics and accident analysis, it is recommended that injury and protection criteria be prepared for the body regions indicated in table 1. At this time there is no way to submit statistically certain information on the type and limits of the injuries or protection criteria for any region.

The limited protection criteria measurement capability of the dummy defined in the Federal Motor Vehicle Safety Standards (FMVSS) shows that substantial research work must be done in this field. The mechanical load data to be measured on the dummy or derived from test data are indicated in table 2. Furthermore, the reproducibility of the measuring instrument dummy must be substantially increased to provide more certainty of the test data. This will be dealt with in detail further on.

It was mentioned earlier that future research must show whether the suggested data suffice in describing the risk of injury to a human, and to define, if possible, their upper permissible limits.

The specified FMVSS dummy can only be used for measurement of acceleration on the head, on the thorax and on the pelvis in the three main axes, and force in the left and right femur. If one looks at how reproducible these measurements are and what kind of

Table 1. Recommendation for the elaboration of injury and protection criteria as a function of the direction of load application

<table>
<thead>
<tr>
<th>Region of the body</th>
<th>Direction of load introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frontal impact</td>
</tr>
<tr>
<td>Head</td>
<td>X</td>
</tr>
<tr>
<td>Neck</td>
<td>X</td>
</tr>
<tr>
<td>Thorax</td>
<td>X</td>
</tr>
<tr>
<td>Pelvis</td>
<td>X</td>
</tr>
<tr>
<td>Femur</td>
<td>X</td>
</tr>
</tbody>
</table>
Table 2. Suggestions for the measuring of mechanical dummy load data

<table>
<thead>
<tr>
<th>Body region</th>
<th>Stroke and derivations by time</th>
<th>Evaluated acceleration</th>
<th>Angles and derivations by time</th>
<th>Force</th>
<th>Momentum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>Acceleration in the center of gravity in 3 directions</td>
<td>HIC acceleration increase over time</td>
<td>Bending angle around X and Y axes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck</td>
<td>Deformation along X-direction</td>
<td>SI acceleration increase over time</td>
<td>Longitudinal force</td>
<td>Transversal force</td>
<td></td>
</tr>
<tr>
<td>Chest</td>
<td>Acceleration in the center of gravity in three directions; translational</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelvis</td>
<td>Acceleration in the center of gravity in three directions, translational</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Femur</td>
<td>Deformation</td>
<td>Longitudinal force</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

parameters the measured results influence, the following factors have to be analysed.

- Precision of manufacturing
- Precision of repair and adjusting work, aging
- Test environment, such as change of velocity, vehicle interior, seating, positioning, temperature, and humidity

**DUMMY MEASUREMENT TECHNIQUE**

**Dummy Manufacturing Process**

To avoid differences in the dummy manufacturing process, the FMVSS Part 572 has very precisely defined design and performance criteria. Aside from the fact that the thorax requirements are difficult to fulfill, we have found that large variations can occur in the results of testing the same dummy [6], even in tests in accordance with the part 572 procedure. Humanoid systems produced the results shown in table 3 in a cycle test.

If we compare the maximum deviation for each dummy to the mean value, then we find in the 14 ft/s chest test a maximum deviation of +5.0 percent to -5.1 percent from the mean peak force and a deviation of +23.5 percent to -12 percent for the chest deflection, for the 22 ft/s test a maximum deviation of +7.6 percent to -12.2 percent for the peak force and +13.4 percent to -19.7 percent for the chest deflection.

Even when the test equipment for the dummy is the same, the response variations for the tested dummy are significant. An evaluation of a series of dummy tests, which were performed by an independent testing institute, gave the differences shown in table 4. The results of test series No. 1 were set 100 percent.

The question of how much the differences in the Part 572 test influence the full scale barrier and/or the sled test can not be answered yet. One reason is that the Part 572 tests are done partly on the disassembled dummy, and another reason is the overall measurement tolerance.

Another source of variation is the impact direction to the dummy. Daniel et al. [7] reported a variation of the accelerometer
Table 3. Thorax cycle test of humanoid systems

<table>
<thead>
<tr>
<th>Testing company</th>
<th>Test speed (ft/s)</th>
<th>Peak force (lb)</th>
<th>Deflection (inch)</th>
<th>Hysteresis (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dummy 1:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humanoid 1</td>
<td>14</td>
<td>1 039</td>
<td>0.91</td>
<td>61.0</td>
</tr>
<tr>
<td>Humanoid 2</td>
<td>14</td>
<td>1 086</td>
<td>0.97</td>
<td>57.4</td>
</tr>
<tr>
<td>Company A</td>
<td>14</td>
<td>1 150</td>
<td>0.9</td>
<td>61.2</td>
</tr>
<tr>
<td>Company B</td>
<td>14</td>
<td>1 100</td>
<td>1.1</td>
<td>58.0</td>
</tr>
<tr>
<td>Humanoid 1</td>
<td>22</td>
<td>1 924</td>
<td>1.47</td>
<td>65.8</td>
</tr>
<tr>
<td>Humanoid 2</td>
<td>22</td>
<td>1 816</td>
<td>1.58</td>
<td>64.2</td>
</tr>
<tr>
<td>Company A</td>
<td>22</td>
<td>1 770</td>
<td>1.4</td>
<td>60.0</td>
</tr>
<tr>
<td>Company B</td>
<td>22</td>
<td>1 700</td>
<td>1.7</td>
<td>58.0</td>
</tr>
<tr>
<td>Dummy 2:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humanoid 1</td>
<td>14</td>
<td>1 210</td>
<td>0.86</td>
<td>68.0</td>
</tr>
<tr>
<td>Humanoid 2</td>
<td>14</td>
<td>1 114</td>
<td>0.84</td>
<td>65.0</td>
</tr>
<tr>
<td>Company C</td>
<td>14</td>
<td>1 232</td>
<td>0.91</td>
<td>53.0</td>
</tr>
<tr>
<td>Humanoid 1</td>
<td>22</td>
<td>1 711</td>
<td>1.54</td>
<td>75.0</td>
</tr>
<tr>
<td>Humanoid 2</td>
<td>22</td>
<td>1 910</td>
<td>1.54</td>
<td>70.2</td>
</tr>
<tr>
<td>Company C 1</td>
<td>22</td>
<td>1 984</td>
<td>1.14</td>
<td>52.2</td>
</tr>
<tr>
<td>Company C 2</td>
<td>22</td>
<td>2 086</td>
<td>1.30</td>
<td>55.8</td>
</tr>
<tr>
<td>Dummy 3:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humanoid 1</td>
<td>14</td>
<td>1 103</td>
<td>1.00</td>
<td>64.1</td>
</tr>
<tr>
<td>Humanoid 2</td>
<td>14</td>
<td>1 082</td>
<td>0.95</td>
<td>64.4</td>
</tr>
<tr>
<td>Company D 1</td>
<td>14</td>
<td>1 059</td>
<td>0.66</td>
<td>54.9</td>
</tr>
<tr>
<td>Company D 2</td>
<td>14</td>
<td>1 110</td>
<td>0.63</td>
<td>51.4</td>
</tr>
<tr>
<td>Humanoid 1</td>
<td>22</td>
<td>1 873</td>
<td>1.54</td>
<td>61.0</td>
</tr>
<tr>
<td>Humanoid 2</td>
<td>22</td>
<td>1 892</td>
<td>1.47</td>
<td>59.0</td>
</tr>
<tr>
<td>Company D 1</td>
<td>22</td>
<td>1 544</td>
<td>1.09</td>
<td>55.6</td>
</tr>
<tr>
<td>Company D 2</td>
<td>22</td>
<td>1 724</td>
<td>1.33</td>
<td>50.0</td>
</tr>
</tbody>
</table>

output if the impact angle varies at the head, chest, and femur.

The variation differences between the dummy of an older generation and the Part 572 dummy shows how important the manufacture specification is. In a test series on a Bendix sled the differences between a Sierra 1050 and a Part 572 dummy were evaluated.

The differences in the behaviour between the two dummies can be seen in figures 3 to 6. For the restraint system, normal emergency locking retractor were used. The figures demonstrate only the differences between the dummy outputs and not the performance of the restraint system as a function of velocity change.

Tolerances in Measurement and Calculation Output

The measurement tolerances are in the area of ± 2 percent. The calculation process gives another ± 0.5 percent tolerance, if all parameters are kept as constant as possible. The test conditions were: ΔV=30 mi/h; the acceleration versus time parameter was half sine 26 g peak and 90 ms duration; Part 572 dummies were used; and the restraint system was standard emergency locking 3-point belts. Table 5 gives the average results and the standard deviations of the 15 tests performed.

It can be seen in table 5 that the dummies themselves contribute major variations in addition to the tolerance in testing and the calculation process.

Test Environment Influence

In addition to the tolerances mentioned above, the environment for the tested dummy is influential. The following parameters are of importance:

- Vehicle tested
- Restraint system
Table 4. Dummy A

<table>
<thead>
<tr>
<th>Test performed</th>
<th>Test 1 (percent)</th>
<th>Test 2 (percent)</th>
<th>Test 3 (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1—Head drop test (specification range 210-260 g)</td>
<td>100</td>
<td>92.0</td>
<td>88.8</td>
</tr>
<tr>
<td>2—Neck pendulum test (specification range 63° - 73°)</td>
<td>100</td>
<td>101.5</td>
<td>100</td>
</tr>
<tr>
<td>3—Lumbar flexion test:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Return angle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum 0°</td>
<td>100</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>Range of push force</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20° (20-32 lb)</td>
<td>100</td>
<td>85.2</td>
<td>74.0</td>
</tr>
<tr>
<td>30° (27-39 lb)</td>
<td>100</td>
<td>81.8</td>
<td>90.9</td>
</tr>
<tr>
<td>40° (35-47 lb)</td>
<td>100</td>
<td>83.3</td>
<td>83.3</td>
</tr>
<tr>
<td>4—Abdominal compression test:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 inch (26-43 lb)</td>
<td>100</td>
<td>106.0</td>
<td>90.9</td>
</tr>
<tr>
<td>1.3 inch (41-63 lb)</td>
<td>100</td>
<td>100</td>
<td>95.9</td>
</tr>
<tr>
<td>5—Chest impact tests:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed 14 ft/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum load-1 400 lb</td>
<td>100</td>
<td>100.7</td>
<td>101.0</td>
</tr>
<tr>
<td>Maximum deflection-1 inch</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Speed 22 ft/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum load-2 100 lb</td>
<td>100</td>
<td>99.9</td>
<td>101.6</td>
</tr>
<tr>
<td>Maximum deflection-1.6 inch</td>
<td>100</td>
<td>114.2</td>
<td>114.2</td>
</tr>
<tr>
<td>6—Knee impact test (force range 1 900-2 500 lb):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left side</td>
<td>100</td>
<td>99.6</td>
<td>100.5</td>
</tr>
<tr>
<td>Right side</td>
<td>100</td>
<td>98.7</td>
<td>99.4</td>
</tr>
</tbody>
</table>

- The change of velocity and acceleration-time function if a sled is used
- Dummy-seat friction and seat spring rate
- Test temperature, humidity
- Dummy placement

If one tries to calculate the importance of single points, the following can be achieved.

The test speed can be controlled very precisely. At most test areas the impact speed is controllable at a 30-mi/h nominal test speed between 29.7 and 30.3 mi/h. The ± 0.3 mi/h difference results in tolerance from the 30-mi/h value of less than 2 percent.

Because the seats and dummy clothes might differ slightly from test area to test area, the large variation influence should be mentioned here. We can, with our own test results, support the findings by G.M. [8]. In Bendix sled tests (ΔV = 32 mi/h) we found an average of 30 percent lower HIC with leatherette seats than with cloth seats.

The influence of dummy clothes is small; of much more importance is the seat cushion spring rate. The change of spring rate can occur if seats are used several times during sled tests or a car is subjected to different
tests. The normal tolerances are included in table 5.

The temperature of the dummy has a significant influence on dummy motion. In a Society of Automotive Engineers (SAE) paper [9] the following tolerances for a temperature range of 68°F + 140°F were observed (68°F data = 100 percent):

- Head $a_{res} = 107$ percent
- Chest $a_{res} = 103$ percent
- Chest SI = 114 percent

The influence of the humidity has not yet been investigated in depth.

The dummy replacement is of minor importance in tests with standard 3-point belts if no contact with the vehicle interior occurs. With head contact, placement influence can be significant.
Table 5. Average results and standard deviations

<table>
<thead>
<tr>
<th>Item</th>
<th>Confidence level (percent)</th>
<th>Parameter</th>
<th>Head</th>
<th>Chest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$a_{res}$ (g)</td>
<td>HIC (-)</td>
<td>$a_{res}$ (g)</td>
</tr>
<tr>
<td>Mean value</td>
<td></td>
<td>59.00</td>
<td>468</td>
<td>31.4</td>
</tr>
<tr>
<td>Standard deviation</td>
<td></td>
<td>± 15.85</td>
<td>± 7 g</td>
<td>± 2.6</td>
</tr>
<tr>
<td>± S</td>
<td></td>
<td>84.15</td>
<td>±11.9%</td>
<td>± 8.2%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td></td>
<td>2.3</td>
<td>±14 g</td>
<td>± 5.1</td>
</tr>
<tr>
<td>± 2S</td>
<td></td>
<td>97.7</td>
<td>±23.8%</td>
<td>±16.4%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td></td>
<td>0.15</td>
<td>±21 g</td>
<td>± 7.7</td>
</tr>
<tr>
<td>± 3S</td>
<td></td>
<td>99.85</td>
<td>±35.7%</td>
<td>±24.5%</td>
</tr>
</tbody>
</table>

COMPARISON OF TEST MEASUREMENT AND ACCIDENT INVESTIGATIONS

The tolerances of test measurements are germane to comparison with real world accidents. There are three possible problems in correlating dummy test with accident data:

- The 30-mi/h barrier test may not be representative
- The dummy may not give valid correct output
- The biomechanic data applied to the dummy may not allow a valid prediction of the AIS

In two studies [10, 11] the first problem was eliminated by accident simulation tests. The result of these tests showed that even with HIC-values well above the limits of FMVSS 208, the vehicle occupants were uninjured or received minor injuries. Furthermore, the measured acceleration in the chest did not correlate directly with actual injuries during the accidents.

ALTERNATIVES

The known alternatives to dummy testing are volunteer tests, cadaver tests, and mathematical models. The volunteer test can be used only for tests where no injuries are expected. The cadaver tests contribute importantly to the determination of injury levels. Cadaver test research work has been reported, for example, in SAE papers. [12, 13] The cadaver test can never be used as a compliance test. The only alternative is the use of mathematical models for which a knowledge of the number of parameters is necessary. The use of these models for compliance testing might not be possible in the near future.

In our opinion, the main problems of biomechanic criteria and dummies lie with the admixture of research work and compliance testing. To design more complicated dummies is not the best solution. There should be a clear differentiation between research and standard compliance. The volunteer, cadaver, and complicated dummy testing should be reserved for research work only. For compliance testing, a dummy should be developed based on the research data existing today. This dummy should have very simple and easily replaceable parts and, instead of the accelerometers used today, impact severity indicators for the chest and head.

Femur force measurement should be maintained. A new dummy chest should allow the
deformation of the chest with a precise measurement technique. The dummy head should have mounted, in the center of gravity, an impact severity indicator. This indicator should react to the acceleration time input based on three axes and the rotational input.

