NHTSA'S EVALUATION OF A POTENTIAL CHILD SIDE IMPACT TEST PROCEDURE

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ABSTRACT

This paper details the National Highway Traffic Safety Administration's (NHTSA) ongoing research to evaluate and develop a potential dynamic side impact test procedure for child restraint systems (CRS). Federal Motor Vehicle Safety Standard (FMVSS) No. 213, "Child Restraint Systems" currently only requires that U.S. marketed child restraints meet dynamic testing simulating a 48.3 kmph (30 mph) frontal impact. NHTSA's initial program consisted of evaluating a side impact sled buck designed by TK HOLDINGS INC. (Takata) and conducting a small number of full-scale moving deformable barrier (MDB)-to-vehicle side impact crash tests to verify the sled performance. The results from these initial tests were presented in a 2009 ESV paper by Sullivan et al. [1]. This paper presents subsequent tests and vehicle surveys conducted to determine characteristics of various components of the side impact test bucks such as the seat cushion, door panel, and an armrest that would result in improved real world representation of the side impact sled test procedure. This paper also presents the results of tests conducted with the modified side impact test buck using a variety of CRS models currently in the U.S. market.

The test procedure with the modified test buck produced repeatable results and was able to distinguish the performance of different child restraint models in side impact. The design of the side wings on child restraints for head protection and the stiffness of the child restraint padding were factors affecting the containment of the dummy and the injury measures.

BACKGROUND

NHTSA has been assessing test equipment and test methodology to replicate a representative side impact scenario that could potentially be developed into a future child restraint dynamic side impact test procedure under Federal Motor Vehicle Safety Standard (FMVSS) No. 213.

The agency analyzed vehicle crash tests to determine initial test parameters such as impact velocity, impact angle, and seat velocity for passenger vehicles. Initial sled tests were conducted using a sled test buck (modified Takata sled) consisting of a sliding seat (representing a vehicle seat) and a padded rigid wall side structure (representing the vehicle door) Sullivan et al. 2009 [1].

The sliding seat acceleration pulse and velocity was determined from the right rear sill lateral accelerations of ten small vehicles in side impact crash tests conducted in accordance with the FMVSS No. 214, "Side Impact Protection" Movable Deformable Barrier (MDB) test procedure. The derived velocity was approximately 27 to 29 kmph (17 to 18 mph).

The vehicle door velocity was determined by integrating the door lateral accelerations of four of the 10 vehicles tested under FMVSS No. 214, which had door accelerometer data available. Results showed a lateral velocity range between 31.4 kmph and 33.0 kmph (19.5 to 20.5 mph). A 32 kmph (20 mph) velocity was selected as the target speed of the door on the sled buck. This door velocity was achieved using a half-sine acceleration pulse for the sled/door, with a peak acceleration of about 28 G's and a duration of about 55 milliseconds (ms).

A range of sled buck impact angles was determined by using the right rear side sill longitudinal and lateral accelerations of the 10 vehicles tests. These accelerations were integrated to obtain the component velocities which were then used to calculate the angle of the resultant acceleration with respect to the lateral axis of the vehicle during the crash event. This calculation was made between 5 and 60 ms, which corresponds to the typical time from initial motion of the struck vehicle through peak loading on the near side occupant. The impact angle estimated by this process was in the range of 0-20 degrees.

Summary of Initial Test Parameters:
- Sled pulse - 1/2 sine, 28 G peak, 55 ms duration
- Sled velocity – 32 kmph (20mph)

- Honeycomb dimensions (2.3 PCF, 3/8" cell wall): 300 mm thick x 342 mm wide x 125 mm long
- Sliding seat initial position (-) 260 mm from honeycomb
- Sliding seat acceleration – matching established corridors, 20 G peak, 55 ms duration
- Range of impact angles (0 – 20 degrees)

Detailed information on the previously established parameters are available in Sullivan et al. (2009) [1].

Sullivan et al. (2009) [1] concluded that the sled test procedure appeared to be repeatable and was able to distinguish between child restraint models using some of the injury measures. Comparison of results from side impact sled tests using the Q3s dummy (3-year old child side impact test dummy) with comparable full-scale vehicle side impact crash tests (moving deformable barrier (MDB) into the side of a vehicle) indicated that the dummy responses exhibited similar trends in the sled and full vehicle crash tests.

This study is a continuation of NHTSA's previous work [1] developing a dynamic sled to replicate the performance during a vehicle crash of a properly restrained 3-year-old child.

This paper presents the evaluation of different test parameters such as the door stiffness, simulated armrest, impact angle and the geometry of the seat and door for refining the test procedure to better represent vehicle, CRS, and dummy responses observed in select vehicle crash tests (Sullivan et al. (2009) [1]). Sled tests were performed with CRS models currently available in the U.S. using the 3-year-old side impact (Q3s) and the 12-month-old (CRABI) child test dummies.

IMPACT ANGLE SELECTION

As described in Determination of Sled Buck Angle in Sullivan et al. (2009) [1], a reference frame was used in which a pure left-to-right lateral impact was zero degrees and a pure frontal impact was 90 degrees. Using results from ten MDB-to-vehicle side impact crash tests, the agency estimated that the mean impact angles over the time period of interest ranged from 4 to 15 degrees, while the angle at any specific time ranged from -8 to 22 degrees. Based on this observation, in addition to purely lateral (0 degree) impact simulations, tests were performed with the sled buck rotated to simulate impacts at 10, 15 and 20 degrees during the initial program in an effort to evaluate the effect of the test buck's impact angle on dummy kinematics.

Results of the aforementioned angled sled tests, which are discussed in more detail in Sullivan et al. (2009) [1], indicated that impact angle had an effect on some injury metrics while it had minimal effect on others. Comparison of the sled tests simulating different impact angles to the four MDB-to-vehicle crash tests previously conducted in this program indicated that a sled impact angle of 10 degrees provided reasonable replication of the dummy/CRS kinematics observed in the crash tests. In addition, as shown in Table 1, the average impact angle computed from the vehicle right rear sill velocities in the 10 MDB-to-vehicle crash tests is approximately 10 degrees. Based on these observations, a 10 degree impact angle was selected for the next phase of sled testing.

Table 1.
Impact Angle (degrees) Based on Right Rear Sill Velocity of Side Impact Crash Tests

Average Angle from 5-60 ms	**7.6**
Average Maximum Angle from 5-60 ms	**12.7**
Average Angle at time of Peak Pelvis Lateral Acceleration	**8.4**
Average of 3 methods	**9.6**

SLED BUCK CHARACTERISTICS

Geometry of Test Buck

NHTSA determined that the simulated side door and the United Nations Economic Commission for Europe Regulation No. 44 (ECE R44) test seat fixture used by Takata for the side impact buck were acceptable for use in proceeding with the development of a side impact test methodology.

The agency recently conducted a survey of late model passenger vehicles to obtain dimensional characteristics of rear seats in these vehicles. The following characteristics were assessed: seat pan and seat back cushion length, width, angle, and thickness; shoulder belt and tether anchor distances; shoulder belt and lower anchor spacing; rear seat clearance; armrest and windowsill dimensions. The 24 vehicles surveyed represent the U.S. fleet, and include passenger cars, multi purpose vehicles (MPV) and trucks.

