MADYMO SIMULATION STUDY TO OPTIMIZE THE SEATING ANGLES AND BELT POSITIONING OF HIGH BACK BOOSTER SEATS

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ABSTRACT

Data from the Partners for Child Passenger Study shows that booster seat use among children ages 4-7 years has increased and its use is beneficial in terms of injury risk when compared to vehicle seat belts. However, results from sled tests with a 6-year-old Hybrid III ATD in four different high back booster seats (HBB) at a speed (56 km/h) higher than current compliance requirements (48 km/h) did not show corresponding benefits in some designs. Potential hypothesis for the apparent differences are 1) the lack of biofidelity of the ATD spine and neck 2) lack of high severity crash data from the field and 3) the possible differential performance of different HBB due to their design. A number of studies aimed at improving the biofidelity of the ATD have been done, but no study has looked at the differential performance of the HBB due to their design.

The study objective was to use mathematical models to investigate and assess the Hybrid III 6-year-old ATD performance due to the variation in seating angles of a HBB and seat belt positioning across the ATD. Mathematical models of the HBB and FMVSS 213 bench seat were developed using the multi-body MADYMO software. The standard MADYMO 6-year-old ATD model was used to assess the performance. This model was validated against a sled test and further parametric analyses were conducted. Parameters changed were the overall angle and the base angle of the HBB and the seat belt routing angle. The standard injury metrics (HIC, head and chest accelerations, Nij, and excursions) were used to quantify the ATD performance.

The study demonstrated that by optimizing the ATD seating posture and the belt positioning across its chest, improved ATD performance is achieved. An optimized angle of 5 degrees for base angle and 100 degrees for overall angle of the HBB, in combination with a belt angle of 40 degrees achieved better performance than the validated baseline model.

INTRODUCTION

The National Highway Traffic Safety Administration's (NHTSA)[1] and American Academy of Pediatrics (AAP)[2] currently recommends that children over 40 lbs and approximately between 4 and 8 years of age (unless the child is 57 inches tall) should be restrained using a belt positioning booster seat. A belt-positioning booster improves the fit of both the lap and shoulder portions of the vehicle seat belt. A poorly positioned vehicle seat belt may lead to rapid, "jack-knife" and/or "submarining" effect, which increases the risk of intra-abdominal and spinal cord injuries, also known as "seat belt syndrome". Poorly positioned belt may also lead to injuries to the face and brain due to impact of the head with the child's knees or the vehicle interior[3-8] , in the event of crash.

Epidemiological data from the Partners for Child Passenger Safety (PCPS)[9], a national data source of children in crashes, collected over a period of 5 years, shows that the belt-positioning booster seats provide added safety benefits over seat belts to children through age 7 years, including the reduction of injuries classically associated with improper seat belt fit in children.[10-12] This data also shows that there is an increase in the use of these belt positioning booster seats among children ages 4-7 years[13]. It is estimated that currently there are about 30 different types of belt positioning booster seats available to use for children who have outgrown child seats, but are yet not tall enough for adult seat belts[14].

Studies done in the laboratory[15-17] however, did not show corresponding benefits that were seen in the epidemiological studies. The study by Menon, et al.[15] looked at the performance of the various child restraint systems by conducting a series of sled tests with the Hybrid III 3 and 6-year-old child Anthropomorphic Test Devices (ATD) at a range of speeds namely 24, 40 and 56 km/h. It was observed in this study that the Hybrid III 6-year-old ATD, in the high back belt positioning booster seat at 56 km/h experienced, a significant neck flexion resulting in the chin and face contacting the chest of the ATD.

This phenomenon was also observed by Sherwood, et al.[16] who used the same make and model belt positioning booster seat to test at a speed of 48 km/h. The study attributed the unusual response to the stiff upper spine of the Hybrid III 6-year-old ATD. In order to better understand this phenomenon Menon, et al., conducted another study with a Hybrid III 6-year-old ATD in four different HBB seats at a speed of 56 km/h.[17] Although the biofidelity of the ATD has been questioned, the extreme behavior of the ATD was not observed at lower speeds and even at 56 km/h speed the extreme flexion of the neck was observed only in two of the four high back booster seats. The primary purpose of this study was two folds. The first purpose was to ascertain if the high back booster design had an effect on the ATD kinematics and secondly to evaluate the performance of these individual high back booster seats against the Injury Assessment Reference Values (IARV)[18] as measured by the Hybrid III 6-year-old ATD. In the study by Menon, et al. it was noted that the seating angles differed for the different high back booster seats, thus changing the ATD posture. The seat base inclination ranged from 0° to 10°, the seat back inclination had a variation of only 5°, from 105° to 110° and the overall seat angle varied from 90° to 100°. It was also seen that although the upper anchorage of the shoulder belt was the same, the angle of the belt across the ATD differed in the different high back booster seats due to the attachment point of the shoulder belt on the booster seats. The angle of the belt varied from 45° to 100°.