For the compliance test, the test tolerance should be considered when determining the limits.

CONCLUSION

Our results show that the dummy tests today are not sufficient from the point of dummy performance and biomechanical criteria. Differentiation between research and compliance dummies and the criteria for these dummies is necessary. With this new approach, progress in automotive safety can be achieved, whereby new research results could be more easily adopted.

REFERENCES


The Determination of Tolerable Loadings for Car Occupants in Impacts

J. WALL, R. W. LOWNE, and J. HARRIS
Transport and Road Research Laboratory
Department of the Environment
Crowthorne, Berkshire

ABSTRACT

The methods used at the Transport and Road Research Laboratory to determine tolerable loadings for car occupants in impacts are based on correlating injuries received by living human car occupants in accidents with measurements made on dummies or test devices suitable for research or approval testing in laboratory simulations of these accidents. Where suitable accident data exist a statistical technique is used which enables the proportion of the population at risk who will suffer injury at any given level of loading to be predicted. Predictions of the effect in terms of injury incidence to the population can be made for any level of load limitation. These predictions may be used in forming regulations and to guide the design of vehicle systems, for example of occupant restraints. Three examples are discussed; the loadings produced by a safety belt, the knee/thigh/hip loading resulting from knee impact with the fascia and loadings on car occupants in side impacts.

INTRODUCTION

If safety belts and other occupant protection features of the car interior are to be further improved they must be designed to match closely the greatest forces that various parts of the human body can safely bear in an impact. Thus the proportion of impact energy of the occupant which can be absorbed in the space available is maximised. These tolerable loads vary from individual to individual and a knowledge of this variation is also essential when considering the effects of adopting any given design load level on the numbers of injuries to be expected.

This paper reviews a method of human tolerance estimation usually followed in the United Kingdom for determining the loads on a test dummy which are representative of loads critical for injuring car occupants in vehicle impacts (injury threshold levels). There are various approaches to the problem of determining injury threshold levels for different parts of the human body. Anthropomorphic dummies, whilst useful for studying general load distributions on the human body exerted by various restraint devices, cannot provide any data on injuries unless the dummy has been designed to fail at the same loads as a human being. Such design presupposes knowledge of the human injury threshold level. Tests with live animals can produce data that are of value as a very general guide, but even the large apes are so different from man that it is quite probable that their injury patterns as well as threshold levels will differ from those of humans for most impact conditions. Human volunteer tests can provide data on voluntary tolerance levels but cannot be expected to determine serious injury levels. Tests using cadavers have provided most of the accepted data for human serious injury threshold levels with some correlation with live human volunteer tests at lower noninjurious impact levels. Such tests are however open to criticism on several points. The cadavers have no muscle tone or muscular reaction. Quite often they have been embalmed and a disproportionate number of the cadavers used may be from old people, those in poor physical condition, or people who have been confined to bed for some considerable time prior to death.

In view of these problems, the method adopted by the Transport and Road Research...
Laboratory (TRRL) is to collect data from actual accidents and to attempt to interpret these data to determine injury threshold levels. Either the vehicle deceleration is deduced from the vehicle damage and accident circumstances and used to specify a test impact condition on a dummy or an impact test form is projected into the part of the vehicle damaged by the injured person. In both cases it is possible to make measurements on the dummy or test form and to correlate these measurements with the injury data from the accidents. Using statistical techniques it is possible not only to estimate injury tolerance levels for the population as a whole but also where sufficient accident data exist to predict how these tolerance levels vary within the population at risk.

ACCIDENT AND INJURY DATA COLLECTION

In one system of accident data collection which has been employed at the Transport and Road Research Laboratory, only accidents in which at least one person had been seriously injured and retained in hospital were investigated [1]. Medically qualified members of a Traffic Medicine team regularly visited the various local accident hospitals and interviewed road traffic accident casualties on a voluntary basis to discover details both of the accident and of the injuries resulting from the accident. The vehicles involved in the accidents investigated were examined both internally and externally and the damage noted and photographed. An attempt was made to associate the occupants’ injuries with various internal features of the vehicle by looking for damage to the vehicle interior caused by the impact of the occupant.

The sample of road accident casualties is obviously not representative of the whole population of those involved in road accidents and care must be taken when using the results. Nevertheless, it represents the most important group of injuries, namely the most serious ones. The sample of casualties investigated is eminently suitable for the determination of human tolerance to impact injury.

TEST DEVICES

For assessing occupant protection in vehicles the test device used needs to be not only sufficiently representative of the occupant for the impact under investigation but also simple, robust, easy to calibrate, and capable of producing reproducible results.

Three human tolerance investigations have been carried out at the Transport and Road Research Laboratory to date and each used very different devices which met these requirements in different ways.

The first investigation [2] was into the tolerable load that can be transmitted along the femur to the hip joint as a result of occupant knee impact in a vehicle accident. The device used was a solid metal cylinder with a hemispherical end of size and mass to represent the size and effective mass of a car occupant’s knee in an impact (fig. 1).

The second investigation [3] was to determine tolerable loads on the human frame in side impact accidents to permit evaluation of the injury potential of vehicle side structures. For this a special dummy has been developed (fig. 2). It is essentially a load measuring device rather than an anthropomorphic dummy with sophisticated biokinetic fidelity and is intended specifically for use in a position adjacent to the point of impact, to evaluate the distribution and magnitude of the forces acting on the dummy. A specialised dummy was required for this evaluation because the anthropomorphic dummies in general use for assessing the safety of motor vehicles are usually only equipped to measure accelerations (head and chest and occasionally pelvis). In side impacts the vehicle occupant may be separated from the introducing object by no more than the thickness of a door. Under impact loading this structure may collapse possibly forming creases, which may cause high local loadings on the vehicle occupant.

Figure 1. Knee impact form.
The decelerations to the thorax and the pelvis that might result from such forces may in many instances be of relatively low magnitude and injury would not occur if the same level of deceleration was caused by widely distributed loads. In order therefore to evaluate the injury potential of a vehicle side structure, a knowledge of the skeletal forces as well as the dummy decelerations is required (fig. 2).

In the third investigation which was into tolerable levels of loading applied to car occupants by three point lap and diagonal safety belts [4] a sophisticated test dummy developed specially for occupant protection assessment work was used (fig 3). This OPAT (Occupant Protection Assessment Test) dummy was developed as a result of a co-operative contract between the British Government, the Motor Industry Research Association, and...
Ogle Design Ltd. It was designed to be a simple robust test dummy capable of giving repeatable results under similar test conditions yet being sufficiently human like in performance for use in tests for the development of safer road vehicles. The construction and development testing of the dummy have been described elsewhere [5, 6, 7]. Particular attention was paid to the dynamic behaviour of the chest, including an inertia component to simulate the dynamic loading from the chest contents, and a means of load transfer from the arms of the rib cage via the scapula. The shoulder action and pelvic design have made this dummy particularly suitable for tests to evaluate seatbelts. This dummy, while not designed specifically to comply with all aspects of the part 572 specification, is currently undergoing evaluation for the National Highway Traffic Safety Administration (NHTSA).

Clearly the technique for human injury tolerance determination described in this paper is applicable to any suitable dummy or test device but the dummy used must itself be calibrated against the accident data.

MEASUREMENTS USED TO COMPARE SEVERITY OF ACCIDENTS AND TEST IMPACTS

To relate the accident data to the transducer readings obtained during the laboratory tests some method of categorising the severity of the accident is necessary. The tolerance level of the hip joint to forces caused in road accidents by knee impacts with vehicle fascias, was estimated from the depth and type of dent in the fascia. These depths and types of damage were reproduced in similar fascias using the kneeform and so the forces measured could be correlated with the injury data. In determining human tolerance to injury in side impacts, the external deformation of the vehicle side structure was used as a measure to compare the severity of the impact on the road with the impact in the tests. This deformation was reproduced in both car-to-pole and car-to-car side impacts.

In the case of wearers restrained by seatbelts there is seldom any reliable indication on the belt of load levels attained in the impact. Permanent stretch of the webbing is an unreliable indicator because recovery occurs slowly. Deformation of the anchorages occurs very infrequently but when present it could be used. Rupture of the seatbelt also occurs very rarely but it then gives a good indication of the peak load which has been exerted by the seatbelts on the wearer during the impact. For the investigation carried out at the Laboratory it was decided to use change of velocity during impact as an indicator in order to make maximum use of the available injury data. This indicator was estimated using results from impact tests on similar vehicles at various speeds and with similar frontal damage and by taking account of the details of the individual accident events recorded by the investigation team. Only accidents with a predominantly frontal component were considered. Tests were then carried out using the OPAT dummy restrained by typical safety belts on a dynamic test rig at various impact speeds with typical car deceleration pulses to decelerate the rig. The belt and dummy measurements from these tests were correlated with the injury data from the accident investigations.

STATISTICAL TECHNIQUES

Where sufficient accident data exist, as in the case of the knee, thigh, hip, and seatbelt loading investigations, the proportion of occupants likely to be injured for each value of loading can be estimated from the results by relating test loadings to injury in the actual accidents using a statistical technique known as probit analysis [8]. This, in effect, enables the calculation of a probability regression curve to predict the expected likelihood of injury at any level of loading for the whole population from which the sample comes. The method also permits the estimation of the probable accuracy of the analysis that is improved not only by increasing the size of the sample but also by choosing a particular parameter representing the loading which is closely linked to the injury mechanism.

Using these regression curves together with the distribution of impact severities found in the accident sample, estimates can be made of
the effects of design modifications on the overall injury rates to be expected from the population represented by the sample.

As an example of this technique, figure 4 gives the predicted incidence of skeletal chest injury attributed to seatbelts in accidents as a function of shoulder belt tension measured on the OPAT dummy in representative laboratory tests. Table 1 gives the numbers in the sample involved in accidents who, on the basis of figure 4, might be expected to suffer such chest injury. From figure 4 and table 1 it can be seen that fitting a seatbelt with a shoulder belt energy-absorbing device limiting the load to 7 kN would have very little effect on the overall incidence of chest injuries because very few people would be expected to experience such high loadings. However, if the limit were set between 4 and 5 kN these injuries would be reduced by about half. The predicted effect of various settings of a shoulder belt load limiter on the incidence of chest injuries caused by seatbelt loadings is plotted in figure 5. When carrying out this type of analysis it must be remembered that the figures considered here are only those concerning injuries due to seatbelt loadings. Fitting a force-limiting device may mean that there is more forward movement of the occupant in the vehicle and so more risk of injury due to impact with the interior of the vehicle. If the webbing of the belt is made stiffer when the force limiter is fitted to reduce this forward movement then it may mean that overall injuries due to belt loadings may increase. This would be due to the higher incidence of injuries to people at the lower end of the tolerance spectrum in low velocity impacts as a result of the somewhat higher loads developed by the stiffer webbing in these impacts.

This technique permits consideration of appropriate load settings for modifications to the seatbelt consisting of a crash tensioning device used in addition to a load limiter. It is important not to set the tensioning loads too high when these devices are used. For example, in all accidents, 4.5 kN was generated in the shoulder strap. Figure 4 and table 1 indicate that the reduction in these cases of chest injuries attributed to seatbelts would remain close to 50 per cent; however, this saving would be decreased and might well become a loss because of the considerable additional number of low severity impacts which would then be included in the sample because the 4.5 kN load would be generated in these and there would be about a 17 per cent expectation of chest injury for these extra cases. The ratio of slight to fatal and serious injuries to seatbelt wearers reported in Great Britain in 1973 was about 3.5 to 1 [9]. If it is assumed that all the slight injury-producing impacts would have triggered the seatbelt tensioner, fitting such a device set to 4.5 kN would have resulted in a net 155 per cent increase in chest injuries attributable to seatbelt loadings. There would need to be a very considerable reduction in injuries to other parts of the body to offset this, apart from the additional cost of the device. If the tensioner had been set to 2 kN then the figures predict a 20 per cent reduction in chest injuries due to seatbelt loading and in addition there would be a reduction in head injuries due to the reduced forward movement brought about by the tensioner eliminating slack in the belt system.

Finally all these calculations have not taken into account any possible dependence of the risk of chest injury on the duration of loading. Over the range of duration involved
Table 1. Analysis of accident chest injury data and shoulder belt tensions measured experimentally with an OPAT dummy

<table>
<thead>
<tr>
<th>Change in velocity (km/h)</th>
<th>Numbers in sample</th>
<th>Numbers in sample with chest injury attributed to belts</th>
<th>Shoulder belt tension on OPAT (kN)</th>
<th>Predicted incidence of injury</th>
<th>Predicted number of chest injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>In accident sample</td>
<td>If shoulder belt limiter is set at</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6kN</td>
<td>5kN</td>
</tr>
<tr>
<td>26</td>
<td>1</td>
<td>0</td>
<td>3.1</td>
<td>6</td>
<td>0.1</td>
</tr>
<tr>
<td>27</td>
<td>3</td>
<td>0</td>
<td>3.3</td>
<td>7</td>
<td>0.2</td>
</tr>
<tr>
<td>29</td>
<td>1</td>
<td>0</td>
<td>3.5</td>
<td>8</td>
<td>0.1</td>
</tr>
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<td>0</td>
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<td>9</td>
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<td>13</td>
<td>0.5</td>
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<td>2</td>
<td>0</td>
<td>4.3</td>
<td>15</td>
<td>0.3</td>
</tr>
<tr>
<td>37</td>
<td>1</td>
<td>0</td>
<td>4.5</td>
<td>17</td>
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<td>1</td>
<td>4.7</td>
<td>19</td>
<td>0.6</td>
</tr>
<tr>
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<td>87</td>
<td>26</td>
<td></td>
<td>26.1</td>
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</table>

Predicted reduction in risk of chest injuries attributed to belt loadings (%) 7.0 32.0 61.0

in this analysis this effect is thought to be low.
Sufficient accident data are not yet available to permit the application of such techniques to the study of human tolerance to side impacts.

HUMAN TOLERANCE INVESTIGATIONS

Knee/thigh/hip

This investigation was reported in reference 2. Briefly, data were collected from accidents in which the knees of the occupants had caused damage to fascias. This damage was reproduced in the Laboratory on identical undamaged fascias by impacting with a cylindrical knee form with a hemispherical end of radius 40 mm having a mass of 20 kg. The deceleration of this knee form was used to calculate the peak force which was related to the presence or absence of injury to the hip joint of the occupant in the corresponding accident. Table 2 lists the incidence of injury and the measured equivalent loads on the knee form required to reproduce the accident damage for the three models of vehicle considered. Figure 6 is a plot of percentage of population likely to suffer hip injury against knee form load. Figure 7 plots the percentage reduction predicted in hip injury against the knee form load requirements levels.
Side Impact Loadings

These studies will be reported fully at the forthcoming Stapp Conference [3]. The side impact dummy was seated in a vehicle adjacent to the site of impact and the vehicle was impacted either by a mobile barrier or against a pole depending on the circumstances of the accident to produce comparable intrusion damage. Estimations of tolerance levels from these data are imprecise because of the

Table 2. Knee, thigh, and hip tolerance

(Predicted incidence of skeletal hip injury in three models of car)

<table>
<thead>
<tr>
<th>Load (kN)</th>
<th>Accident sample size</th>
<th>Number of skeletal hip injuries in sample</th>
<th>Predicted incidence of injury % (see Fig. 6)</th>
<th>Predicted number of injuries without load limitation</th>
<th>With requirement for kneeform load limit of 6kN</th>
<th>5kN</th>
<th>4kN</th>
<th>3kN</th>
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<td>6.0</td>
<td>4.6</td>
<td>1.3</td>
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</table>

Reduction—skeletal hip injury (%)

2 25 79 99
accident was reproduced on an impact rig. Deceleration pulses, seatbelt anchorage geometry and types of seatbelt were typical of those vehicles involved in the accidents.