Results of the survey found that the average seat back angle was 20 degrees and the average seat pan angle was 15 degrees, both of which correspond to the angles of the test seat fixture used in the modified

Takata buck. The armrest thickness (protrusion of armrest in the door) for the 24 vehicles surveyed ranged from 25 mm (1 in) to 105 mm (4.1 in) ; 1 vehicle was at or below 50 mm (2.1 in), 8 vehicles were between 51 mm and 70 mm (2.75 in), 10 vehicles were between 71 mm (2.75 in) and 80 mm (3.1 in), and 5 vehicles were above 81 mm (3.1 in).

This paper will discuss the new door padding material that was identified and evaluated using dynamic free motion headform (FMH) impact tests which are described in detail in the section **Door Characteristics** of this paper. Also identified was an armrest padding material for use in conjunction with the door panel padding. The armrest chosen for subsequent sled tests consisted of a 64 mm (2.5 in) thick padding material attached to the 51 mm (2 in) thick door panel (details are provided in the **Armrest** section in this paper).

Figure 1 shows the side impact sled test buck windowsill and top of armrest heights, measured relative to the seat cushion angle, overlaid onto the windowsill and armrest heights for each of the surveyed vehicles. The solid black lines represent the sled buck features and the colored lines represent different vehicles. The armrest design and placement selected for use on the sled buck are discussed in more detail later in this paper.

Although other seat cushion dimensions were assessed during the vehicle survey, only the cushion angles were evaluated during the side impact sled test methodology development at this time. Once a test methodology is selected, further evaluation of the effect of cushion thickness, length, lower anchorage placement, etc. will be conducted if deemed necessary.

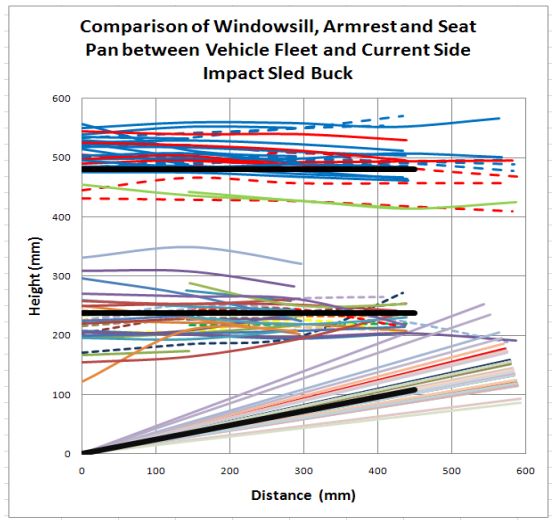

Figure 1. Comparison of Windowsill, Armrest and Seat Pan between Vehicle Fleet and Current Side Impact Sled Buck.

The dimensions of the test buck door structure and armrest design and placement relative to the seat cushion structure, used during sled tests, are shown in Figure 2.

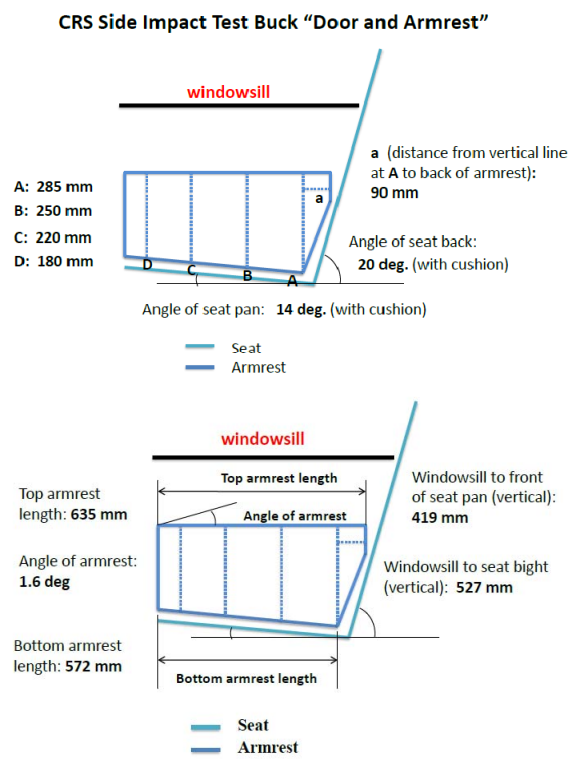

Figure 2. Side Impact Sled Buck Door and Armrest Structure Dimensions.

Seat Cushion Stiffness

A quasi-static test with a 203 mm (8 in) diameter indentation plate (see Figure 3) was performed to measure the rear seat cushion stiffness of 13 vehicles. The tested vehicles were:

- 2006 Honda Ridgeline
- 2006 VW Passat
- 2007 Ford Expedition
- 2007 Ford Five Hundred
- 2007 Saturn Vue
- 2008 Ford Taurus X
- 2008 Mazda CX-9
- 2008 Nissan Sentra
- 2008 Subaru Tribeca
- 2008 Toyota Highlander
- 2008 Nissan Versa
- 2003 Ford Crown Victoria
- 2005 Chrysler 300C

In addition to actual vehicle seat cushions, quasi-static force deflections were measured for three different test seat fixture cushions: FMVSS No. 213, ECE R44 and the New Programme for the Assessment of Child restraint Systems (NPACS) foams. The NPACS foam was considered in the analysis because as part of the World Forum for Harmonization of Vehicle Regulations Working Party on Passive Safety (GRSP) Informal Group on Child Restraint Systems' effort on side impacts, the group has been evaluating a new foam for the seat cushion designated under NPACS [2] as a potential replacement for the existing ECE R44 seat cushion.

Figure 3. Quasi-static Test in Vehicle Rear Seat Cushions (left) and in the FMVSS No. 213 Frontal Test Buck (right).

As shown in Figure 4, one of the outboard rear designated seating positions (DSP) of each vehicle was measured in three locations on the longitudinal centerline (102 mm (4 in) from front edge (1*), 102 mm (4 in) from seat bight (2*), midway between point 1 and 2 (3*)), and in two additional locations at the front of the seat (102 mm (4 in) from outboard edge (4*), highest point on the inboard side - at least 203 mm (8 in) from location 1(5*)). The middle rear DSP of each vehicle was also measured at two locations on the centerline (102 mm (4 in) from front edge (6*) and 102 mm (4 in) from seat bight (7*)). The test buck was measured at 102 mm (4 in) from the front edge of the seat cushion.

Figure 4. *Rear Seat Measurement Locations.

Figure 5 shows the force vs. displacement plots of the different vehicle rear seat cushions and the different foams (FMVSS No. 213, ECE R44 and NPACS) on the test buck. The plot shows that the FMVSS No. 213 foam (red dotted line) is comparable to the 2003 Ford Crown Victoria (orange solid line). All other vehicles show stiffer responses. The NPACS (red & orange with dots) and ECE R44 (dark blue with dots) are also stiffer than the FMVSS No. 213 foam and more representative of the vehicles selected in this study.