The findings from the above mentioned study confirmed that the high back booster seat design had an effect on the ATD kinematics and also showed that there is a difference in the injury measures obtained from the ATD, when measured in different high back seat designs. These observed results not only highlighted the need to conduct research for improving the biofidelity of the Hybrid III 6-year-old ATD neck, but also called for dedicating research to understand the effect of variation of the high back booster seat design on the 6-year-old ATD responses, especially at higher speeds. Since all the tests conducted with high back booster seats used the same Hybrid III ATD, and showed a difference in the performance, this study examined this hypothesis of possible differential performance of different high back booster seat designs using mathematical models. Also with the increase in the number of children using high back booster seats, it is only reasonable to conduct studies to understand the differential performance of the different high back booster seat designs to anticipate any problems in future and to avoid them from occurring.

OBJECTIVE

The objective of this study was to use mathematical models to investigate the effects of

1) ATD posture by varying the seating angles of a high back booster seat
2) Seat belt positioning across the ATD
3) Environment change by replacing old FMVSS 213 bench seat with the new FMVSS 213 bench seat and a vehicle seat
4) Use of a top tether

This would identify key design characteristics of the high back booster seats that reduce injury metrics in a sled test environment and lead to possible design guidelines for high back booster seats.

In order to achieve the above objectives a mathematical model of an Evenflo Express high back booster seat was developed along with the sled environment and validated against the sled test, performed in the study by Menon, et al.[17], of the high back booster seats at 56 km/h. The Evenflo Express was chosen among the four high back booster seats tested. This validated model served as the baseline model and allowed parametric studies to be conducted on it. The parametric studies included changing the angle of the seat base and overall angle of the high back booster seat, which in turn changed the posture of the ATD, and changing the angle of the shoulder belt routing from the point of attachment on the booster seat over the ATD's chest. Additionally as part of the parametric study top tethers were included and the old FMVSS 213 bench seat model was replaced with the new FMVSS 213 bench model and a vehicle seat model.

METHODOLOGY

Model Development

These model simulations were performed in the multibody simulation environment Mathematical and DYnamic MOdel (MADYMO) v.6.2.[19]. MADYMO is a computer program that simulates the dynamic behavior of physical systems with an emphasis on the analysis of vehicle collisions and assessing injuries sustained by the occupants. The study involved developing of the HBB and FMVSS 213 Sled model. The HBB model seat was modeled using the facet elements along with the planes and ellipsoids. The HBB model was considered rigid with defined mass and inertia. The facet elements were used mainly to define the geometry of the HBB. The model of the HBB was considered rigid to have a computationally efficient model in conducting the parametric study.

Bench and Vehicle Seat Models Two FMVSS 213 benches were modeled in this study i.e. old FMVSS 213 bench and new FMVSS 213 bench. The old FMVSS 213 bench was based on the dimensions of the actual FMVSS 213 test bench seat as outlined in the standard[18]. This modeled bench was represented by ellipsoids and the material properties for these ellipsoids were based on the materials specified in the standard (Figure 1). The seat cushion properties were derived from foam tests that were conducted as part of the sled test performed by Menon, et al.,[17] which is also used as the baseline sled test for this project and for the validation of the developed model.

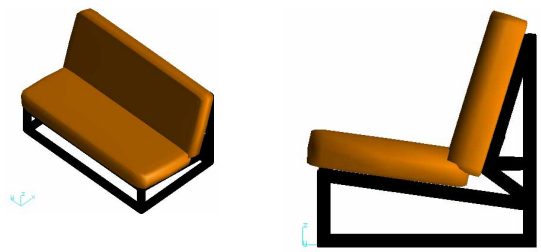

Figure 1. MADYMO model of FMVSS 213 bench seat

The new bench seat model was based on the new FMVSS 213 standards in a similar manner as described above. The difference between the new and old standards of the FMVSS 213 bench was that in the old 213 bench the seat back assembly was flexible whereas for the new 213 bench the seat back assembly was fixed and not allowed to move during the test and both the seat back and seat cushion angles have been changed as shown in Table 1.