Only injuries attributed to seatbelt loadings in impacts with a predominantly frontal component were considered. Three specific types of injury were selected: fracture of the clavicle, fractured ribs, and internal abdominal injuries. It was decided to use rib fracture as an indication of thoracic tolerance level as, although the consequences of such injuries can range from discomfort if only one rib is fractured to death if multiple rib fractures occur, the fracture of even one rib is an indication that seatbelt loadings are approaching dangerous limits.

Each of these injuries was associated with the change of velocity estimated for the vehicle in which it occurred. The incidence of the injuries in the accident sample was correlated with the loadings measured in the tests using probit analysis as described in the tests on side impact loadings.

CONCLUSIONS

The techniques adopted at the Transport and Road Research Laboratory to determine human tolerance levels by correlating laboratory test data with accident injury data have the following advantages:

1. The tolerance levels are based on a sample of the population at risk and the injuries occur on living human beings involved in accidents.
2. The levels are expressed directly in terms of measurements made on test devices such as impact forms or anthropomorphic dummies that can be used for assessing new occupant protection installations either for research or for ensuring compliance with regulations.
3. Where sufficient accident data exist the variation of the tolerance level within the population at risk can be determined.
4. With this information the likely effects on the incidence of injury of new regulatory requirements or
changes in design features can be estimated.
5. Because of the current need for estimates of human tolerance levels these procedures should be much more widely used and should be an outcome of all suitable crash injury surveys.

ACKNOWLEDGMENTS

This work forms part of the programme of the Transport and Road Research Laboratory and the paper is published by permission of the Director.

REFERENCES

3. Harris, J. The design and use of the TRRL side impact dummy. Paper to be presented at the 20th Stapp Conference.

A Contribution of Sports Medicine to the Knowledge of the Resistance of the Human Body to Impacts and on the Means to Protect Motor Vehicle Occupants

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Some people might be surprised that sports medicine can contribute to the knowledge of the problem of car occupant safety. Most people believe that a sports physician is just the health officer sitting at the edge of the sports field ready to intervene in the event of an accident. Sports medicine is not limited to this. Many scholars work at sports medicine institutes on biomechanics and physiology applied to maximum human performance. It is this study of maximum human performance that deals with the problems related to the resistance of the human body to stress.

Sports medicine now covers such areas as the safety of racing car occupants and the resistance of the human body to impacts that may be similar to those occurring in a car crash.
The resistance of the human body has been studied through the use of dummies, corpses, and animals; nevertheless, these cannot sufficiently simulate the behaviour of the human organism in the event of collisions. We expected corpses to behave as live bodies do. However, the corpses were poorly ossified, badly preserved, and usually from sick, old, or very deteriorated subjects, which are much more fragile than healthy subjects in automobile crashes.

As far as the utilization of volunteers is concerned, it is evident that the tests cannot be taken to the point where serious lesions could occur.

Furthermore, in Italy it is forbidden by law to use human subjects (even volunteers) for experiments that might prejudice in any way the physical integrity of the person. The only source of information originates from the analysis of actual incidents. Needless to say, some of the harmful events that take place in the various sports fields are particularly suitable for study, especially on account of the fact that they occur on healthy subjects whose anthropometric and constitutional data may be considered sufficiently concentrated from a statistical viewpoint and particularly pertinent to the automotive population. In most cases, we deal with young subjects, rarely exceeding 30 years of age, in good physical condition, and in a good state of muscular efficiency.

At this point I would like to examine, in depth, the response of the human organism to harmful events and to impacts having almost equal characteristics and intensity, whose results are absolutely different.

I will use a few examples to clarify this point. In offshore motorboating competitions, the pilots—usually three to a boat—drive and stand side by side. Therefore, the stress caused by the wave-motion that is usually represented by strong vertical oscillations, produces absolutely identical accelerations in all three pilots (who are housed in identical binnacles with suitable safety padding). During offshore competitions there have been cases of pilots suffering from bilateral fractures of the femur; one pilot suffered a rupture of the acetabulum, whereas the nearby pilots—exposed to the same accelerations—suffered no injury at all.

There have been cases of "wedge-shaped" fractures of the spinal column, and, specifically, in the back section between the eighth and the twelfth vertebra. It must be pointed out, however, that the impacts have been so traumatic for some people have produced no injuries at all in the people sitting by their side. Incidentally, the impacts caused by wave motion from the consequent accelerations suffered by the hulls have not caused any structural yielding or damage to the boats—only to the people.

Another example occurred when the first ejection seat/parachutes were made for "Martin Baker"-type fighter plane pilots. At the moment of the ejection, which was achieved by means of an explosive charge, a high percentage of pilots suffered fractures to the upper part of the spinal column, between the eighth and the twelfth vertebra. The percentage of fractures among all pilots who parachuted was 45 percent. It is particularly interesting to note that the remaining 55 percent of the subjects, even though bound to the same type of ejector and, therefore, exposed to the same acceleration, suffered no injury whatsoever. This is just more proof of the differing responses of the human body to the accelerations.

We may presume that the reason for the fracture of the spinal column was the excessive elasticity of the seat, because of the rubber lifeboat that was folded up to be used as a cushion on the pilot's seat. At the time of ejection, the seat would rapidly push up the cushion that would reach a certain speed prior to reaching a pilot's buttocks; the energy gained by the seat was applied to the rest of a pilot's body. The safety boat was moved and the pilots then sat directly on the seat to eliminate the possibility of fractures of the spinal column. An example that more closely resembles a problem of car impacts concerns circuit pilots who steer in a prone position, with the thoracic cage leaning on a special cushion. In this position, the accelerations and the impacts follow a chest/back direction, just as they do in a frontal motor vehicle crash. Using this steering technique and faced with the same conditions some pilots have
suffered rib fractures whereas others received no injuries.

In the field of sports, instances have been witnessed in which individual responses to accelerations and impacts of similar character have been completely different.

The response varies according to age, sex, race, corporeal composition, and genetic constitution. Another aspect involves people who have practiced the same sport for many years and who have, therefore, been exposed to similar impacts having the same intensity. As people get older, the seriousness and types of injuries are bound to vary. For instance, in identically intense impacts, fractures are more frequent in older subjects and sprains and dislocations are more frequent in the younger subjects who often emerge unharmed from impacts that would be quite harmful for older subjects.

One puzzling element in the evaluation of the results attained in the study of the resistance of the human body to impacts is represented by the methodology being used and by the units of measurement; there is a wide range of both. This has produced divergent lines of thought and confusion. The points of view of researchers in the evaluation of thoracic cage behaviour in collisions is quite typical. Deceleration was once used as the unit of measurement; at present, the rib deflection method is more widely used. Both methods present advantages and disadvantages, however, it must be borne in mind that the deflection measurement is strongly influenced by age.

During the life span of a human being, the thoracic cage composition, initially, is basically cartilaginous with a high elastic component. Progressive ossification of the ribs reduces the elasticity and makes the rib cage stiff. Given a certain impact, a child might suffer very serious injury to the inner organs and the major vessels, with a high deflection of the thoracic cage that would not injure the ribs. In the same impact, an older subject could suffer a series of rib fractures without the corresponding injury to the inner organs.

As far as thoracic cage injuries are concerned, different responses also result from the various surfaces involved in impacts. It is, therefore, clear that these different types of reactions must condition and serve as a guideline for the construction of the means of containment for human bodies within the vehicle.

At this point we might conclude by saying that we are in the dark about the human body's resistance to impacts. The results obtained from the tests are discouraging in terms of practical application.

However, the picture is not so grim. Biomechanical studies have offered significant contributions to the knowledge of how the human organism behaves during impacts. We have, nevertheless, witnessed a multiplication of the phenomena being studied and a differentiation and personalization of the measurement techniques (a frequent occurrence in scientific fields). The cognitive process has led to an innumerable series of results that often clash with each other instead of leading to a simple equation with a final result. We might say that if an equation is found, it is one in which the unknown, that is to say the \( x \), is the predominant figure with very few steady points. We have reached the point where we have to be realistic and logical. We must begin a process by which one starts cutting off all the dry branches, that is to say, those methods that are superfluous.

This phase of critical re-examination is absolutely necessary because, should we experimentally evaluate all the possible responses of the human body to different types of impacts and should we try to correlate such responses with all the various tests designed to test the vehicle (both as a structure and in relation to the occupant containment means), while verifying, on a statistical basis, all the data obtained, it is highly probable that the entire production of vehicles would not be sufficient to guarantee the exactness of the results, should it be sacrificed in crash tests.

On the other hand, it seems that until now no serious consideration has been paid to some of the brilliant results attained in the sports field through the use of simple safety means that were enforced by sports regulations as soon as they had been proposed. The sports' legislative bodies, in fact, have not waited to obtain the results of biomechanical enquiries, nor could they do it, given the
problems that puzzled and are still puzzling those competent in the field; but they have availed themselves of what was available on the basis of mere common sense. In this instance, I refer to the results that were obtained in motor sports where it has been possible to apply and impose a limitation of the human body mobility within the vehicle.

At present, in the categories of stock car races (batch-produced cars coming from the United States and Europe), the only mandatory requirements set forth by the regulation are the use of particular efficient safety belts and an additional bar frame to strengthen the interior of the car.

Through a brief and incomplete survey on the number of injuries that have occurred in relation to the seriousness of the impacts, it has been possible to make a big step forward in the pilot’s protection by using very simple means.

In the batch-produced car races there have been frontal collisions, crashes against the guard rail, lateral impacts, pile-ups, and so forth. Notwithstanding the very dramatic damages suffered by the vehicles and the consequent deep distortion of the structures, the lesions suffered by the pilots have been less than expected and far less than those that could have occurred in collisions of the same intensity, on the same automobile models had they not been reinforced with bars and had the vehicle occupants not been secured with the safety belts.

There is another aspect of the problem to be kept in mind—in sports such as motorboating or motorcycling where it is not possible to enforce the same system to protect the driver (namely, the driver cannot be bound to the vehicle), the safety level in accidents has not changed for the better in the last few years, but has remained more or less the same.

Human body containment systems, such as safety belts, have reached a level of perfection that may be considered to be optimum. This is evidenced by parachute descents where it is possible, in competitions, to delay the opening of the parachute. The decelerations caused by the opening of the parachute have an extremely high intensity; but the containment belts have been perfected to the point that they do not cause any injury whatsoever.

In conclusion, we must say that it is impossible not to agree with the Mackay report submitted in Brussels during the automobile symposium organized by the European Community Commission. He said that we have not yet reached the maturity to impose final regulations but that this is the time to deal with the problem through transitory safety regulations until we have a better and deeper knowledge of biomechanics. We have, therefore, come to the point when the answers must come from common sense and from the few reliable data available rather than from the largely incomplete and controversial knowledge provided by biomechanical studies. We have probably asked too much of biomechanics: we have asked for the solutions to impossible problems, and we have asked for reliable answers to problems whose elements consist of a series of variables, when nothing is more variable and unsteady, in terms of behaviour patterns, than the human machine.
Prediction of Thoracic Injury Using Measurable Experimental Parameters

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ABSTRACT

Researchers all over the world have conducted over 100 simulated car crashes in which cadavers have been restrained by various types of safety belt systems. The large investment of time, effort, and funds associated with these research investigations warrants an analysis of the resulting data from a global viewpoint to identify injury trends and possible design criteria for near-term application. Such an attempt has been made and is discussed.

Large variations in test instrumentation, test conditions, and belt system configurations utilized by the various researchers limited the analysis to those measured engineering parameters and observed injury evaluations that were common to all the experiments.

This very minimal set of event descriptors, when subjected to an analysis, has shown injury (defined in this context to be the number of observed thoracic fractures) to be a statistically significant function of the maximum upper torso belt force, cadaver weight, and cadaver age at death. Implications and consequences of such results are discussed.

INTRODUCTION

The seatbelt system is the most commonly and widely utilized automotive crash protection system in world use today. Its use is currently mandated in numerous countries and municipalities, and there are significant pressures to increase this sphere of mandatory use.

This study represents an initial effort to derive and evaluate a simple, nonequivocal measure that can readily assess the crash protective qualities of a candidate belt system and to provide a simple and justifiable dynamic test criteria for protection standards generation. It should also provide both manufacturers’ and standards’ monitors with a simple, inexpensive, and valid method for determining the compliance of a system with the mandated performance requirements.

Fortunately, there is a large body of test data devoted to the performance and protective capabilities of belt restraints in crash situations. Some of these tests have utilized human volunteer subjects, but the majority have utilized unembalmed cadavers. The cadavers were used because it is assumed that the nature and intensity of injuries produced in a cadaver will be similar to that produced in a living subject under the same conditions.

This effort has collated all currently available cadaver test data and subjected them to a statistical analysis to determine if any meaningful relationships exist between any of the measured engineering parameters, such as forces, accelerations, deflections, and the physiological consequences (that is, injury) of each test event. It also analyzed the resulting relationship to determine possible strategies for further tests and/or to identify preliminary system design criteria for near-term applications.

In no manner whatsoever should the result of this effort be construed to be a final product. It is intended to be an assessment of a continuous process at a specific point in time that can hopefully provide guidance in the design of present and future belt systems and stimulate avenues of future experimental testing.

The following section identifies the sources and types of information now available on the performance testing of belt systems. This is followed by: (1) a discussion of the scaling technique employed in this analysis, (2) the actual analysis of the data, and (3) a discussion of the results of the analysis and some potential applications.

DATA

A perusal of the literature reveals the magnitude of the effort devoted to evaluating
and testing belt restraint systems with cadaveric specimens. Well over 100 tests have been performed.

The reported efforts of Cromack et al. [1]; Patrick et al. [2]; Fayon et al. [3]; and Schmidt et al. [4, 5] constitute the majority of the available data. These data are supplemented by efforts of the Highway Safety Research Institute (HSRI) [6] and the Calspan Corporation [7].

Since each of these research efforts was motivated by different sources, the experimental protocols governing data acquisition varied considerably, and, as a result, the data that are measured and observed consistently throughout all the tests is a rather small subset of the total collected. Table 1 demonstrates this paucity of common data in all three major data areas: anthropometric descriptors of the subject, engineering parameters measured during the test, and assessments of the injuries resulting from the test. The final consistent data set is presented in the appendix and consists of test source; age, sex, and weight of the subject; maximum upper torso belt force experienced by the subject during the test; and the number of observed fractures in the thoracic area resulting from the test (this is the sum of all rib, sternal, and clavicular fractures). Table 2 gives the means, ranges, and standard deviations of the final data base.

No attempts were made to isolate the data base from individual restraint system designs,
such as 3-point, 2-point plus knee bar, or systems with energy-absorbing elements. No adjustments were made to account for any geometric variations between the various belt systems, nor were attempts made in any way to normalize the testing conditions to a common base; all deceleration profiles were accepted.