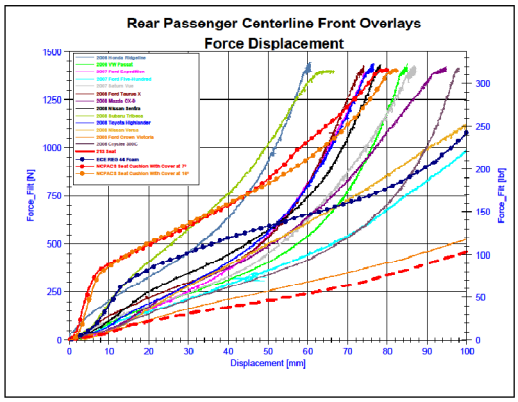

Figure 5. Force Displacement Curves for Rear Passenger Vehicles (Centerline Front) and Different Foams.

<u>FMVSS No. 213, ECE R44 and NPACS sled test results and selection of foam</u> As previously mentioned, NHTSA has been closely monitoring the GRSP's Informal Group on Child Restraint Systems'

development of a potential side impact test method. Due to a lengthy delivery time to procure the NPACS foam for the seat cushions, foam comparison testing was conducted with the ECE R44 foam material which had been previously purchased. While the ECE R44 foam is not as stiff as the NPACS foam, based on the quasi-static tests its force deflection characteristics are more similar to those of the vehicles selected in this study than the FMVSS No. 213 foam.

Sled tests were conducted to determine what effect(s) the seat cushion stiffness has on the performance of the dummy and the CRS. All tests were conducted using the Q3s dummy. Three CRS models were used for the tests: Evenflo Triumph Advance DLX, Maxi-Cosi Priori XP, and Graco SafeSeat Step2 (Cozy Cline). Both the FMVSS No. 213 and ECE R44 foams were evaluated. Each foam was tested using the appropriate cover specified by its respective standard (FMVSS No. 213 with vinyl cover; ECE R44 with cloth cover). Each CRS model was tested twice. Results were compared to their respective results from the full-scale vehicle crash tests discussed in Ref. [1].

Figure 6 and Figure 7, respectively, show comparisons of the Q3s dummy's HIC15 and chest deflection results when sled tests were conducted using the FMVSS No. 213 and ECE R44 foams to construct the seat cushion. For each type of seat cushion, sled results for both injury measurements were greater than those observed in the crash tests. The FMVSS No. 213 seat cushion is 152 mm (5.9 in) thick while the ECE R44 and NPACS seat cushions are 127 mm (5 in) thick. This 25 mm difference may be a contributing factor to the observed variation in HIC15 values due to relative vertical positioning of the head with respect to the windowsill. However, because the relative height of the windowsill to the seat cushion seat bight is well within the range of what was measured for that metric during the vehicle survey described earlier, no additional analysis of the seat cushion thickness effect and relative head-to-windowsill positioning was performed at this time.

Comparisons of the spine lateral acceleration and upper neck tension are shown in Figure 8 and Figure 9, respectively. For these two injury measurements, values observed in the crash tests tended to be either comparable or greater than corresponding results from the sled tests, regardless of seat cushion type used in the sled test.

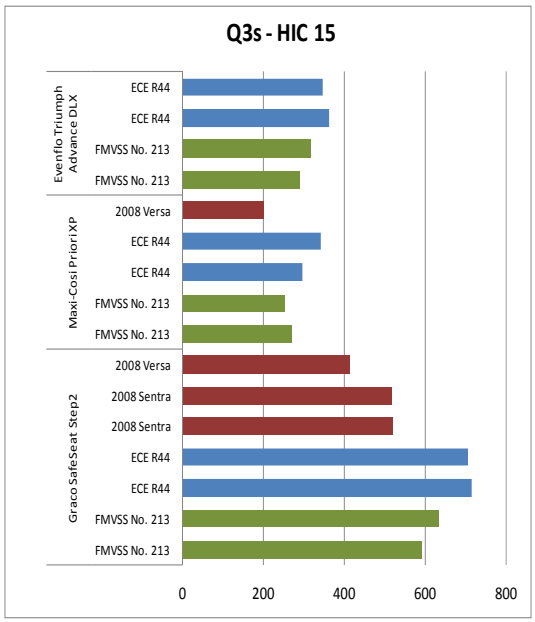

Figure 6. Q3s HIC15 Results; FMVSS No. 213 vs. ECE R44 Seat Cushion.*

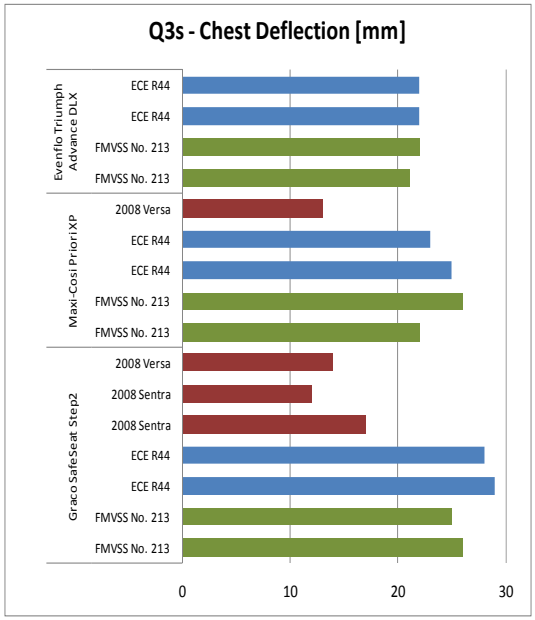

Figure 7. Q3s Chest Deflection Results; FMVSS No. 213 vs. ECE R44 Seat Cushion.*

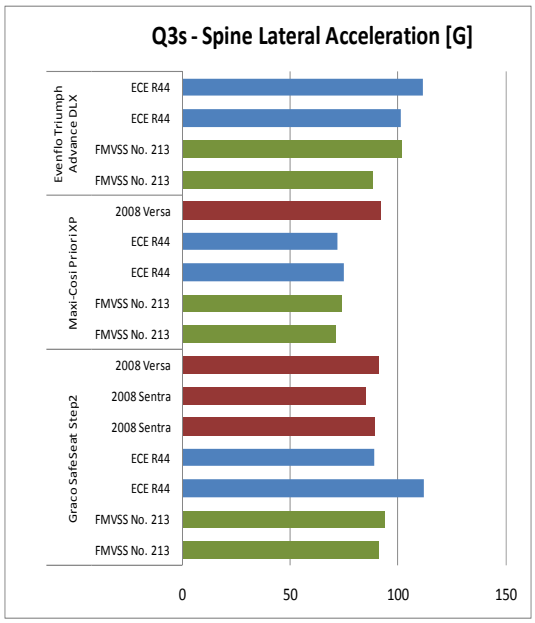

Figure 8. Q3s Spine Lateral Acceleration Results; FMVSS No. 213 vs. ECE R44 Seat Cushion.*

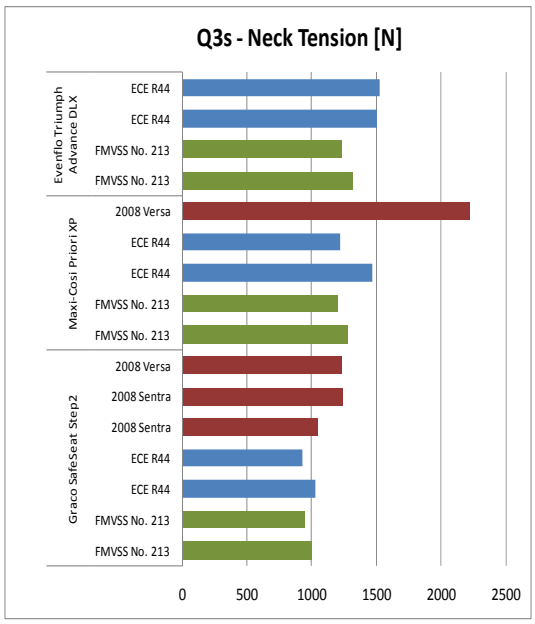

Figure 9. Q3s Upper Neck Tension Results; FMVSS No. 213 vs. ECE R44 Seat Cushion.*

* No vehicle crash test was performed with the Evenflo Triumph Advance DLX CRS model.