Table 1.
Differences between the new and old FMVSS 213 bench seats

	Old 213 Bench	New 213 Bench
Seat Cushion angle	8°	15°
Seat Back Angle	15°	22°
Seat Back Assembly	Flexible	Fixed

For the vehicle seat model the backseat of a Ford Windstar was modeled as ellipsoid structures with dimensions approximating the actual seat. The seat bottom was tilted rearward 16° from horizontal and the seat back was reclined 24° from vertical (Figure 2). This model was based on Sherwood et al.[18].

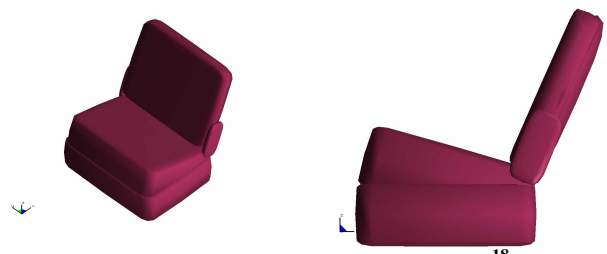

Figure 2. MADYMO model of vehicle seat[18]

Child ATD The Hybrid III 6-year-old child ATD model from the MADYMO database was used (Figure 3) to simulate the child occupant. The standard Hybrid III 6-year-old ATD model is a representation of the physical ATD. It constitutes the same basic geometry, inertial properties, joints and stiffness functions. It is represented in a multibody environment with rigid bodies, interconnected by kinematic joints and an ellipsoid geometry. Forces and moments are recorded at the same position as the measurement capabilities of the physical ATD.

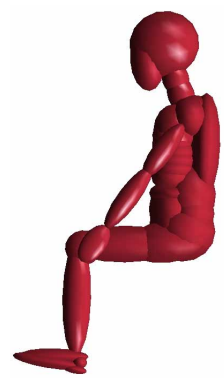

Figure 3. MADYMO models of a HYBRID III 6-year-old ATD

Belt Model The belt model, which is representative of the three point sled/seat belt, was modeled in MADYMO by means of a hybrid belt system, which uses a multibody belt model combined with a finite element mesh. This hybrid belt system consists of a multibody belt, which was attached to the vehicle anchor points, and a finite element belt for contact with the ATD. In the actual sled test, the ATD and booster seat were restrained to the FMVSS 213 test bench by a three-point belt and hence in the developed model, finite element belt was wrapped around the booster seat as well.

High Back Booster Seat Model The high back booster (Evenflo Express Booster) seat was modeled as one rigid body with geometry described by facets, ellipsoids and planes. This geometry sufficiently described both the frame and the seating surface. The geometry was obtained by taking actual

measurements from the booster seat and then incorporating into the model building.

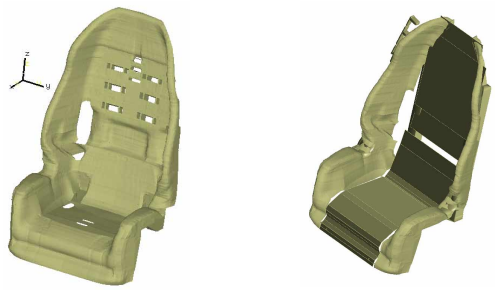

Figure 4. High back booster seat model

Model Validation

The model was validated according to the standard procedure against the sled test performed by Menon, et al.,[17] with the high back booster (Evenflo Express Booster) seat. The pulse used in the test was a 56 km/h FMVSS 213 type pulse (Figure 5). The developed model consisted of a 6-year-old ATD model from the MADYMO database seated in a HBB seat and restrained with a three-point belt to the standard FMVSS 213 test bench. The ATD kinematics from the model was matched with that of

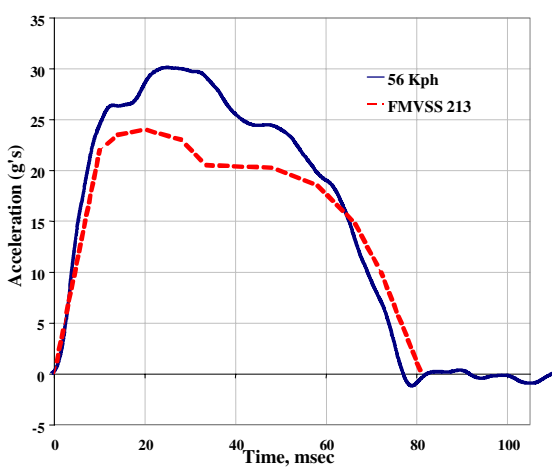

Figure 5. 56 km/h and standard FMVSS 213 48 km/h acceleration pulse

the Hybrid III 6-year-old ATD in the sled test. The other output parameters compared for the injury measures included the HIC, head accelerations, Nij, chest deflections, chest acceleration, head and knee excursions. Validation of the model was quantified using a statistical approach based on Pipkorn, B. et al. [20], where the standard deviation, peak values and coefficient of correlations between the two curves were calculated.