**SCALING APPROACH**

It became obvious early in this effort that a scaling approach must be utilized to somehow normalize the large variability in the test data caused by differences in cadaver weight and stature. Because the maximum upper torso belt force is the only common engineering test parameter available for this analysis, and several investigators [3, 4] have not uncovered significant relationships between absolute force applied to the thorax and any injury measure, it was decided to scale this parameter. The concept described in Whitaker [8] and successfully applied in scale model simulations of automotive crashes [9] was utilized. It assumes linear relationships between the three fundamental physical units of any model and its prototype. That is,

\[
\begin{align*}
L_p &= \lambda_1 L_m \quad \text{(Length)} \\
M_p &= \lambda_2 M_m \quad \text{(Mass)} \\
T_p &= \lambda_3 T_m \quad \text{(Time)}
\end{align*}
\]

Then, assuming both density and modulus of elasticity to be identical in the model and prototype (a requirement needed to use the identical materials in each), the following relationships between the various \( \lambda \)'s are derived:

\[
\rho M = \rho_p
\]

where \( \rho_i \) has units of \((M_i) (L_i^{-3})\): Mass/Volume.

Combining 1 into 2 gives

\[
\frac{M_m}{L_m^3} = \frac{M_p}{L_p^3} = \lambda_2 \frac{M_m}{L_m^3}
\]

and then \( \lambda_3^2 = \lambda_2 \)  

or \( \lambda_1 = \lambda_2^{1/3} \)

that is to say, the length scale factor must be the cube root of the mass scale factor.

Similarly, when enforcing

\[
E_m = E_p \tag{6}
\]

where \( E \) has units of \((ML/T^2)(1/L^2)\): Force/Area

Substituting (1) into (6) yields

\[
\frac{M_m L_m}{T_m L_m^2} = \frac{M_p L_p}{T_p L_p^2} = \lambda_2 \frac{M_m \lambda_1 L_m}{L_m^3 T_m \lambda_2^2 L_m^2}
\]

results in

\[
\lambda_2^2 \lambda_1 = \lambda_2 \tag{8}
\]

Substituting (4) into (8) yields

\[
\lambda_3^2 \lambda_1 = \lambda_1^3
\]

establishes the following

\[
\lambda_3^3 \lambda_1^2 \quad \text{or} \quad \lambda_3 = \lambda_1. \tag{9}
\]

This requires that time scales with the same ratio as length. To maintain the above assumptions requires that force scale as,

\[
F_p = \lambda_1^2 F_m
\]

since \( F_p = \lambda F F_m \)

where \( F \) has units of \(ML/T^2\)

then

\[
\lambda_F = \frac{F_p}{F_m} = \frac{M_p L_p / T_p^2}{M_m L_m / T_m^2} = \lambda_3^2
\]

Because the test data did contain the mass of each subject, \( \lambda_1 \) is calculated as \((165/Ms)^{1/3}\) where 165 is the mass to which all experiments are being normalized. A new variable designated the "normalized belt force" (NBF) was generated by the following relationship

\[
\text{NBF} = \text{TFB} \left[ \frac{165}{M_s} \right]^{3/2} \tag{11}
\]

where TFB = maximum upper torso belt force  
\( M_s = \text{mass of test subject} \)
165 = mass to which experiment is being normalized.

This scaled parameter is generated and used with full knowledge that the fundamental assumption of this scaling technique (each test subject must be an exact geometric scale model of the prototype) is violated. However, an empirical analysis of the existing data suggests that while the data do not conform in the strict sense, they do conform in a general sense, that is, the assumptions are violated but not seriously. This analysis, utilizing the same regression techniques (to be discussed in the next section) as in the final analysis but on the logarithm of each variable, arrived at the following relationship between the number of fractures and age, mass, and torso belt force.

\[
\log (NF + 10) = -1.0298 + .637 \log (AGE) + .723 \log (TBF) - .455 \log (MASS) \quad (12)
\]

This relationship minimizes the deviation of the logarithm of the dependent variable (NF) in the least squares sense. Taking the antilog of (12) yields,

\[
NF + 10 = .0933 \frac{(AGE)^{.637} (TBF)^{.723}}{(MASS)^{.455}} \quad (13)
\]

Upon examination, the exponential relationship between TBF and MASS of (13) can be rewritten as follows,

\[
(TBF)^{.723} = \left[ \frac{(TBF)}{(MASS)^{.629}} \right]^{.723} \quad (14)
\]

and it can be noted that the quantity in brackets differs only slightly from the quantity derived in the above discussed scaling approach, that is

\[
TBF \left[ \frac{165}{M_s} \right]^{.\frac{2}{3}}
\]

**ANALYSIS OF DATA**

The final consistent data set, including the scaled variable NBF and another variable (TBF/MASS), was subjected to a multiple-step linear regression algorithm contained within the McDonnell Douglas Automation Company's Conversational Statistic Analysis package. This routine selects the most important independent variable first and works towards the least significant. The significance is determined by the degree to which a variable accounts for variation of the dependent variable (in this case the number of fractures) in the least squares sense. Table 3 is the correlation coefficient matrix for the individual variables.

Allowing the algorithm to select the “best” linear combination of independent variables to predict observed fractures, equation (15) resulted.

\[
NF = -18.66 + .00955 NBF + .327 AGE \quad (15)
\]

with \( R = .775 \)

STD ERROR = 4.786

f ratio = 79.27

The addition of any other additional variables to the above equation was not statistically justified.

With the introduction of the additional independent variable suggested by the empiri-
cal log analysis, NBF × AGE, the following relationship was determined as the most effective in reducing the absolute error between the observed and predicted injury level.

\[ NF = -3 + 0.002 \times (NBF) \times (AGE) \]  \hspace{1cm} (16)

with \( R = 0.776 \)

\[ \text{STD ERROR} = 4.72 \]

\[ f \text{ ratio} = 157.4 \]

The two derived relationships are essentially equivalent both from the statistical viewpoints of their resulting multiple correlation coefficients and standard error of predictions. Each is also overwhelmingly substantiated by the \( f \)-ratio test that implies that when \( f > 9.0 \), there is a greater than 99-percent confidence level that the independent parameters should be included in the expressions.

Detailed examination of each function indicates that equation (16) is better behaved in the low belt force, low age ranges than equation (15) and, therefore, is the preferred function. It will be the one referred to in the following discussions. Figure 1 demonstrates the accuracy of the derived function by comparing directly the predicted and observed number of fractures of each and all experimental points. Were the function 100-percent accurate, all points would fall on the 45-degree line. Figure 2 consists of contour plots of a constant number of rib fractures as a function of the two independent variables, age and normalized belt force, and demonstrates the greater susceptibility of the elderly to injury when exposed to an identical crash intensity.

Determination of whether the resulting function possesses adequate predictive capability is an extremely difficult problem. However, by comparing the predictive capability of equation (14) to that of another proposed thoracic injury criterion, a relative measure of performance can be established.

Neathery et al. [10] found that the percent of thoracic anterior-posterior compression (\( P/D \)) and the age of the subject were sufficient and statistically justifiable variables for the prediction thoracic injury (in the sense defined by the Abbreviated Injury Scale (AIS)) during blunt chest impact. The resulting function had a multiple correlation coefficient of .875 and a standard error of .885. For comparison purposes, an analysis of these same data was repeated to determine how predictive \( P/D \) and age were of their observed thoracic fractures.

\[ NF = -30.47 + 78.69 \frac{P}{D} + 0.186 \text{AGE} \]  \hspace{1cm} (17)

with \( R = 0.76 \)

\[ \text{STD ERROR} = 5.26 \]

\[ f \text{ ratio} = 12.89 \]

This is slightly inferior but essentially equivalent to the present analysis. It must be understood that the antithesis of the now identified function is as predictive of AIS as is
Neathery's function, but it cannot be verified. However, this aspect will be pursued if and when injury data defined in terms of AIS become available.

The success of any empirical process depends on two primary elements: the quality and completeness of the available data, and the power and versatility of the process that is being utilized to form the relationship between the selected dependent variable and the independent variables. In this particular analysis, the large variety of test crash pulse utilized, the variety of belt system configurations employed (2-point, 3-point systems with a variety of anchor point locations and energy-absorbing characteristics), and the absence of any detailed anthropometric measures of the test subjects are all factors that contribute to the resulting function's performance. Also, the regression technique that was employed could only generate linear functional relationships, and were it not for the prior application of the scaling technique discussed, the performance would definitely be less than what was achieved.

However, if the predictive level achieved by this relationship is deemed adequate by a user, the large variety of conditions and lack of specific test details now become an asset. They allow a user to utilize this relationship in a much larger set of potential applications.

DISCUSSION

The function put forth in the previous section predicts the number of thoracic fractures as a function of three independent variables: the weight of the subject, the age of the subject, and the maximum upper torso belt force to which he is exposed. Applying this relationship to the design of a belt restraint system requires a knowledge of all of the variables, and the following discussion is intended to demonstrate the responsibility that is assumed when applying this simple functional relationship.

In its most fundamental form, the function is,

\[
\text{Number of fractures} = -3 + 0.0002 \left( \frac{165}{M_s} \right)^{\frac{3}{2}} (TBF) (AGE)
\]

Table 4. Fatal accident involvement rate

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<th>Age</th>
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where one independent variable, upper torso belt force, is at the control of the system’s designer and the other two parameters are descriptors of the population for which the system is intended.

Assume now that other processes have determined that maximum benefit would be gained if one were to design a seatbelt system to produce the minimum number of thoracic fractures in a population representative of the population now being killed on our Nation's highways. The National Highway Traffic Safety Administration’s Fatal Accident Reporting System [11] indicates involvement rates as a function of age and sex as shown in table 4. Typical weight distributions for the male and female populations [12] are shown in table 5.

The simplest and most straightforward application of this injury relationship is to assume that all members of the target population will be exposed to the same maximum upper torso belt force and that average number of fractures that the population

Table 5. Weight distribution

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\textsuperscript{a}Data points.
\textsuperscript{b}Interpolated data point.
would sustain is a measure of the system's effectiveness. Figure 3 is the result of such an analysis and shows that the lower the maximum belt force, the lower the resulting average injury.

Several factors prevent setting an extremely low level for the upper torso belt force. The primary factor is that the heavier portions of the target population will translate excessively relative to the compartment and involve their heads and possibly their thoraxes in an impact with the windshield or dash.

To address this phenomenon, a more detailed analysis was performed. This required additional assumptions of crash conditions under which the system is to perform. Once again, it was assumed that other processes have determined that a 30-mi/h frontal barrier crash is the most representative crash condition and the belt system is effective in a vehicle of the subcompact category. A Honda Civic was selected as typical of this type of vehicle. Figure 4 shows a typical displacement-time history of the passenger compartment as this vehicle undergoes a 30-mi/h barrier crash.

A small mathematical simulation, shown in figure 5, was devised. It contains a rigid torso mass (an appropriate proportion of each total body mass) that is attached to the decelerating vehicle compartment by a belt element.

Figure 6 shows the force deflection properties assumed for this element. It allows (a) that the passenger can translate 2 inches...
relative to the compartment before any belt force is generated (an effort to account for belt slack), (b) that the belt system strokes at a constant predetermined load, and (c) that after 12 inches of total torso stroke relative to the compartment, the torso belt force level increases linearly to an 8 000-pound force at 15 inches of stroke. (This is the penalty imposed for excessive compartment translation and is meant to be representative of all the increased injury consequences due to it.)

The model was run under the 30-mi/h barrier crash condition for each age and weight classification in the target population for each of 10 different yield levels of the belt system. For each yield limit, the average number of thoracic fractures was calculated utilizing the involvement rate tables. The results are presented in figure 7. They demonstrate that there exists an optimum load level at which the belt systems should stroke to minimize average overall injury. Above this optimum load a design does not fully utilize the interior stroke and presents a higher load to all members of the population, and below this level the heavier population utilizes all

Figure 7. Average injury of target population in 30-mi/h frontal barrier crash with 12 inches of internal stroke available as a function of belt force yield limit.

CONCLUSIONS

The efforts to assemble and analyze data generated in the more than 100 cadaver seatbelt crash tests were successful and did result in the development of a meaningful relationship, which shows that injury, defined in this context to be the number of thoracic fractures, is a function of the maximum upper torso belt force and two rudimentary anthropometric descriptors, age and weight.

The scaling relationship, \( N_{BF} = T_{BF} \left( \frac{165}{M_s^{2/3}} \right) \), proved to be a successful technique in normalizing the observed upper torso belt force for the variation in the mass of test subjects.

The resulting injury relationship can be utilized to define the optimum characteristics of a seatbelt system provided that the crash conditions under which the system is to be used and the target population that the system is to protect can be identified and quantified.

The essential engineering parameter necessary to correlate the performance of a belt system to thoracic injury is the easily measured upper torso belt force.

RECOMMENDATIONS

As a result of this study, the following recommendations are presented to stimulate further and more fruitful efforts:

- Because injury was defined for the purpose of this study as the number of thoracic fractures, an analysis of the same data
should be life-threatening injuries to internal organs in the young population, where skeletal damage is not so prevalent.

- Continued research with cadavers is needed to directly address the hypothesis presented here. Such design aspects as system geometry, load onset effects, and total trajectory control should be investigated and be incorporated in a predictive function should they prove significant.

REFERENCES


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I would like to thank you for your invitation to the Conference and for giving the Commission the opportunity to participate in the panel discussion.

As you are no doubt aware, the initial objective of the Commission's regulatory activities was to create a common market where goods would circulate freely without regard as to whether they are made by national manufacturers or are imported, provided they satisfy certain requirements.

In the motor vehicle sector, this has been achieved by the creation of the European Economic Community (EEC) type-approval system. In creating this system, the Commission has never confined itself to harmonizing the existing national standards, but has always tried to improve safety and reduce air pollution and noise, as far as this was acceptable to the member states. Now that this type-approval procedure is nearly completed, the Commission is already studying the evolution of regulations concerning motor vehicle construction. It is quite clear that these future regulations should reflect the most up-to-date scientific knowledge. In this context, the Commission has always appreciated the most valuable information provided by the delegates to all the Experimental Safety Vehicle (ESV) Conferences.

In December 1975, the Commission organized its last European Symposium based on the trends in the regulations concerning motor vehicle design. All interested circles, such as government, industry, and research and consumer groups were represented. I would like to take this opportunity to quote some of the conclusions of the Symposium that are of special interest for this Conference:

- There is a need to improve the safety, not only of car occupants, but also of the unprotected road users, especially pedestrians, who are frequently struck by cars.

- Impact test methods for cars must be developed that truly reflect the reality of road accident situations and that lead to greater safety in relation to the desired future vehicle population. For example, the safety of large-car users should not be improved at the expense of the occupants of the small cars that are widely used in Europe.

- It is desirable, over the long term, that any safety regulations be set out in the form of performance standards. These standards should be specified in terms of acceptable injury tolerance levels to be measured in realistic standard tests. Therefore, it is necessary to switch from specifying design rules for the different car components (such as safety belts, steering assemblies, and windscreens) to defining comprehensive performance standards in which injury criteria for given improved test conditions are examined on dummies or similar appropriate test devices.

However, as far as injury criteria are con-
cerned, the scientific and biomechanical knowledge still needs to be improved, and, in order to define the appropriate types of crash tests to be used, the state of accident analysis must be reconsidered. Finally, a concerted effort in research and development is needed to develop suitable test choices—dummies that adequately reflect human response to collision forces, and at the same time provide reasonable reproducible performance.