Door Characteristics

Real world analysis showed that 43% of AIS2+ injuries are caused by contact with the door interior [National Automotive Sampling System (NASS) 1995-2008]. To create a representative environment in the sled test, the agency determined the door contact characteristics for 8 vehicles by performing FMH tests.

The test consisted of a 3.5 kg child headform launched towards the door at 24 and 32 kmph (15 and 20 mph, respectively) at a horizontal impact. The FMH was directed at different locations on the door where the head of the dummy was most likely to make contact (see Figure 10) and certain hard spots on the door. The impact points were selected based on the Hybrid III 3-year-old, 6-year-old and 10-year-old head CG and top of the head locations. The areas of contact were determined by tracking the head trajectory of different sized seated dummies, while they were being leaned forward creating an arc. The vehicles tested were:

- 2008 Nissan Sentra
- 2008 Nissan Versa
- 2004 Volvo XC90
- 2005 Chevy Trailblazer
- 2005 Toyota Highlander
- 2005 Infiniti FX35
- 2005 Nissan Pathfinder
- 2008 Dodge Caravan

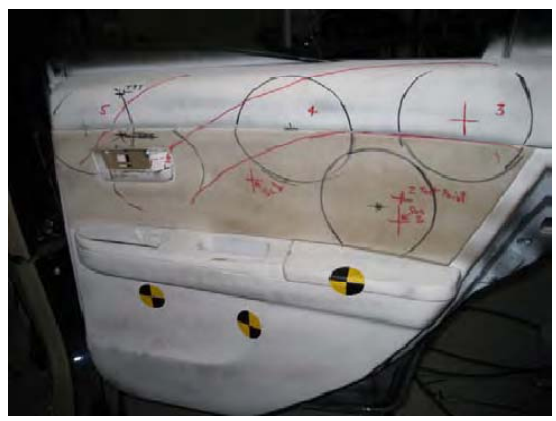

Figure 10. FMH Door Characteristics Testing.

Each of the eight vehicles had between four to six evaluation points. These targeted locations were used to assist in the evaluation of door stiffness characteristics.

Three foams with different stiffness values ("stiff", "average" and "soft") were selected for use in the sled tests as the door padding. These different foams were also impacted with the FMH test to determine their characteristics. Figure 11 shows the plotted door stiffness values for the vehicle tests as well as for the selected foam materials. The colored (red, green and blue) solid lines show the characteristics of

the three selected foams. The remaining solid lines are the characteristics of the vehicle interior doors. Three of the vehicle interior doors (shown in the colored dashed curves) closely match the characteristics of three selected foams, with the red lines representing the "stiff", the green lines representing the "average", and the blue lines representing the "soft" characteristics.

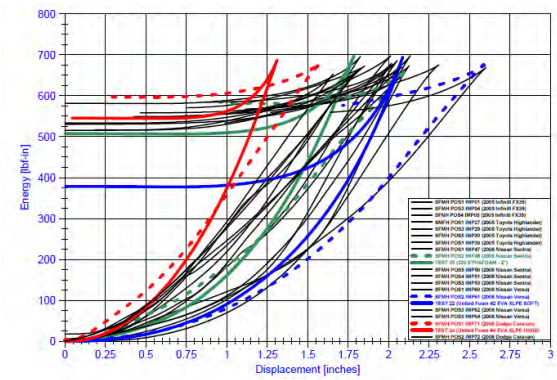

Figure 11. Vehicle Door and Foams Energy Displacement; Tests at 24 kmph (15mph).

<u>Testing Results with 3 Differing Door Panel Paddings and Selection of Foam</u> Following the completion of the component door panel FMH tests, a series of sled tests were conducted to assess padding stiffness effects on the performance of the two CRS models which had been used during the MDB-to-vehicle crash tests.

The foams identified from the FMH tests were selected and designated as "soft", "average" and "stiff". The name brands for the foams were United Foam # 2 ("soft"), Ethafoam 220 ("average") and United Foam # 4 ("stiff"). Each panel measured 51 mm (2 in) thick and was cut to the shape of and applied to the simulated door wall panel (see Figure 17).

The Q3s dummy's HIC15 and chest deflection results, when restrained in the Graco SafeSeat Step 2 and Maxi-Cosi Priori XP seats, for the "soft", "average" and "stiff" door panel foams are shown in Figure 12 and Figure 13, respectively.

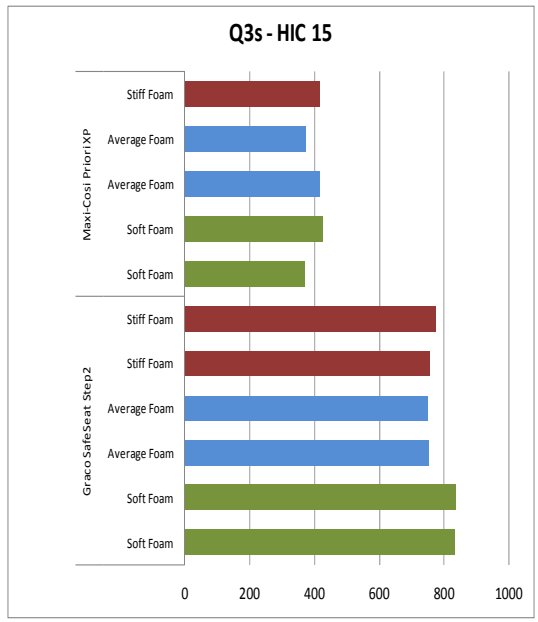

Figure 12 . Q3s HIC15 Results; Soft, Average and Stiff Door Panel Foams.

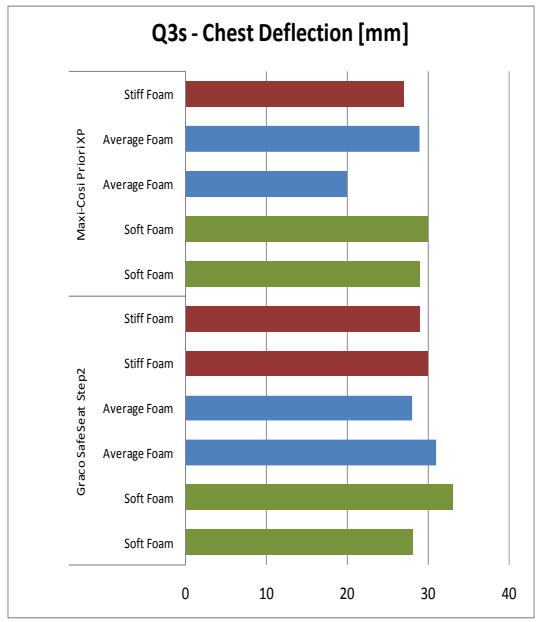

Figure 13. Q3s Chest Deflection Results; Soft, Average and Stiff Door Panel Foams.