Parametric Study

Parametric studies were conducted at 48 km/hr on the validated model of the HBB with the 6-year-old ATD model as the baseline model. The acceleration pulse used as input for the model was a standard FMVSS 213 48 km/h acceleration pulse shown in Figure 5. The parametric studies included

1) Changing the angle of the booster seat base angle and overall booster angle which in turn changed the posture of the ATD (Figure 6)
2) Changing seat belt routing angle across the ATD (Figure 6)
3) Conducting simulations with the best seating angle and the best belt angle from both the parametric studies based on overall ATD responses.
4) Conducting simulations with the new FMVSS 213 bench seat and vehicle seat
5) Simulation with the top tether

The detailed matrix for the parametric study is given in Table 2

Table 2.
Matrix for Parametric Studies

Parameter		Top Tether use
HBB angle in degrees (Base angle/ Overall angle) Best angle	0 / 100	No
	0 / 90	No
	5 / 100	No
	5 / 90	No
	10 / 100	No (Baseline)
	10 / 90	No
Belt angles in degrees	40	No
	60	No
	70	No
Best angle	Old 213 bench	No
		Yes
	New 213 bench	No
		Yes
	Vehicle seat	No
		Yes

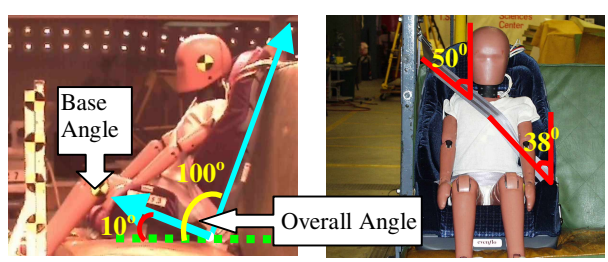

Figure 6. Booster seat base inclination and overall booster angle and shoulder belt angle

RESULTS

Validation Results

The model was validated based on the experimental sled test at 56 km/h. The kinematics of the model matched well with the sled test and is show in Appendix A - Figure A.1 along with the validation results in Figures A.2. Overall both the kinematics and the statistical tests showed a good correlation between the model and actual sled test. Thus the model was considered robust for further parametric analyses.

Parametric Analyses

Baseline For all parametric studies the pulse used was a 48 km/h standard FMVSS 213 acceleration pulse (Figure 5). The baseline model was simulated with the HBB in the original setup (Figure 6) with the FMVSS 213 pulse and was used for all the comparisons for the parametric analyses. Responses of the ATD with the baseline setup are shown in Table 3

Table 3.
High back booster baseline results

	Units	IARV	Baseline
Head Acceleration	m/s^2	-	828
HIC	-	1000	813
Chest Acceleration 3MS	m/s^2	600	505
Pelvic Acceleration	m/s^2	-	479
Neck Forces	N	-	3453
Neck Moments	N.m	-	41
Chest Deflection	m	0.040	0.032
Head Displacement	m	0.813	0.439
Knee Displacement	m	0.915	0.606
Belt Forces	N	-	3747
NIJ	-	1	1.46

Change in High Back Booster Angles The parametric analysis of the model was conducted by varying the base angle and the overall angle of the HBB. The combination of the changes in the base angle and overall angle are as shown in Table 4 and Figure 9. The angles for the baseline model were 10° base angle with an overall angle of 100° (Figure 6).

Table 4.
High back booster angle changes for parametric study

	Base Angle (degrees)	Overall Angle (degrees)
HBB Angle	0	100
		90
	5	100
		90
	10	100
		90

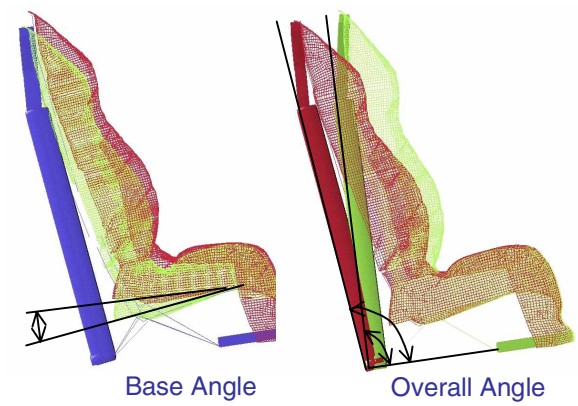

Figure 9. High back booster change in angles

The outcomes of the paparametric analysis with varying angles are as shown in Figure 10. The results in the figure are expressed as the change in the percentage of the various parameters, measured for the ATD model, in comparison to the baseline model. All values above zero or positive indicate that the values were higher than the corresponding baseline values. While the decrease in the parameter as compared to the baseline configuration is shown with the negative percentage values. Based on the parametric study with angle changes the simulation with a base angle of 5° in combination with the overall angle of 100° showed the best performance based on kinematics and peak response values and is highlighted in Figure 10.