Mr. Chairman, these are the general lines of future research and development in Europe in the field of motor vehicles, and it seems to me that they correspond largely to the results of the present conference. This shows quite clearly the great interest in an exchange of information between the United States and Europe.

Japan

Mr. TAKEAKI KOYANAGI
Deputy Director, Automobile Division
Machinery and Information Industries Bureau
Ministry of International Trade and Industry

A recent review of traffic accidents in Japan indicates that the number of fatalities has been decreasing year after year since 1970 when it was at its peak. The number of fatalities this year shows a further decrease from that of last year. The downward trend is especially remarkable in Tokyo. Thus the number of traffic fatalities this year so far has been reduced to a rate comparable to that of the early 1930's.

The contributions to this reduction include vehicular safety, tightening of police control, improvement in road traffic safety equipment, and promotion of drivers' safety consciousness.

In this downward tendency of the total number of fatalities, however, the accidents involving pedestrians have marked only a slight decrease in number, and they account for a high percentage of the total fatalities. Pedestrian protection will be considered as an important question hereafter.

An analysis of pedestrian fatalities by age has disclosed that the largest number of cases involve children. This fact suggests that children are not so careful in their daily activities, and that successful safety training for them can hardly be expected.

As a measure for reducing pedestrian accidents, improvement in road conditions is considered to be the primary necessity. Of course, effective improvement of the motor vehicles themselves is desirable, but it will inevitably involve great difficulty.

The first step in vehicle design from the viewpoint of pedestrian accident prevention should be an improvement in visibility to permit the driver to operate his vehicle while avoiding contact with the pedestrian. A reduction in pedestrian fatalities in collisions is also a matter of extreme difficulty.

Head injuries caused by hitting the road surface are responsible for most of the pedestrian fatalities in traffic accidents in Japan. An effective measure for the prevention of such accidents is extremely difficult to find.

In Japan, several years ago, various vehicle front constructions were researched and tested with dummies. Because of the differences in the dummies' behavior, however, useful data were not obtained.

The pedestrian dummy, which requires very complicated manipulation by strings, is a measuring instrument with less repeatability than the occupant dummy. Even occupant dummies currently available have some problems to be solved, such as inaccuracy in repeatability as a measuring instrument and behavior patterns deviating from their human models.

The development of an air cushion as an occupant protection system has been going on. In our country, however, there has been no public opinion supporting the use of air cushions in motor vehicles. On the other hand, the air cushion has not yet undergone a sufficient examination of its reliability. Especially in the case of small vehicles, this occupant protection system requires a change in the construction of the instrument panel.
and reveals some shortcomings that should be eliminated before practical use.

As an occupant restraint system, the seatbelt is considered most desirable for practical results. In Japan, however, the seatbelt-wearing population is still very low. It is necessary to carry out a belt-wearing promotion campaign side by side with the development of a seatbelt that would be easier to use.

In Japan today, traffic accidents are investigated by the police in the minutest detail. Furthermore, under the auspices of the Ministry of Transportation, a close analysis of traffic accidents that have occurred in designated areas is jointly conducted on a periodic basis by the police, university professors, doctors, and engineers. The further evidence accumulated in such investigations is expected to present what are really essential items for development in the future.

The United Kingdom

J. W. FURNESS
Chief Mechanical Engineer
Department of the Environment

The U.S. Department of Transportation is to be congratulated on yet another successful Experimental Safety Vehicle (ESV) Conference. The technical presentations have been to a high standard, and the papers will no doubt be given further consideration later.

Now that the safety arguments have been set out and balanced against costs and benefits and the limits of natural resources, it seems appropriate to consider the future activities in the ESV/Research Safety Vehicle field. In my opinion, sufficient data are now available for us to formulate standards for cars in the 1980's. My tentative suggestions, which are intended to supplement the requirements set out in various regulations published by the U.N. Economic Commission for Europe (ECE), are as follows:

Primary Safety:
1. Braking and tyre tests to be carried out on both wet and dry road surface conditions at speeds up to 110 km/h (70 mi/h) to ensure good road adhesion and directional stability under different conditions of loading.
2. Forward and rearward vision standards to ensure good visibility both in dry and adverse weather conditions.

Secondary Safety:
1. Occupant protection requirements to be assessed from crash tests incorporating two instrumented dummies representing the 50th-percentile male. The dummies would be restrained by correctly fitted lap and diagonal belts. The tests would include:
   a. Partial frontal tests possibly at 55 km/h (35 mi/h) to simulate a 40-percent overlapping vehicle-to-vehicle crash.
   b. 90-degree side impact test at 40 km/h (25 mi/h) conducted with a mobile barrier fitted with a deformable front end intended to simulate a standard front end of a car. A special side-impact dummy may be necessary for measuring purposes.
   c. A compatibility test representing a car-to-car crash using the mobile barrier referred to above and impacting both the front and rear of the vehicle at 45 km/h (28 mi/h).

During these impact tests, the forces imposed on different limbs and body positions of the dummies must not exceed acceptable levels of human tolerance as proposed in the European Experimental Vehicles Committee paper on biomechanics.

The mobile barrier would incorporate a low-level bumper, the top of which does not exceed 380 mm (15 inches) from the ground.

Front bumpers of cars would be required to be standardised at a similar height to door sills, that is, 380 mm (15 inches) to the top of the bumper and at least 30 mm (3 inches) deep. This could result in reductions of injuries in car-to-pedestrian accidents.
In all the impact tests, belted dummies would be used, and the mandatory wearing of seatbelts seems essential if injuries are to be minimised or avoided. It is unreasonable to expect cars to be designed to provide unrestrained occupants with the same level of protection as restrained occupants.

In some countries, injuries to pedestrians impacted by cars account for 40 percent of all injuries caused by these vehicles. This proportion will increase as car occupants become better protected. Clearly, further work needs to be done on the design of the front end of cars to reduce:

- Injuries to pedestrians including children
- Aggressivity in side impacts
- Property damage

The above objectives could probably be met by soft nose sections on cars that incorporate a structural member or bumper at a standardised height aligned more closely with the height of door sills and floor frames that have high structural strength. The purpose of this low bumper would be to align itself with the more usual heights of door sills and floor pans that have high structural strength and that, if fully utilised, could be very beneficial in reducing injuries to occupants of cars that have been impacted from the side. If fully utilised, this approach could be very beneficial in reducing injuries to both pedestrians and the occupants of cars impacted from the side.

ECONOMY

In the United Kingdom, low-weight cars have been in popular demand for many years. The need to conserve materials is well recognised as a means of minimising manufacturing costs. Progressive reductions in vehicle weight are being achieved by the wider use of lighter materials such as aluminum and plastics.

ENERGY

Three-quarters of the vehicles in use in the United Kingdom are below 1 120 kg (2 500 lb), the bulk of these being between 800 and 1 120 kg (1 750-2 500 lb). Engine capacities range in the main from 1 000 to 2 000 cc and give an overall fuel consumption on the order of 38 to 33 mi/gal, which is in line with the U.S. targets.

Economic pressures, in particular the high cost of fuel, have encouraged vehicle users to be more economy conscious. However, it has been recognised that cost has little effect on the actual demand for fuel. Since 1973 the cost of petrol in the United Kingdom has trebled, but the demand is only marginally reduced. Economic pressures are also affected by means of taxation. Fuel taxes have now led to an equalization of the prices of petrol and diesel.

Energy consumption by road vehicles can be reduced by improved aerodynamics, improving vehicle maintenance, and by encouraging improved driving habits. It is estimated that such measures could save 5-10 percent of road fuel consumed. A mandatory requirement for the publication of fuel consumption data is likely to be introduced in the United Kingdom in the near future.

Other means of reducing the total demand for transport fuel are also being studied, that is, better utilisation of public road and rail transport.

The use of alternative types of fuel is being studied including diesel, methanol, hydrogen and battery electric. Diesel engines are extensively used in the United Kingdom in heavy goods vehicles and public service vehicles and could be used more widely in light delivery vehicles, taxis, and fleet cars travelling high annual mileages. Battery electric vehicles are used widely for local delivery goods vehicles but are not likely to be readily acceptable for cars because of battery design limitations and the poor overall energy conversion of these vehicles, which (when power station efficiency is included) is only 10-16 percent compared with 25 percent for petrol engines and up to 35 percent for diesel engines.

ENVIRONMENT

The United Kingdom’s policy is to prevent total vehicle emissions from rising above 1971 levels. To achieve this, cars and vans are
required to conform with the ECE Regulation 15 concerning gaseous emission of pollutants. This limits the amounts of hydrocarbon and carbon monoxide emitted. Nitrogen oxide control will soon be added. The levels have recently been reduced and will be further reduced by about 1980. Petrol lead levels are also being reduced. Currently the limit is 0.55 g/l, but this is being reduced to 0.50 g by 30 November 1976 and to 0.45 g by 1 January 1978. A further large reduction will be necessary in 1980 to maintain 1971 standards for total emissions.

Regulations are currently in force regarding smoke emission from diesel engines. Air pollution from motorcycles and mopeds is likely to be controlled in the near future (about 1980). Gaseous emissions from diesel engines are being kept under review.

CONCLUSIONS

The extent to which the above safety and environmental criteria will eventually be adopted is yet to be decided. It is desirable for performance standards to be agreed upon internationally. It is hoped that in the next 2 or 3 years great progress will be made to harmonise international regulations. If this is done, improvements in safety and environmental standards, together with better use of energy and material resources, should be achieved.

In Britain we will continue to strive for harmonisation of vehicle legislation through the U.N. ECE and the European Economic Community. Much progress has already been made in the U.N. forum where all the major vehicle-producing countries are represented. Worldwide standards for vehicles could be agreed upon and harmonised given the spirit of cooperation that has been at these ESV Conferences (if the United States, Europe, and Japan can resolve the problem of regional differences). The harmonisation of test methods is probably the area that will pay the quickest dividends. This applies equally to vehicle safety, air pollution, and the control of noise.

France

MARC HALPERN-HERLA
Directeur
Organisme National de Securité Routière (ONSER)

The papers presented in plenary session and in the special seminars have given us a better insight into current vehicle safety research orientations. We are now wondering about the orientation of future research.

With regard to France, we can recapitulate the guidelines on which research policy in this field has been and will continue to be based. We will begin with some general principles:

First, vehicle safety research is not an end in itself. Its purpose is to attempt to reduce, at a reasonable cost, the losses entailed by highway accidents. It should accordingly result, inter alia, in improved vehicle regulations. It would be hard to understand if the results achieved by virtue of painstaking effort on the national level and by international cooperation were not sooner or later—and the sooner the better—reflected in terms of regulations.

It must also be mentioned that safety is not the only goal of vehicle design. The other areas for improvement and of community concern are well known: air pollution, noise, and energy consumption. Research must be oriented, therefore, towards solutions for improvement of these areas together or, in any case, for improvement of some of them without detriment to the others.

Finally, research in France is done in cooperation with the other European countries. Whenever possible, we try to identify a consensus among the experts so as to facilitate decision making in vehicle regulations at the European Economic Community level.

More concretely, what are the paths along which we anticipate that research in France will be directed? These paths are in no way novel, and most of the countries actively
engaged in a research program seem to be taking them.

First, better knowledge of the conditions under which accidents happen is indispensable. It is thus a question of developing what is designated in French by the neologism "accidentology." This necessitates the maintenance and even the extension of a system for accident and traffic observation at various levels of precision and depth. It is necessary to supplement the national statistics that necessarily include only a slight amount of technical data.

It is also indispensable to advance knowledge in collision biomechanics regarding human tolerances and their translation into terms of performance measured on a dummy. In this regard, the report of the European Experimental Vehicles Committee (EEVC) specialist biomechanics groups has demonstrated the priority research areas. Those recommendations will be followed by France.

In the field of vehicle technology, the first step is to improve the safety of car occupants as well as that of the other victims involved (primarily, injured two-wheel riders and pedestrians). We believe that the subsystem studies are sufficiently advanced to go forward with the manufacture of a lightweight (7 to 900 kg) prototype vehicle demonstrating the feasibility of ensuring the safety of adult occupants under the conditions recommended by the EEVC at acceptable additional costs. Research still needs to be done on effective and acceptable means of protection for small children (ages 5 to 9) in cars, as well as for injured pedestrians (adults and children), and for unbelted occupants in low-speed collisions, like those in urban areas. Beyond these safety concerns on the 1980 horizon, we further believe that it is necessary for the research centers to explore the feasibility of protection of occupants against impact levels appreciably higher than those now being given consideration. Safety studies on two-wheeled vehicles must be undertaken with greater scope, but this field does not fall within the concerns of this conference.

Along with research aimed at enhancing secondary safety by alterations of the passenger car, it would be of interest to try to reduce the violence of collisions by action relative to obstacles hit that are not cars. These are either fixed obstacles or very heavy vehicles such as trucks. As to fixed obstacles that can be either insulated by crash barriers or weakened, research should be oriented towards optimization of means of absorption of energy between the vehicle and the obstacle hit. In the case of trucks, research should aim at limiting their aggressiveness particularly in cases of head-on collisions.

Finally, a substantial program should embark on accident prevention, a field neglected in recent years. This program should begin with detailed surveys of primary safety, such as those done since 1970 with secondary safety. The goal of these surveys will be to better assess the advantages of various possible prevention measures affecting vehicles. It now seems profitable to seek various means of driving aids, especially for speed, vigilance, and alcoholism. The relations between vehicle dynamics and highway safety should also form the subject of in-depth research.

Concurrently, it seems indispensable to schedule a substantial set of studies devoted to an assessment of the various safety improvements recommended or decided on. The purpose of such an assessment is to verify that the proposed goals are attained, or, if not, to enable poorly treated problems to be examined anew.

We believe that this coordinated aggregate of research work should make it possible to pave the way for the development of an even safer vehicle, following the generation of cars of the 1980's.
We have met for three days here in Washington, and we have absorbed a wealth of scientific knowledge; two new models—Research Safety Vehicle (RSV) prototypes—were presented to us. In the name of the German delegation, I would first like to thank our American friends for the superb organization and for an exceedingly friendly reception. We have come to take for granted that the results of research and experimentation will be communicated and publicly disclosed. But if we think back to the time of the first conference, we are reminded that such generous exchange was not always the order of the day. We must remain committed to this present spirit as we look into the future.

I do not intend to deal with any specific subject matter here; we feel we are in complete agreement with almost all other nations on the objectives governing our research. What I would rather do is discuss the direction for our future efforts.

The sixth Experimental Safety Vehicle (ESV) Conference has vividly demonstrated that, in addition to striving for safety, we must also give consideration to the environment, to energy consumption, and to the economy, and presumably these objectives will also determine the future of the American automobile. We have noted with the greatest interest the clear recognition given here to conflicts between stated goals: the conflict between the desire to reduce noxious emissions and the need to cut energy consumption, and primarily the conflict between the wish to reduce weight and the requirements of increased safety.

A great number of findings presented during this conference have shown the protective value of the restraining devices—and, in particular, that of the safety belt system. It is quite indisputable that vehicle modifications can be successful only to the extent that restraining devices are also made effective. In the Federal Republic, this has strengthened our conviction that we are moving in the right direction by making compulsory the use of the safety belt.