Corresponding comparisons for the spine lateral acceleration and upper neck tension, respectively, are shown in Figure 14 and Figure 15.

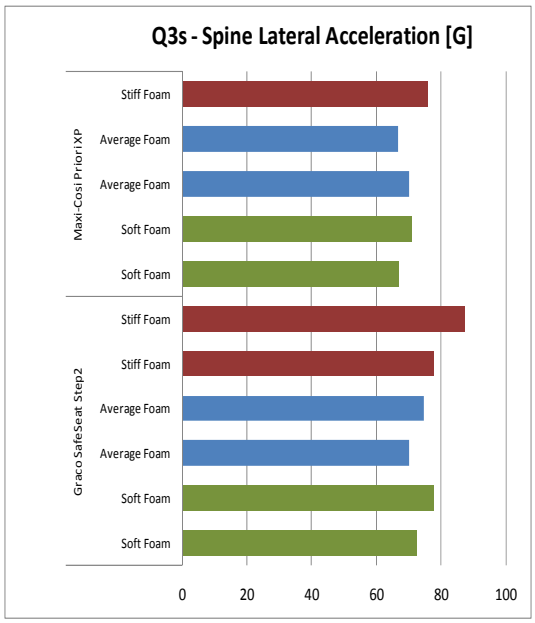

Figure 14. Q3s Spine Lateral Acceleration Results; Soft, Average and Stiff Door Panel Foams.

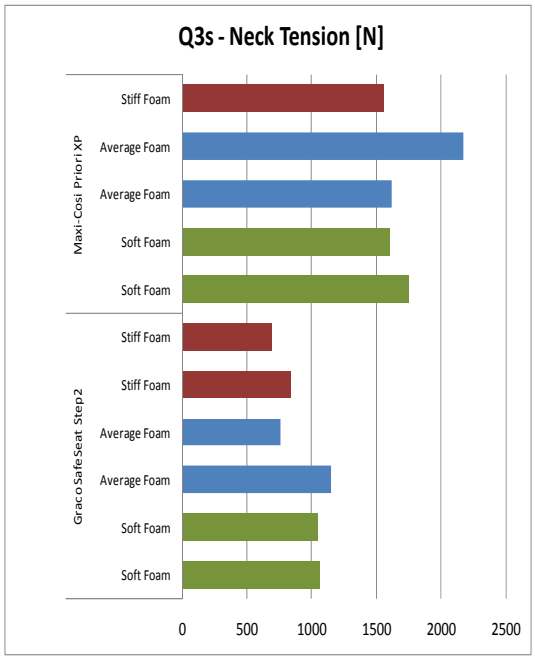

Figure 15. Q3s Upper Neck Tension Results; Soft, Average and Stiff Door Panel Foams.

The door foam used in NHTSA's original testing was replaced with the "average" foam from this series of tests due to the apparent minimal stiffness effect on dummy responses and due to the lower cost and availability of the foam. Although the Dow Ethafoam 220 material is relatively easy to obtain commercially, other materials with similar physical properties could be used in its place.

Armrest

In an effort to improve replication of the kinematic responses of the CRS and dummy in the sled tests to those observed in comparable vehicle crash tests, the addition of an armrest to the side door panel of the sled test buck was investigated.

<u>Testing results with different foams and selection of foam</u> Four of the eight vehicles previously tested with the FMH to assess door panel force displacement characteristics also had impacts to the armrests. Additional FMH testing was conducted on these four vehicles to determine their armrest characteristics, which were observed to be similar to the stiffer door panels (see Figure 11). In turn, FMH tests were conducted on various padding material combinations in an effort to have a door panel/armrest configuration in the sled test buck with similar characteristics.

The configuration of 51 mm (2 in) of Ethafoam 220 fronted with 64 mm (2.5 in) of the "stiff" United Foam #4 provided similar characteristics as the vehicle armrests and stiffer vehicle door panels (yellow curve in Figure 16). The armrest/door padding configuration is shown installed on the sled buck door structure in Figure 17.

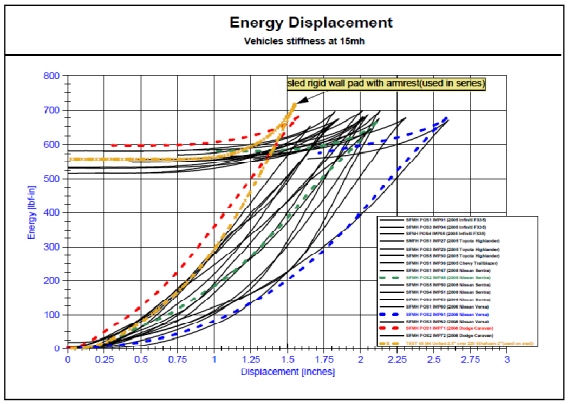

Figure 16. Selected Armrest Configuration Along with Vehicle Door and Foams Energy Displacement; Tests at 24 kmph (15mph).

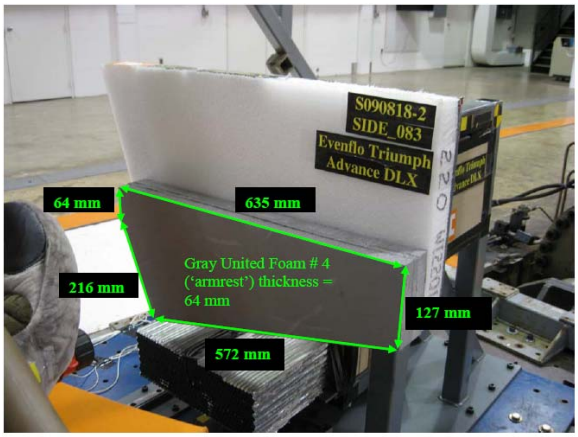

Figure 17. Armrest/Door Padding Configuration.

The same two CRS models, Maxi Cosi Priori and Graco Safe Seat 2, were sled tested with the armrest/door configuration. The results were compared to those from door padding only sled tests and the actual vehicle tests. The Q3s dummy's HIC15 and chest deflection results are shown in Figure 18 and Figure 19, respectively, with corresponding comparisons for the spine lateral acceleration and upper neck tension, respectively, shown in Figure 20 and Figure 21.

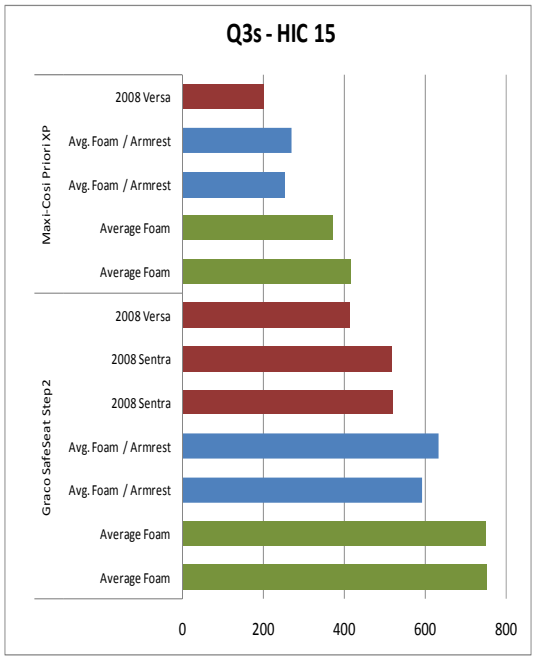

Figure 18. Q3s HIC15 Results; Armrest "Average" Foam Configuration Compared to "Average" Foam Only and Crashed Vehicle.

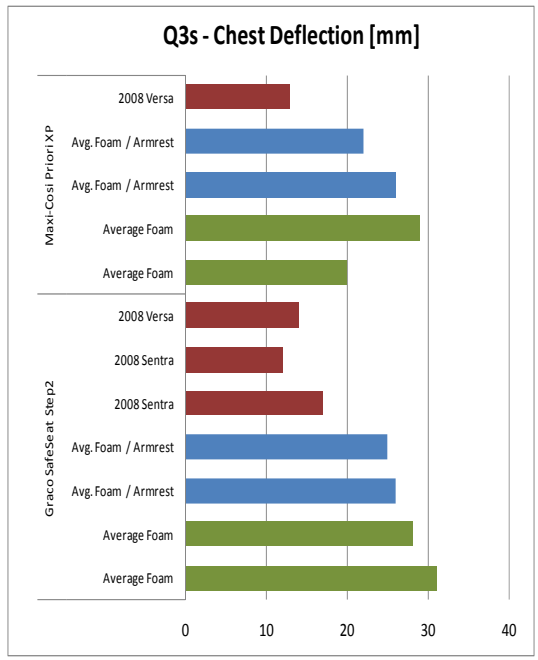

Figure 19. Q3s Chest Deflection Results; Armrest "Average" Foam Configuration Compared to "Average" Foam Only and Crashed Vehicle.

The addition of the armrest tended to reduce the HIC15 values. Chest displacements also tended to be lower with the armrest present, although not as pronounced as for the HIC15.

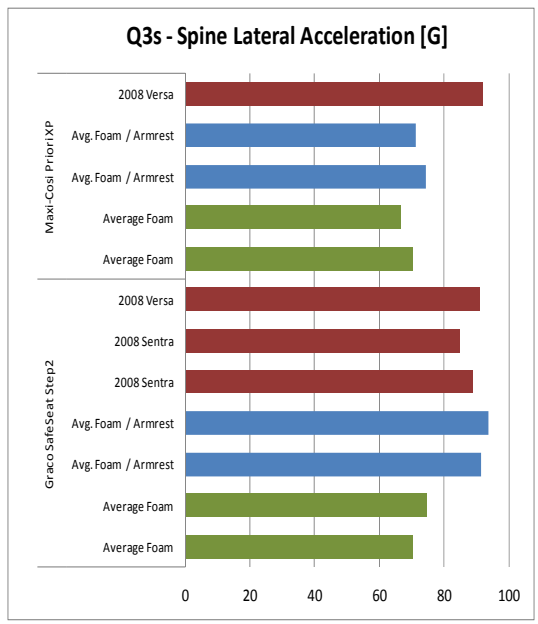

Figure 20. Q3s Spine Lateral Acceleration Results; Armrest "Average" Foam Configuration Compared to "Average" Foam Only and Crashed Vehicle.

The spine lateral acceleration tended to increase (depending on CRS model) with the armrest present. Upper neck tension was a less repeatable measure to use for comparative purposes (see Figure 20 and Figure 21, respectively).

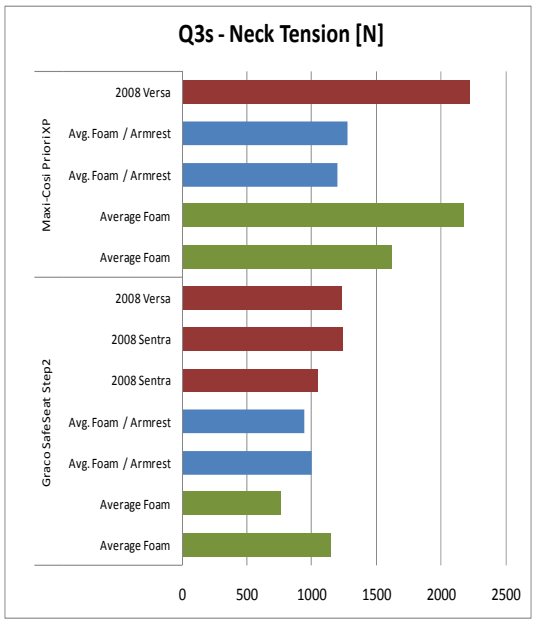

Figure 21. Q3s Neck Tension Results; Armrest "Average" Foam Configuration Compared to "Average" Foam Only and Crashed Vehicle.

SECOND PHASE SLED TESTS

A series of tests consisting of forward-facing and rear-facing child restraint models was conducted to assess performance of various CRS models. The Q3s dummy was used for testing different CRS models including 3-in-1, combination, and convertible CRS types. The 12-month-old CRABI dummy was used for testing infant carriers and convertible type CRS. Figure 22 and Figure 23 contain HIC15 and chest deflection results, respectively, for the sled test conducted with the Q3s dummy in forward-facing configuration.

Tests with the Q3s dummy showed that CRSs with larger side wings and more padding, either on wing and/or as head inserts, resulted in lower HIC values than CRSs with smaller side wings and less padding. The side wing design varied among CRSs, from a side wing that completely covered the head of the dummy (considered a better design) when viewed from the side to a CRS with a side wing that only covered a small portion of the dummy's head (considered a poorer design). Some CRS designs included a head cushion, which is additional padding near the side of the dummy's head (considered a better design), while others did not have the extra padding (considered a poorer design). No padding characterization and no assessment of the CRS' structural design were performed.

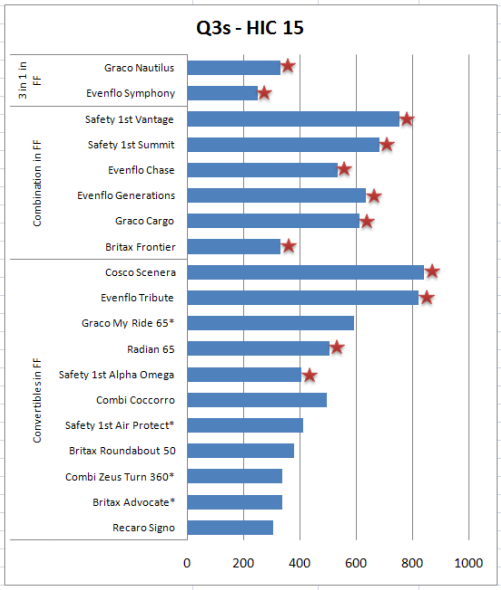

Figure 22. HIC15 Results for the Q3s Dummy in Forward-Facing CRS in Sled Tests.