The two RSV's exhibited here for the first time should meet with favourable public response. All of us have noted the encouraging progress achieved between the early first-generation ESV's and the present RSV's; this is particularly true in regard to new environment and economy factors, but not least in regard to reduced collisions between vehicles and pedestrians.

Where should future development lead from our point of view? We feel that the knowledge gained should, as before, be applied in practice; more specifically, this knowledge should guide administrative procedures. This is where the importance of the task goes beyond research and development. We must exert all our efforts toward general agreement on new findings and, at the same time, strive to bring existing laws and regulations into harmony. I want to emphasize again what was said in the report submitted by German industry: We are particularly pleased that the Government of the United States has urged before the Economic Commission for Europe that testing procedures and technical requirements be gradually brought in line, and we hope very much that this will soon lead to the urgently needed coordination between European and American rules and regulations.

Regarding the future growth of these conferences, we naturally assume that objectives will have to expand—an expansion aimed at the automobile of the decade of the 1980's. We proposed annual informal meetings of a limited number of experts in the fields of legislation, research, and industrial production. The object of such meetings would be to present the latest state of the art, to discuss contemplated measures, and to bring combined action to bear on these measures. These meetings can also determine when it would be best to call the next general conference.
And, if a suggestion is in order, we propose closer coordination with other, similar conferences. Proceeding in this manner, we are convinced that past successful activities can properly be exploited and that, together with new exigencies, they will point to the proper directions for the future.

Italy

Dr. GAETANO DANESI
Ministry of Transport

As you have noticed in the course of this Sixth Experimental Safety Vehicle (ESV) Conference, Italy, and specifically its Government, its industry, and its motor vehicle world are looking with interest to the development of study and research set in motion as a consequence of bilateral and multilateral agreements signed with the United States and with some European countries.

Nobody can deny that the Italian contribution was a valuable one and that it reflected, at least in the first phase of ESV and Research Safety Vehicle programs, a consistent economic commitment that was nevertheless willingly met by all the interested parties in Italy in the belief that greater safety in road traffic was well worth even heavy financial burdens. We have in mind the auspicious aim—the reduction of traffic fatalities.

Let me thank the U.S. Government, the promoter of this policy of study and research, as well as the governments of our fellow North Atlantic Treaty Organization countries. I avail myself of this opportunity to address a grateful salute to Mr. H. Taylor for his wisdom and sagacity as President of the European Experimental Vehicles Committee and for his intention to carry on with a valid research program.

Unfortunately, the Italian Government is fighting a hard battle against economic difficulties now striking our country. I am quite sure we will overcome this uneasy situation, but I must say that austerity is affecting all of our country’s initiatives and enterprises, including study and research activities. Our ambitious programs will, therefore, have to be reexamined after a pause for reflection.

This does not necessarily mean the activities carried on until now will be interrupted; we shall go on with them using the available resources and shall take advantage of the results acquired from the latest studies, which are numerous and worthy of consideration.

As soon as possible, we shall resume our initial policy, specifically regarding the problems of compatibility and biomechanics. We are well aware of the objective difficulties that will arise when dealing with them.

We will not deviate from the path clearly indicated at the Kyoto conference and here in Washington—the part specifically indicated by Dr. Sirignano in his opening address.

Italy is available for continuing the programs along the new guidelines that emerged during this conference. In the meantime, she only asks for a longer period to prepare herself for the various meetings that will be held in the future in the various countries. We think it advisable to foresee a period of not less than 2 years between this conference and the next one.

I cannot conclude without stating how pleased Italy would be to host the next ESV conference. However, as I said before, the present serious economic situation leaves us no possibility of hosting it, and that I deeply regret.

Finally, I would like to express our gratitude to the U.S. Government for the splendid hospitality and to assure all the government officials and experts who participated in this important meeting of Italy’s spirit of cooperation.
As I indicated in my remarks on Tuesday, very little vehicle research and development is conducted in Canada. I do not, therefore, propose to make a formal, 10-minute statement. I would, however, like to make two observations on the subject.

Listening to the papers presented at this conference, it has seemed to me that research and development in vehicular safety may have reached some kind of plateau. The very significant efforts in this area over the last few years, for which the Experimental Safety Vehicle (ESV) programme has provided a major stimulus, have left us with a number of safety systems that have been developed technically to the point where they could be incorporated in production vehicles. It is encouraging to see the way in which the lessons of the ESV programme are filtering down into the detailed design of many current vehicles. However, more advanced vehicle systems, such as antilock brakes or inflatable belts, are unlikely to appear in this way. Until they do, we shall be no more knowledgeable about their real value and real costs than we are at present.

I would suggest that large-scale field experiments with selected systems form a logical next step in vehicle safety research and development. The Restraint System Evaluation Program recently concluded by the National Highway Traffic Safety Administration was, in several respects, a model of what could be done. It is, therefore, particularly unfortunate that both the program and the production of vehicles equipped with air-bag systems terminated before any unequivocal conclusions had been reached on the effectiveness of this type of occupant restraint. I would not wish to understate the technical, legal, and logistical problems of conducting such experiments, or their costs. However, if we do not do something of the sort, we have to choose between forgoing the potential benefits of advanced systems and mandating their fitness on the basis of limited development testing and rather inherently speculative projections of their performance in the real world. Neither option seems more attractive.

My second observation is really in a similar vein, but it addresses crash avoidance research more specifically. I simply point to the need to consider and to measure much more carefully than has generally been done to date how the driver uses the crash avoidance systems on his vehicle and how he responds to changes in the design of those systems. From a conventional engineering point of view, such changes may be self-evident improvements. Unless driver behavior is introduced into the analysis, it is the purest presumption to conclude that the probability of collision has actually been reduced. The accident avoidance seminar yesterday afternoon provided some excellent contrasts between the two research approaches.

This concludes my statement on future vehicle safety research and development.
The European Experimental Vehicles Committee

Mr. HAROLD TAYLOR
Chairman, European Experimental Vehicles Committee
Head of the Safety Department
Transportation and Road Research Laboratory

As we come towards the end of the Sixth Experimental Safety Vehicle (ESV) Conference, we can look back with satisfaction at the wealth of interesting and valuable information presented. Our thoughts turn naturally to considering the way this international programme should best proceed in the future. It is no secret that some people feel that many of the objectives of the original programme—so ably piloted by the United States—have now been met, and, therefore, some changes may be desirable. In commenting on these matters, I must emphasize that I shall be expressing my own personal views, but, it is hoped that, because of my long involvement in the programme, they may be of some value.

A collaborative international programme initiated at a government level prospers if it has clear objectives, and if there is an equally clear willingness on the part of all the participants to recognise the viewpoints of others. If necessary, they must be prepared to adapt their own approaches in the interests of further progress in collaboration. These aspects distinguish a programme of this kind from the more conventional scientific, or technical, conferences in which information is presented and views may be expressed, but the participants are under no obligation to make any response to them. In the case of car safety, many opportunities exist for exchanging scientific and technical information through numerous conferences and other occasions; in my view, the international programme needs to have objectives beyond this level if it is to have a viable future.

The European Experimental Vehicles Committee (EEVC) has prospered in promoting car safety because it has met these requirements. The working groups serve to coordinate and reconcile the views of participating countries, and EEVC's work provides support to policy formation in the various European bodies concerned with harmonisation of vehicle standards; and it does so with the active encouragement of these bodies.

Finally, may I say a word on the possible extension of scope—or broadening—of the international programme, at present mainly concerned with safety aspects of cars. Most countries have recognised that car occupant and pedestrian casualties may grow to unacceptable levels unless further major improvements in car safety can be introduced. This realisation strengthens the bonds of collaboration and has enhanced the success of the international ESV programme. Furthermore, car safety research can readily be seen to be supporting the formulation of policy, internationally, from which specific actions will result.

If formal international collaboration is to be extended to other undoubtedly complex areas, it will be highly desirable for the link between research and policy to be well established, especially if, as seems possible, several agencies may be involved in each country.
FOREWORD

By Elliot Richardson, Chairman of the Energy Resources Council

In view of the Nation's long-range need to conserve energy and the fact that the motor vehicle fleet is the largest single user of our decreasing petroleum supplies, the Energy Resources Council (ERC) established a Federal task force to study motor vehicle fuel economy goals beyond 1980. These goals were to be compatible with environmental, safety, and economic objectives.

The task force consisted of representatives of the following departments and agencies:

- Department of Transportation (DOT)
- Environmental Protection Agency
- Energy Research and Development Administration
- Federal Energy Administration
- National Science Foundation

This group has also drawn upon other departments of the Government.

The task force has now completed its study and has submitted its draft report to the ERC.

Not only is the motor vehicle a principal user of petroleum, it is also a critical element in our national economy and lifestyle. Therefore, consideration of the future characteristics of the vehicle fleet, as influenced by possible combinations of market forces and Government policies, constitutes a matter of substantial interest and concern to government, industry, and the public—and involves major issues of choice. Accordingly, the ERC believes that the report should be published in draft form to provide the basis for broad public exposure and discussion of the information and issues it presents. The technical conclusions identified in the report will, of course, have to be assessed in relation to these issues as the ERC moves toward the specific formulation of governmental policies. In this process, the draft report should serve to refine and focus the associated debate.

DOT has been requested to act for the ERC in disseminating the report and in establishing a docket for public comments. Comments, suggestions, or criticisms should be addressed to:

The Assistant Secretary for Systems Development and Technology
U.S. Department of Transportation
Washington, D.C. 20590

MOTOR VEHICLE GOALS BEYOND 1980—BASIS FOR THE STUDY

On March 21, 1975, the Chairman of the Energy Resources Council (ERC) in a letter to the council members stated:

As part of the Nation's long range effort to conserve energy, there is a need to set motor vehicle fuel economy goals beyond 1980—keeping in mind the need for compatibility with environmental, safety, and economic objectives. The Secretary of Transportation was requested to lead a joint Federal task force to recommend these goals.¹

The assigned task force consisted of the:

- Department of Transportation (DOT)
  Hamilton Herman (Task Force Manager)
- Environmental Protection Agency (EPA)
  Eric O. Stork
- Energy Research and Development Administration (ERDA)
  Gene G. Manella
- Federal Energy Administration (FEA)
  Robert F. Hemphill, Jr.
- National Science Foundation (NSF)
  Ronald M. Powell

The task force has also drawn upon other departments of the Government including the Department of Commerce (DOC), the Department of Defense (DOD), the Department of

¹ See appendix 1 for letter of assignment.
EXPERIMENTAL SAFETY VEHICLES

Labor (DOL), and the National Aeronautics and Space Administration (NASA).

ORGANIZATION AND PUBLICATIONS

The task force formed the following eight study panels on automobiles:

- Air Quality, Noise, and Health (EPA Chairman)
  Edward F. Tuerk
- Safety—National Highway Traffic Safety Administration (NHTSA Chairman)
  Roger Compton
- Fuels and Materials Resources (ERDA Chairman)
  Richard W. Hurn
- Automotive Design (DOT Chairman)
  Richard L. Strombotne
- Automotive Manufacturing and Maintenance (DOT Chairman)
  Richard L. Strombotne
- Marketing and Mobility (FEA Chairman)
  Carmen Difiglio
- National, Industrial, and Consumer Economics (DOT Chairman)
  Robert Nutter
- Alternate Implementation Strategies (DOT Chairman)
  Irwin P. Halpern

Additional substantial contributors are cited at the back of this report.

Each panel prepared a report of its studies, which has been published and which served as input to the task force analysis.

The task force analysis is contained in three volumes:

- Volume 1: Executive Summary
- Volume 2: Task Force Report
- Volume 3: Appendices

A separate group was established under DOT chairmanship to study goals for commercial motor vehicles after 1980. This group drew upon additional resources from the Interstate Commerce Commission (ICC) and the U.S. Postal Service. The draft report of this group has also been published.

KEY CONSIDERATIONS UNDERLYING STUDY

The automobile occupies a critical role in national mobility, economics, environment, and safety, and, therefore, in the American lifestyle. It is, and will continue to be for the foreseeable future, the most universally accepted form of personal transportation in the United States. It is the most flexible and responsive transportation mode and is used for 90 percent of all personal travel (fig. 1).

In the national economy, expenditures for operation of the automobile constitute the fourth largest item on which Americans spend their income—after food, housing, and other services, but ahead of clothing and medical care (fig. 2).

The automobile provides employment for approximately 4.7 million persons (fig. 3).

The automobile, however, also brings with it problems in regard to safety and environmental pollution, and is the largest single consumer of petroleum, using approximately 31 percent of our petroleum supplies.

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Figure 1. Personal travel by mode.

![Figure 1](source: Derived from U.S. Dept. of Transportation National Transportation Statistics, 1975, fig. 5)

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Figure 2. Personal consumption expenditures (total: $1 trillion).

![Figure 2](source: Survey of Current Business, March 1976.)
In respect to petroleum, the situation is critical in both the long and the short run. In the short run, the Nation has become dependent on uncertain petroleum imports to an undesirable extent, and this dependency results in a large outflow of dollars from our economy. In the long run, a worldwide petroleum shortage is projected in the next 50 years. This is especially true with respect to domestic production.

This study, then, has been generated by the relationship between our dependence on the automobile in our economy and lifestyle and the critical situation that we are facing in regard to petroleum (fig. 4).

The purpose of this study is not to define what should be done in terms of a national strategy to deal with these issues, but rather to set forth in a single comprehensive document the various actions that can be taken to improve the fuel economy of the individual automobiles that will be built in the future, as well as to make clear the implications of taking one or more of such actions.

It is important that policymakers recognize that improving the fuel economy of future models of automobiles cannot be achieved without incurring some kinds of cost. While any increase in the initial price of automobiles may be partially, if not wholly, offset by monetary savings resulting from lower fuel use, there can be other costs that cannot be offset in this manner. Such costs may include lower levels of occupant protection, higher levels of exhaust emissions, less versatility in the uses to which future automobiles may be put in terms of carrying capacity and trailer-pulling ability, or reduced acceleration capability of automobiles.

Whether such costs should be incurred in achieving the national goal of improving automobile fuel economy is a policy decision beyond the scope of this task force. It has been the purpose of the task force to contribute a balanced information base that will make possible informed debate and decisions on these issues without attempting to resolve them at this time.

THE AUTOMOBILE AFTER 1980

Currently, the American consumer can choose from among a wide range of automobiles—from small to large, from two passenger to nine passenger, from modest performance to high performance, from four-wheel-drive sporting vehicles to station wagons capable of towing various trailers, and from numerous other options. These aspects
EXPERIMENTAL SAFETY VEHICLES

underscore the complexity of the marketplace and the automobile product.

The complexity does not end there, however, as Government fuel economy, safety, and environmental regulations impose requirements that must be met by all new cars.

Finally, decisions of the automobile manufacturers must consider not only these requirements, but also many others including manufacturing, employment, materials, and finance.

It is apparent, then, that decisions on the automobile beyond 1980 involve balancing a wide variety of elements from consumer preference to Government regulations and manufacturing and finance requirements. This balancing, in many cases, requires trade-offs between conflicting pressures—such as conflicts between automobile size and weight and the need to minimize these factors for optimum fuel economy (fig. 5).

APPROACH USED IN THE STUDY

Petroleum conservation can be achieved by reduction of motor vehicle-miles traveled (VMT), by improvement in motor vehicle fuel economy, or by both. The task force assigned was to focus on fuel economy. Therefore, discussion of methods for reducing VMT is presented only in brief summary in the main report.