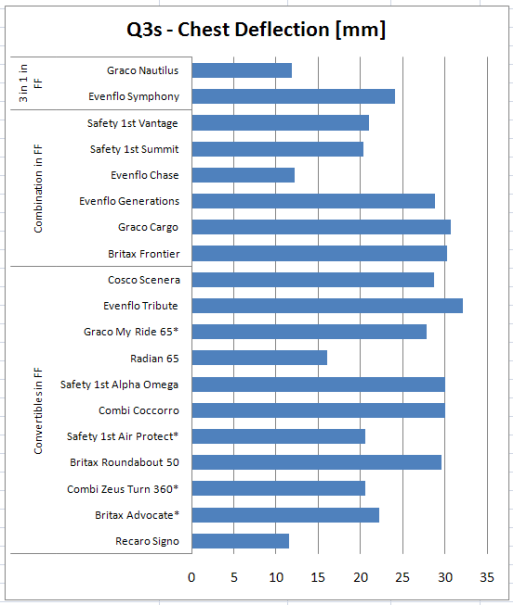

Figure 23. Chest Deflection Results for the Q3s Dummy in Forward-Facing CRS in Sled Tests.

To exemplify, a comparison between two CRS with similar designs was made: the Evenflo Tribute and the Britax Frontier (see Figure 24). The structures of the seats, including the side structure, are very similar, but the Britax Frontier has a head cushion on the side wings at the head location. Results show that

the Evenflo Tribute had a HIC15 and a chest deflection of 821 and 32 mm, respectively, while the Britax Frontier performed significantly better with a HIC15 of 332 and a chest deflection of 30 mm.

Figure 24. Evenflo Tribute (left) and Britax Frontier (right).

The Evenflo Generations performance was compared to that of the Graco Nautilus. These two CRSs have similar designs, but the head cushion insert in the Graco Nautilus completely covered the head of the dummy, while the one in the Evenflo Generations head cushion only partially covered the head of the dummy (see Figure 25). Results show the Evenflo Generations had a HIC15 of 636 and a chest deflection of 28 mm; while the Graco Nautilus had a HIC15 of 333 and a chest deflection of 11mm.

Figure 25. Evenflo Generations (left) and Graco Nautilus (right).

The interaction of the dummy, CRS, and the simulated intruding door is complex, and many factors can influence the performance of the CRS in addition to the padding and wing design. Another trend identified in the performance results was that CRSs that positioned the head of the dummy partially or totally above the windowsill of the door had lower HIC values.

The CRSs that positioned the head totally above the windowsill, which included the Recaro Signo, Britax Advocate, Combi Zeus 360, Britax Roundabout, and Evenflo Symphony, had lower HIC15 values (between 250 and 380). HIC15 values of the CRSs that positioned the head mostly below the windowsill, which included the Radian 65, Safety 1st Alpha Omega, Evenflo Chase, Evenflo Generations, and Safety 1st Vantage, ranged from 406 to 756.

The star markings in Figure 22 and Figure 29 indicate the presence of direct head-to-door contact during the sled test. Twelve of the nineteen tests with the Q3s dummy in a forward-facing CRS resulted in direct head to door contact, while only one of the twelve tests with the CRABI dummy in a rear-facing CRS resulted in head-to-door contact.

Figure 26, Figure 27 and Figure 28 show the spine lateral acceleration, the pelvis lateral acceleration, and the neck tension of the Q3s dummy, respectively.

Additional testing would be needed in order to independently understand the CRS design and the head position with respect to the windowsill effect on injury measures. The observations stated in this paper are made without separating each of these factors.

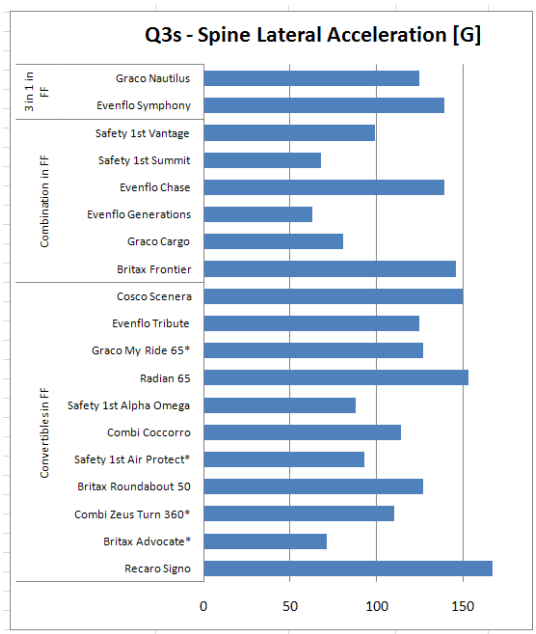

Figure 26. Spine Lateral Acceleration Results for the Q3s Dummy in Forward-Facing CRS in Sled Tests.

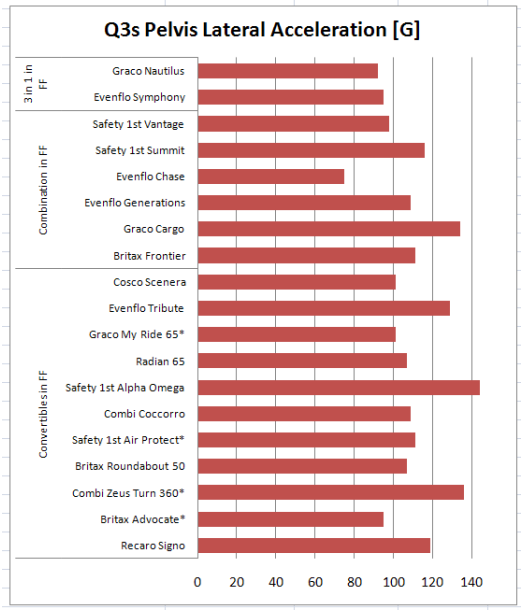

Figure 27. Pelvis Lateral Acceleration Results for the Q3s Dummy in Forward-Facing CRS in Sled Tests.

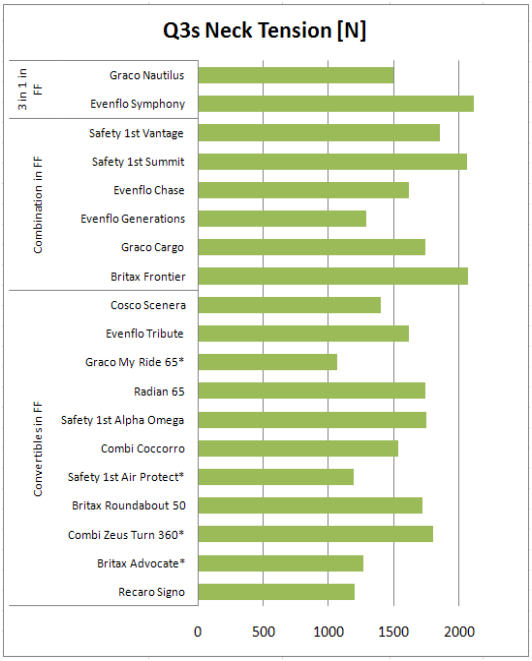

Figure 28. Neck Tension Results for the Q3s Dummy in Forward-Facing CRS in Sled Tests.