Assuming a given mobility, the design of the motor vehicle determines (a) the degree to which the motor vehicle fleet meets the goals of safety, emissions, and fuel economy, and (b) the impacts on national resource availability, the national economy, consumer cost, and the automotive industry (fig. 6).

To estimate and evaluate the potential motor vehicle improvements, the task force:

- Selected a broad range of design concepts
- Simulated the phase-in of these design concepts through production and into the market
- Estimated the resulting effects on:
  - Total fuel use
  - Deaths and injuries
  - Air quality and health
  - National resource availability
  - Automotive industry
  - Consumer costs
  - National economy

It should be emphasized that these evaluations are not forecasts. They are essentially explorations of possible development avenues. These avenues take off from the extensive information available to date.

This report addresses itself to the 1980's and beyond. But, it should be recognized that major efforts to improve fuel economy and safety and to reduce pollution are currently underway and have produced valuable results already.

- Fuel economy has increased dramatically since 1974.
- New car emissions have been reduced substantially, and the trend is continuing.
- Automobile occupant deaths and injuries have declined as a result of improved vehicles and highways, and of lower maximum-speed limits.

The automobile industry is continuing its major efforts directed under further developments. Industry expenditures currently total approximately $600 million per year and are anticipated to continue at this level at least through the 1980's.
Further, Government-sponsored research is also contributing. The Research Safety Vehicle (RSV) and Advanced Power Systems programs illustrate these activities.

It should also be noted that since initiation of the study in mid-1975, there have been a number of changes in regulations affecting the automobile. These changes have, to a considerable degree, already spelled out certain goals for the automobile. Congress has enacted the Energy Policy and Conservation Act (Public Law 94-163), which, in part, prescribes a schedule of fuel economy standards to be met by passenger automobiles manufactured after 1977 and prescribes various other actions to increase automotive efficiency. Further, during the course of this study, amendments to the Clean Air Act have been debated, and congressional action on revised auto emission standards is imminent as of this writing.

**TASK FORCE CONCLUSIONS**

Relative to a baseline of 1975 automobile characteristics (new car size mix, fuel economy, safety, and emissions, etc.), projected without change into the future and accounting for the expected growth in the task force concluded that, with substantial industry effort, investment, and risk, coupled with a reasonable approach to Government regulation, the United States can achieve the goals shown in figure 7.

**Reduction of 40-50 Percent in Projected Automobile Fuel Consumption by 1995**

With the 1975 automobile fleet fuel economy level of 15 mi/gal and with a projected 2-percent-per-year growth in VMT, the annual petroleum consumption over the next 20 years would rise by nearly 50 percent. However, this increase in consumption can be eliminated through the introduction of lighter weight auto structures, more fuel-efficient engines, and more efficient auto drivetrains. Excluding, for the moment, marketing and financial risks, these changes can prevent the projected increase in total fleet fuel consumption and, by the mid-1990's, can provide a net reduction of up to 1-1/3 million barrels per day in fleet fuel consumption as compared to 1975 (fig. 8).

**Improvement of 80-100 Percent in Individual Automobile Fuel Economy**

Projected fuel economy values range from 15 mi/gal for the current six-passenger automobile to more than 30 mi/gal for the six-passenger diesel and advanced-engine-powered vehicles that could be introduced in future years (fig. 9).

The current engine has average 1975 fleet fuel economy performance, and the top 75 has the best 1975 fleet fuel economy. The Current Transmission, typically, is the threespeed automatic, and the upgraded is a four-speed with torque converter lockup. The current structure is the typical 1975 structure; the weight conscious structure is the first step in significant weight reduction without sacrificing interior space; and the innovative structure (the second step in weight reduction) uses 10 to 15 percent plastic/aluminum substitution.

**Improvement of 80-100 Percent in New-Car Fleet Fuel Economy with the Current Automobile Size Mix**

With the current automobile size mix, which is about 50 percent six-passenger cars,
25 percent five-passenger cars, and 25 percent four-passenger cars, the new car auto fleet average fuel economy can be increased 80 to 100 percent by the late 1980's by reducing car weight and by using technologically available powerplants and advanced transmissions (fig. 10).

Actual Fuel Savings Dependent on the Rate of Introduction of New Fuel-Economy Cars

The average fuel economy of the total fleet—new cars plus old cars—lags behind the fuel economy of the new car fleet.

For example, in the illustrative scenario\(^2\) in figure 11:

- Phasing-in of auto concept No. 3 (weight conscious structure, Top '75 engine) begins in 1975 at the rate of 10 percent of new car production, replacing auto concept No. 1 (essentially the current auto).

\(^2\)Innovative structure, Top '75 Otto, upgraded transmission (scenario No. 2). This is one of 10 time-phased scenarios using selected combinations of the 864 automobile design concepts considered.
In 1980, the phasing-in of the auto concept No. 4 begins (adding the upgraded transmission at the rate of 10 percent of new-car production per year).

Finally, in 1985, phasing-in of auto concept No. 5 begins (adding the innovative structure).

Beyond 1995, the new-car fleet is composed of concept No. 5 automobiles.

In 1980, the new car fleet will consist of 50 percent auto concept No. 1, 40 percent auto concept No. 3, and 10 percent auto concept No. 4. New car fleet fuel economy reaches 20 mi/gal. The total operating fleet fuel economy, however, does not achieve this average fuel economy value until 1985.

The cumulative petroleum savings achieved in 25 years by this shift to the more fuel-economical concept Nos. 3, 4, and 5 cars is approximately 17.8 billion barrels.

The absolute value of the savings is dependent upon the rate of introduction of various combinations of fuel-economical new cars, the degree to which consumers purchase the more fuel-economical models, and the balance, timing, and methods used in achieving other important national objectives such as air quality improvement, improvement in vehicle and highway safety, and the maintenance of a strong domestic automotive industry.

Economic Payback

The value to the Nation of the potential automobile fuel savings greatly exceeds the costs ($5 to 10 billion net present value) of the capital investment necessary to obtain these savings. For example, a 25-mi/gal fleet average fuel economy, set against a 1975 average of 15 mi/gal, will save over a 20-year period approximately 9-1/2 billion barrels of petroleum (roughly the size of the Alaskan Prudhoe Bay Oil Field). Even assuming an $11-per-barrel price, this amounts to over $100 billion. Even discounting these savings as they occur at a 10-percent rate, the present value is approximately $30 billion, which yields,
nationally, a discounted return on investment of 300 to 600 percent (fig. 12).

Advanced Engines

The prospect that a revolutionary new engine technology development would make a substantial impact on fuel efficiency within the 1980’s is remote. Fuel efficiency improvements will derive primarily from improvements in present body and frame structures, gasoline and diesel engines, and their drivetrains. However, advanced engine technology, such as the gas turbine or the external combustion Stirling type, might enter the market in the last half of the 1980’s and could provide in the decade of the 1990’s another option for reducing automotive fuel consumption, or for reducing emissions, in addition to offering a multifuel capability.

Electric Vehicles

The prospects for a highly efficient electric car, in the next 10 years at least, appear to be slim. Substantial technological advancement in batteries would be required before the electric car can offer a commercially viable alternative to gasoline or diesel-fueled automobiles. Current and near-term electric automobile deficiencies in range, payload, performance, cost, and overall energy efficiency would have to be overcome. Electric vehicles are feasible for special purposes (such as small postal delivery vans) and offer flexibility in fuel use, but the total national effect on petroleum consumption within the next 15 years will be minimal.

Substantial Reductions Achievable in Auto Deaths and Injuries

A transition to more compact, properly designed, lighter weight automobiles is not projected to increase auto occupant fatalities and injuries. Growth in the number of vehicles, VMT, and number of drivers, however, are predicted to result in a 71 percent increase

Figure 9. Fuel economy for 10 selected auto concepts (four-, five-, and six-passenger autos).

<table>
<thead>
<tr>
<th>Auto concept</th>
<th>Structure</th>
<th>Vehicle description</th>
<th>Engine</th>
<th>Drivetrain</th>
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</thead>
<tbody>
<tr>
<td>No. 1</td>
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<td>Current</td>
<td>Current</td>
</tr>
<tr>
<td>No. 2</td>
<td>Weight conscious</td>
<td></td>
<td>Current</td>
<td>Current</td>
</tr>
<tr>
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<td>Top '75</td>
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</tr>
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<td>Top '75</td>
<td>Top '75</td>
<td>Current</td>
</tr>
<tr>
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<td>Innovative</td>
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<tr>
<td>No. 9</td>
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<td>Advanced(^b)</td>
<td>Current</td>
</tr>
<tr>
<td>No. 10</td>
<td>Innovative</td>
<td>Advanced(^b)</td>
<td>Advanced(^b)</td>
<td>Upgraded</td>
</tr>
</tbody>
</table>

\(^a\)Current emission and safety levels; 0-60 mi/h acceleration time = 15 s; basic car without special options.
\(^b\)Data for Stirling engine have been used to represent future advanced concepts; including Brayton.
### Table

<table>
<thead>
<tr>
<th>Auto concept</th>
<th>Vehicle description(^a)</th>
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<th>Drivetrain</th>
</tr>
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\(^a\)Current emission and safety levels; 0-60 mi/h acceleration time = 15 s; basic car without special options.

\(^b\)Data for Stirling engine have been used to represent future advanced concepts, including Brayton.

### Figure 10

New-car fleet fuel economy of 10 selected auto concepts (fleet mix: 50 percent six-passenger, 25 percent five-passenger, 25 percent 4-passenger autos).

Increased safety belt use appears to warrant extraordinary steps to effect such use of the belts that are already in the fleet. These benefits are achieved at low cost and generate no fuel penalty (fig. 14).

New systems such as safety level II would take 10 years at least, and possibly 15 years, to become a major factor in the automobile fleet, because the new cars enter the fleet gradually, and the new systems cannot be introduced immediately. As a complement to high belt use, safety level II would become effective at about the time when the predicted fatalities and serious injuries had risen back to the level of the mid-1970's. By itself, safety level II is predicted to reduce deaths and serious injuries by up to 264,000 by the year 2000.

If, in this 10-to-15-year interim period, high belt use is not effected, there will be 67,000 fatalities and serious injuries that could have been prevented.
# EXPERIMENTAL SAFETY VEHICLES

<table>
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<tr>
<th>Item</th>
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<td>1985</td>
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<td>24.2</td>
<td>26.3</td>
<td>29.2</td>
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</tbody>
</table>

Figure 11. Illustrative Otto engine (scenario No. 2): Auto concept No. 3 phased in 1975, auto concept No. 4 phased in 1980, and auto concept No. 5 phased in 1985 (rate for each 10 percent of new car fleet).
Cumulative Fuel Penalties: Impacts of Safety Requirements

Implementation of safety level II is estimated to increase new car costs by approximately $300 and to increase weight by 150 to 200 pounds. The effects of the estimated weight increases are shown below relative to the cumulative fuel savings potential of the illustrative Otto engine scenario (fig. 11).

Imposition of safety level II could result in the consumption of nearly 0.75 billion barrels of petroleum, at a cost of $8 billion, by the year 2000 (fig. 15).

Continuing Improvement Achievable in Ambient Air Quality

Substantial improvements in air quality have resulted from the automobile emission standards imposed to date. The prospects for further reduction in air pollutants caused by the automobile fleet are excellent. A major factor here is the continued scrapping of older polluting cars and their replacement with the much cleaner cars that meet the Federal emission standards. This replacement will result in improvements in air quality generally, and, therefore, in reductions in the adverse health effects of automobile-related air pollution. Further progress in reducing automobile emissions in concert with fuel economy objectives is likely. The actual extent is, however, controlled by the timing and degree of tighter emission standards, as well as the status of new developments in emission control technology.

The following projections, however, assume the implementation of a nationwide inspection/maintenance program, a condition that does not now exist.

Hydrocarbons (HC). With continued tightening of emissions from stationary and other mobile sources of air pollution as the context for analysis, by the year 2000, average oxidant concentrations would range from approximately 40 percent below the average of the early 1971-74 period for

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**Figure 12. Dollar values of automobile fuel savings associated with various auto concept fuel economies at different discount rates compared to auto industry extraordinary investment.**

<table>
<thead>
<tr>
<th>INDUSTRY EXTRAORDINARY INVESTMENT</th>
<th>DISCOUNT RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>(12 billion bbl)</td>
<td>15%</td>
</tr>
<tr>
<td>(9.5 billion bbl)</td>
<td>10%</td>
</tr>
<tr>
<td>(6 billion bbl)</td>
<td>0%</td>
</tr>
</tbody>
</table>

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**Figure 13. Predicted annual auto occupant deaths and serious injuries from front, side, and rear collision modes.**

<table>
<thead>
<tr>
<th>Safety level</th>
<th>Crashworthiness</th>
<th>Crash avoidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>All FMVSS's pertaining to crashworthiness that are effective for May 1975 cars and those that will become effective during the 1976-80 period (protection for front, rear side, rollover, and fire), 30 mi/h frontal performance.</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>Same as level I plus 40-mi/h passive frontal protection, 20-mi/h passive side protection and egress.</td>
<td></td>
</tr>
</tbody>
</table>

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**Figure 12 Diagram Notes:**

- The extra investment that would be required to accelerate conversion to more fuel economical cars.

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**Figure 13 Notes:**

- Federal Motor Vehicle Safety Standards
continuation of the current 1.5 gm/mi HC emission standard to 50 percent if the statutory level of 0.41 gm/mi were adopted.

Carbon Monoxide (CO). In the case of CO, the current standard of 15 gm/mi would result in average concentrations in the year 2000 approximately 75 percent below the early 1970’s base year averages, while a reduction in the standard to the statutory 3.4-gm/mi standard would reduce the average concentration by about 10 percent more.

Oxides of Nitrogen (NOx). For NOx, reductions in automotive emissions would be substantially offset by increases in emissions from stationary and other mobile sources. A worsening of the baseline air quality (1972-74) would be expected under all emission standards above 1.0 gm/mi. However, a reduction in emission standards from 3.1 gm/mi to 2.0 gm/mi in the late 1970’s would have the effect of reducing the average concentration in the year 2000 by about 20 percent. A further reduction to the statutory level of 0.4 gm/mi would reduce those average concentrations by another 20 percent, approximately.

Some national health benefits projected to the year 2000 are shown in figure 16 to represent the effects of various levels of control (assuming concurrently one set of reasonably aggressive controls for stationary and other mobile sources).

Figure 14. Estimated cumulative deaths and serious injuries prevented relative to voluntary seatbelt use.

Figure 15. Impact of implementing safety level II in 1985 on cumulative fuel savings.
Control of automobile HC emissions from the present 1.5 gm/mi to the statutory level of 0.41 gm/mi will, for example, reduce excess person-days of chest discomfort by some 5,000 cases by the year 2000.

Control of CO at the present level of 15 gm/mi is sufficient to reduce projected excess cardiac deaths and person-days of discomfort to zero by 2000 as emission-controlled cars replace older vehicles. Lower CO emission levels do not change these health indicators.

Control of NO\textsubscript{x} is projected to reduce attacks of lower respiratory disease in children by nearly 600,000 cases per year by 2000 if NO\textsubscript{x} standards are reduced from the present 3.1 gm/mi to 2.0 gm/mi. Benefits of further reduction of the standard to the statutory level offer an additional reduction of 600,000 cases per year.

Study of Alternative NO\textsubscript{x} Control Strategies Needed

Amendments to the Clean Air Act are currently being debated with emphasis on the timing and need to impose the statutory levels of automobile emissions previously prescribed by the Congress. In particular, the need for the statutory NO\textsubscript{x} standard and its full ramifications are being scrutinized. Numerous stationary and other mobile source NO\textsubscript{x} control strategies are being examined in light of the fact that the 2.0-gm/mi automobile NO\textsubscript{x} standard is likely in the near term, which would reduce automobile contribution to 12 percent of the total nationwide NO\textsubscript{x} emissions by the year 2000. Some stationary source control strategies up to three times more cost-effective than reducing auto standards from 2 to 1 gm/mi have been identified. However, it must be noted that a worsening of air quality has been projected for all standards above 1 gm/mi. The further reduction of auto NO\textsubscript{x} emissions below 1 gm/mi has been shown to be at least five times less effective than the 2-gm/mi-to-1-gm/mi case.
Other questions pertaining to the lower NO\textsubscript{x} standards have prompted many to suggest that the Administrator of EPA should be granted authority to set the standard based upon health needs and availability of technology.

### Fuel Economy Impact of Emissions Controls

Relative to no emission control, emissions standards applicable during the 1968-75 time frame and changes in fuel specifications (for example, removal of lead and corresponding compression ratio reduction) have increased fuel consumption in some cases and, in all cases, have increased new car costs by more than $100 per car on the average. Further reduction of emissions under current technology can result in substantial increases in fuel consumption and cost. However, continued development of emissions control technology could reduce or eliminate such penalties.

The agencies represented on the task force had varied estimates as to the probability and extent of fuel economy losses at the levels for standards considered in this report. There was agreement that whatever losses might occur with vehicles when first marketed under tighter emissions standards would diminish in subsequent model years of that same standard. Estimates ranged from negligible fuel economy loss at any level of emissions control considered to losses of approximately 6 percent for the level II (0.41/3.4/2.0) standard and 12 percent or more for future systems meeting the level III (0.41/3.4/0.4) standard. Future losses, at this time, can only be estimated, and such estimates are necessarily judgments on the part of each person and group involved. The actual extent of future fuel economy losses will depend on the timing and stringency of emissions standards, as well as success of the ongoing research and development efforts and manufacturer implementation programs.

The effects of these estimates are shown in figure 17 relative to the cumulative savings of the illustrative Otto engine scenario. By the year 2000, the fuel economy losses associated with the level II emissions standards (0.41/3.4/2.0) could result in the consumption of no additional petroleum or as much as 1 1/2 billion barrels, at a cost of $16.5 billion (assuming $11 per barrel and a 6 percent loss). The losses associated with level III standards (0.41/3.4/0.4) could be negligible or could result in the consumption of an additional 3 billion barrels of petroleum or more, at a cost of $33 billion (assuming a 12 percent loss), as compared to the base case of present emissions standards (1.5/15/3.1).

### Savings in the Cost of Auto Transportation

The average cost per mile of auto transportation at current emission and safety standards is expected to diminish (in current dollars) with the transition to lighter weight and more fuel economical designs. The introduction of more stringent safety and emission standards may, however, increase the initial purchase and maintenance costs of an automobile. The magnitudes of associated cost increases will depend on the severity of the standards imposed (no consumer cost increases, for example, are associated with increased safety belt use). The most severe safety and emissions standards considered would raise the cost per mile by 1/2 to 1 cent, depending upon actual fuel economy losses experienced. Potential cost increases, which could come about through changes in emis-
sion and safety standards, might be offset by the increase in dollar savings on fuel if fuel prices increase (table 1).

Savings in Material Resources

Substantial savings in material resources used in the manufacture of autos will be achieved through the design and use of lighter weight vehicles. For example, 59 million tons\(^3\) of steel will be saved by the year 2000 under assumptions of the illustrative Otto engine scenario.

 Achievement of Fuel Economy Standards Possible

Near Term (1977-80). In the near term, the manufacturers' average fuel economy standards set for 1978, 1979, and 1980 (18 mi/gal, 19 mi/gal, and 20 mi/gal, respectively) appear to be achievable by the automotive industry at current safety and emission standards, provided that the consumer buys cars in the traditional mix of sizes.

1985. The analysis shows that fuel economies in the range of 26.0 to 27.5 mi/gal can be achieved for a full line of automobiles (four, five, and six-passenger cars) under current safety and emission standards. However, to do so, the study indicates that a full-line manufacturer would have to institute one or more of the following steps:

- Reduce automobile acceleration below current norms (risking consumer rejection of the lower performance).
- Provide incentives that would lead to smaller cars taking a larger share of the market than at present.
- Adopt the light-weight diesel in appreciable numbers (although currently an unknown risk exists relative to problems with odor, smoke, and other emissions and uncertain NO\(_x\) standards).
- Accelerate the development and introduction of upgraded transmissions.
- Introduce innovative automobile structures in the early 1980's (a difficult changeover schedule in respect to both development and manufacturing).

Manufacturers of more limited model lines (small cars) would not likely be burdened by such steps. Thus, the manufacturer of a full line of automobiles may be placed at a competitive disadvantage with respect to manufacturers of small cars, imported or domestic. To achieve the 27.5-mi/gal fleet average, the full-line manufacturer will clearly have to place his small cars above 27.5 mi/gal to balance the larger cars that are not likely to meet this mileage. This would mean that the full-line manufacturer's small cars would have to be lighter in weight or, more likely, lower in performance than those small cars of his competitors that could be targeted at 27.5 mi/gal. The difference in performance could have a drastic market impact on the small car of the full-line manufacturer and, thus, make it even more difficult to meet the 1985 fuel economy standards.

Figure 18 shows fuel economy as a function of engine-power-to-weight ratio and percentage of six-passenger cars in the total new car fleet. The 1985 fuel economy goal of the EPCA is indicated by the dashed line at 27.5 mi/gal.

Table 1. Cost of operating an automobile

<table>
<thead>
<tr>
<th>Auto type</th>
<th>Original vehicle cost</th>
<th>Maintenance</th>
<th>Fuel at 60 cents per gallon</th>
<th>Garage parking and tolls</th>
<th>Insurance</th>
<th>Taxes and fees</th>
<th>Interest</th>
<th>Total cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>5.7</td>
<td>3.4</td>
<td>4.1</td>
<td>2.0</td>
<td>1.6</td>
<td>0.5</td>
<td>1.1</td>
<td>18.4</td>
</tr>
<tr>
<td>Weight conscious</td>
<td>5.5</td>
<td>3.0</td>
<td>2.5</td>
<td>2.0</td>
<td>1.6</td>
<td>0.5</td>
<td>1.1</td>
<td>16.2</td>
</tr>
</tbody>
</table>

\(^3\)In 1975, approximately 10 million tons of steel were used in domestic automobile production.
percent. On the other hand, if the power-to-weight ratio is reduced to 0.02 hp/lb (0 to 60 mi/h in 20 s), the fuel economy goal could be attained with six-passenger cars having a 90 percent market share.

Figure 19 summarizes the sensitivity of fleet fuel economy to auto and fleet characteristics. Particularly noteworthy are the benefits from reduced performance or adoption of the diesel. The sensitivity data indicates the fuel economy gains associated with a reduction in the share of six-passenger cars from 50 percent to 30 percent can be achieved by (a) the dieselization of larger cars, (b) accelerated introduction of an upgraded drivetrain, (c) an improvement in Otto engine fuel economy of 10 percent, or (d) a reduction in acceleration performance. These alternative approaches suggest the wide range of options, with varying marketing and technical risk, available to achieve fuel economy goals.

Beyond 1985. With the fuel economy, emissions, and safety steps that will have been put in motion by 1985, the fuel economy of the total automotive fleet will continue to

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Figure 18. 1985 new car fleet fuel economy versus vehicle mix and acceleration performance.

At current mix (50 percent six-passenger, 25 percent five-passenger, 25 percent four-passenger) and a power-to-weight ratio of 0.03 hp/lb (0 to 60 mi/h in 15 s), 1985 new car fleet fuel economy could be 25.2 mi/gal. In order to exceed the fuel economy standard at this performance level, the share of six-passenger cars must be reduced below 15 percent. On the other hand, if the power-to-weight ratio is reduced to 0.02 hp/lb (0 to 60 mi/h in 20 s), the fuel economy goal could be attained with six-passenger cars having a 90 percent market share.

Figure 19 summarizes the sensitivity of fleet fuel economy to auto and fleet characteristics. Particularly noteworthy are the benefits from reduced performance or adoption of the diesel. The sensitivity data indicates the fuel economy gains associated with a reduction in the share of six-passenger cars from 50 percent to 30 percent can be achieved by (a) the dieselization of larger cars, (b) accelerated introduction of an upgraded drivetrain, (c) an improvement in Otto engine fuel economy of 10 percent, or (d) a reduction in acceleration performance. These alternative approaches suggest the wide range of options, with varying marketing and technical risk, available to achieve fuel economy goals.

Beyond 1985. With the fuel economy, emissions, and safety steps that will have been put in motion by 1985, the fuel economy of the total automotive fleet will continue to
improve beyond 1985 to at least 1995 as the later new cars take over the fleet. The resultant fuel economy (potentially in the range of 30 mi/gal) will depend essentially on the market actions, future safety, and environmental regulations, and the results of the ongoing research and development programs.

Good Future for Automotive Industry and Employment

The study indicates that it is possible to achieve desirable improvements in fuel economy, safety, and emissions while also meeting the needs in respect to the many other factors affecting the automobile, such as first cost, operating costs, changeover times, and performance. If this possibility is achieved, as it should be, then the automobile can continue its major role. This means, then, that future prospects for automotive employment and the industry can be good. The Nation will be able to have the valuable mobility provided by the automobile, with automobile use increasing with the increase in the driving-age population.

But There is a Risk

The rapid introduction of new fuel economical automobiles over the next decade dictated by mandatory fuel economy standards will require for the “big four” automobile manufacturers a 15- to 25-percent increase in capital investment ($5 to $10 billion) over their normal spending levels for facilities and equipment. If cars continue to sell at normal rates, this additional capital can be raised in the national money market, or can be internally generated, but there are definite risks associated with these investments:

- The consumer may not buy the lighter cars in percentages that would yield the “mandated” fleet economies. Fines on the manufacturers will not necessarily solve this problem. Alternatively, low consumer acceptance of models offered will result in low total sales. Industry investment and overall economic posture would be jeopardized.
- Ability to react to such uncertainties can create especially serious problems for smaller manufacturers who are less able to put up development funds and to risk major capital on new directions.
- Changes in the national economy that have historically demonstrated overpowering effect on consumer buying power and habits cannot be ruled out.
- Consumer behavioral patterns are shifting and are hard to predict. These changes may have a real effect on acceptance of lighter cars.
- Potential changes in regulations on safety, emissions, and fuel economy create further uncertainties. The same is true with respect to wholly new regulations that may be introduced (such as those for sulfates).
- Unforeseen changes in technology that are not now clear could alter the development path.

ISSUES OF CONCERN

The task force has developed a large amount of useful information and has estimated that a 50-percent reduction in projected fuel use by the national automobile fleet is potentially achievable, provided that the manufacturers can successfully develop and apply the necessary automotive technology and that customers decide to purchase the cars with high fuel economy.

The goal of minimizing petroleum consumption raises important issues in regard to the other important national objectives of improving air quality in metropolitan areas, reducing highway fatalities and accidents, and maintaining a viable and strong domestic automotive industry. Some of these important issues are as follows:

1. How can the American public be convinced of the need for changeover to more fuel efficient motor vehicles and be induced to accept the types of automobiles that will achieve fuel economy? Without public acceptance and purchases, the most fuel efficient design is useless. The mandated 27.5-mi/gal fleet fuel consumption standard in 1985, for example, appears to be technologically feasible but can only be realized with public cooperation and full understanding of the
EXPERIMENTAL SAFETY VEHICLES

purpose. This issue looms as the major dilemma facing the Federal Government and the industry.

2. How rapidly can industry change over to more fuel efficient automobiles without undue burden or impact on itself, on its suppliers, or on levels of employment? Ideally, any changeover should take place gradually, with adequate advance knowledge and with maximum flexibility for each segment of the industry.

3. How should the Nation handle the risk that the automobile industry must accept in motor vehicle changeover to fuel efficient models? The impact of these risks is especially important in the light of the many uncertainties that underlie such changeovers.

4. How can the considerable risks associated with changeover be reduced for the smaller companies?

5. How may the Federal Government effectively balance the sometimes conflicting objectives of reduced energy, increased safety, and improved environmental quality in the requirements it imposes on the automotive manufacturers and their products, especially when these requirements are imposed by several independent agencies with separate authorities?

6. How far should passenger safety and emissions control be mandated into automobile designs? At what point do incremental costs outweigh incremental gains?

7. What changes should be made in Federal policies and regulations to provide effective incentives for automobile manufacturers to more rapidly develop and supply automotive technology having substantial public benefits?

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Closing Remarks

Mr. HOWARD DUGOFF
Chairman of the Sixth International Technical Conference on Experimental Safety Vehicles

Ladies and gentlemen, the overwhelming impression in the mind of an observer of these last 4 days' proceedings has to be the tremendous scope, substance, and diversity of the material presented. Nevertheless, it seems to me that there were a number of fundamental, recurrent themes with particular significance to the parties gathered here. The first is that, while the general topic of our proceedings has been vehicle safety research, the dominating focus has been the motor vehicle regulatory process. Whereas we all recognize that the decisions made by regulatory policymakers are inevitably, and quite properly, influenced by considerations above and beyond technical ones, it is clear that we share a conviction that our job as researchers is to assure that the decisionmaker is provided with the comprehensive and rigorous technical data he needs to make his necessarily subjective judgments thoroughly informed.

We come to see, more and more, how the impacts of the various elements of motor vehicle regulation are inextricably intertwined—with the clear implication for us, as researchers, that the comprehensive and analytical approach (to use the jargon introduced in the London conference, the S3E concept) is indeed necessary if we are to meet the technical support requirements for responsible and effective regulation. These proceedings have also shown clearly, however, that much work needs to be done in the subsystems field that provide the building blocks of our broader integrated studies. In particular, continued efforts are needed to upgrade the accident data base and associated analysis methodology to develop standardized measurement procedures and criteria for the assessment of both active and passive safety performance, and to better understand the fundamental mechanisms of accident and injury causation.

The international program of collaboration in the field of motor vehicle safety and, in particular, these Experimental Safety Vehicle Conferences, which bring us together to exchange and stimulate our ideas, have contributed greatly to our current levels of knowledge and understanding of the matters that we deliberate. I am confident that this program will continue to lead the way in responding to the evolving research requirements of the motor vehicle regulatory community.

Before closing, I would like to express my sincere appreciation to the many delegates whose presentations have provided the substance of these proceedings; to my colleagues on the American delegation, especially Mr. Shively, and to the staff of this hotel for the excellent programmatic and administrative arrangements for the conference; to the U.S. State Department and the Motor Vehicle Manufacturers Association for their hospitality; to our most able and hard-working translators; and to all of you participants and observers for your interest and attention.

Ladies and gentlemen, the Sixth International Technical Conference on Experimental Safety Vehicles is adjourned.