Figure 29 shows HIC15 outcomes for the rear-facing CRS tested with the CRABI dummy. HIC15 results ranged between 273 and 760. HIC15 outcomes did not show an obvious trend with the design of the wings and/or padding of the CRSs. Only two CRS models (Evenflo Discovery 5 and Safety 1st Designer) had little or no side protection. All other CRS designs were considered to have a large enough side wing and sufficient padding to protect the head.

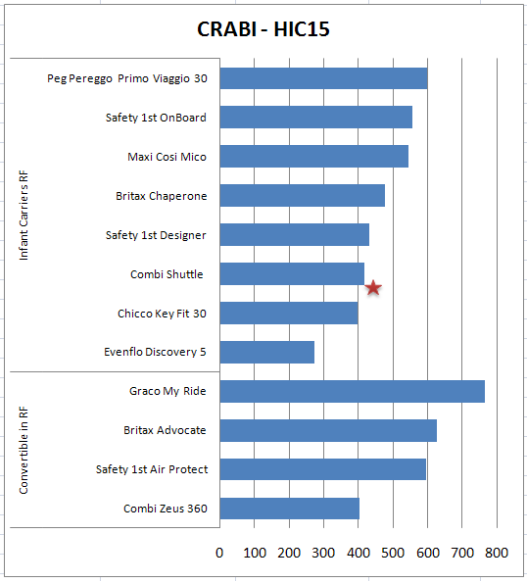

Figure 29. HIC15 Results for the CRABI Dummy in Rear-Facing CRS in Sled Tests.

With the exception of the Britax Advocate, all other rear-facing CRSs positioned the head of the CRABI dummy mostly or totally below the windowsill.

Figure 30 and Figure 31 show the dummy responses for the lateral pelvis acceleration and the neck tension, respectively.

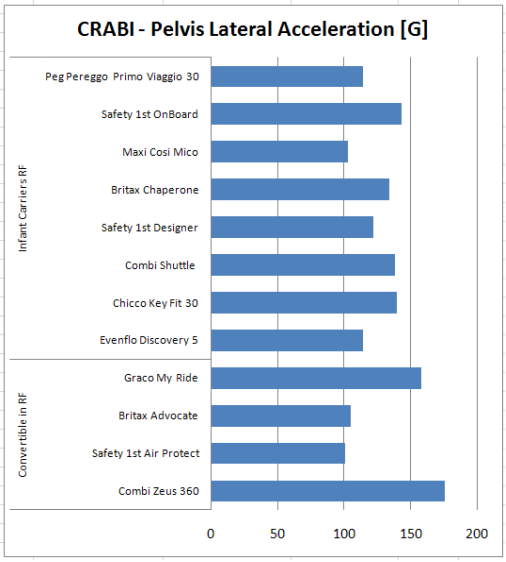

Figure 30. Pelvis Lateral Acceleration Results for the CRABI Dummy in Rear-Facing CRS in Sled Tests.

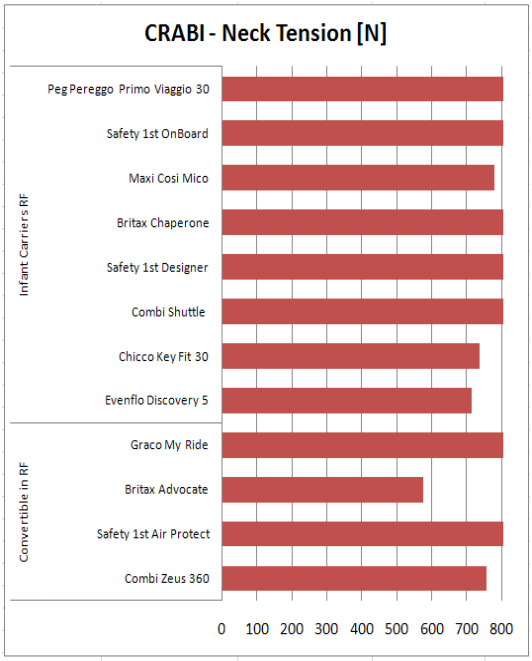

Figure 31. Neck Tension Results for the CRABI Dummy in Rear-Facing CRS in Sled Tests.

A photograph of each CRS model used in this study is located in Appendix A.

Individual test results for the sled tests are available on the NHTSA's Vehicle Crash Test Database. (http://www-nrd.nhtsa.dot.gov/database/veh/veh.htm)

CONCLUSIONS

The following conclusions are based on the results from the sled and crash tests performed in this study:

- A 10 degree test angle showed good replication of dummy and CRS kinematics observed in vehicle crash tests.
- The stiffness of door padding does not appear to have a pronounced effect on dummy injury measures or kinematics.
- A combination of an "average" door stiffness and "stiff" armrest resulted in an acceptable reproduction of dummy injury measures and CRS kinematics observed in vehicle crash tests.
- Seat cushion stiffness does not appear to have a pronounced effect on dummy injury responses, although it did affect CRS kinematics.
- The dummy injury measures of the Q3s dummy in forward-facing CRS showed that CRS models with larger wings and more padding produced lower HIC15 values.
- In contrast to the forward-facing CRS tested with the Q3s dummy, the rear-facing CRS tested with the CRABI dummy did not show a trend between the injury measures and the size of the side wing and/or amount of padding.
- The position of dummy's head with respect to the windowsill was a factor affecting HIC15 values. Rear-facing and forward-facing CRSs that positioned the head totally or mostly higher than the windowsill produced lower HIC15 values, while CRSs that positioned the head mostly or totally below the windowsill produced higher HIC15 values.

FUTURE STUDIES

Additional testing will be conducted to evaluate the performance of some CRSs that accommodate the Q3s dummy in the rear-facing configuration, as well as the CRABI dummy in forward-facing configuration for those CRS that are within the height and weight recommendations.

Also, to better understand the effect of head position with respect to the windowsill testing with a raised windowsill will be conducted.

ACKNOWLEGEMENTS

The authors express their gratitude to Mai Lan Aram and Taryn Rockwell, ALPHA Technology Associate, Inc. for providing the vehicle survey data.

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[2] LeClaire, M. and Chueng, G. (TRL Limited) , "NPACS (New Programme for Assessment of Child restraint Sytems, Phase 1 Final Report" PPAD 9/33/128, Prepared for the Department of Transport, March 2006.

Appendix

Child Restraint System Models

3-in-1

Graco Nautilus

Evenflo Symphony

Combination

Safety 1st Vantage

Safety 1st Summit

Evenflo Chase

Evenflo Generations

Graco Cargo

Britax Frontier

Convertibles

Cosco Scenera

Evenflo Tribute

Graco MyRide 65

Britax Advocate

Radian 65

Cosco Alpha Omega

Combi Coccorro

Recaro Signo

Safety 1st Air Protect

Britax Roundabout 50

Combi Zeus 360

Infant Carriers

Peg Pereggo Primo Viaggio

Safety 1st OnBoard 35

Maxi Cosi Mico

Chicco Key Fit 30

Britax Chaperone

Safety 1st Designer

Combi Shuttle

Evenflo Discovery 5