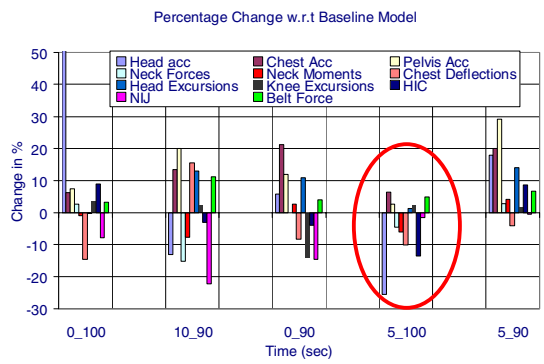

Figure 10 Percentage change from the baseline (10_100) with the change in HBB angles

Change in Seat Belt Angle The baseline seat belt angle was 50° (Figure 6). Parametric analyses were conducted by changing the angle of the belt as shown in Table 4 and Figure 12. These simulations were run with the standard and the modified ATD.

Table 4.
Belt angle changes for parametric study

	Belt Angles (degrees)
Belt Angle	40
	60
	70

Figure 12. Change in belt angle

Figure 13 show the change in percentage from the baseline model for the ATD responses. The simulation with the belt angle of 40° showed the best performance based on the kinematics and peak response values. This is highlighted in Figure 13.

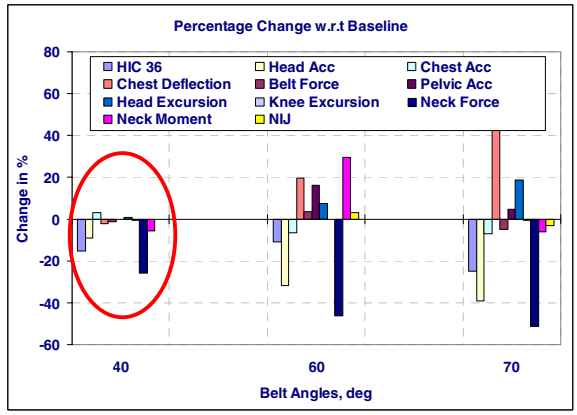

Figure 13. Percentage change from the baseline (50°) with the change in belt angles

Parametric Analysis of Different Environment with Best High Back Booster Seat and Belt Angles
From the above parametric studies for the high back booster a base angle of 5° in combination with the overall angle of 100° and with a belt angle of 40° showed the best performance based on injury metrics measured from the ATD. Using these angles as the optimized angles for best performance, analyses were conducted by changing the environment. For the environment the variables were the new FMVSS 213 bench seat and a vehicle seat.

Response of the ATD is tabulated in Appendix B Table B.1. In general it can be seen that with the change in environment from the old FMVSS 213 bench to the new FMVSS 213 bench the injury parameters like the head and chest acceleration reduced but the pelvic accelerations increased. This was also observed when the vehicle seat was used. Although there are increases in the HIC values, chest deflections, etc., it must be noted that the higher values did not cross their respective threshold values.

Parametric Analysis with Top Tether In order to see if there would be any benefit from using a top tether, simulations were conducted on the optimized models. The tether properties used is shown in Figure 15.

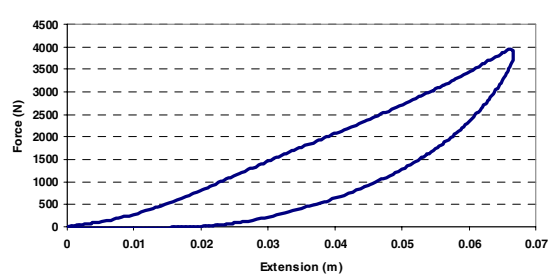

Figure 15 Force-deflection curve for Top Tether

From the kinematics of the simulations it was seen that excursion of the high back booster seat in the vehicle seat has been restricted with the use of a top tether. Table B.1 in Appendix B shows the comparison of the response values with and without top tether use for the three different environments with the standard ATD. It can be seen that in general the head and chest accelerations, knee excursions and neck forces have been reduced with the use of top tether. For the injury values that exceed with the use of top tether none exceeded the IARV. Use of the top tether improved the performance notably in the new FMVSS 213 bench seat of the neck forces and NIJ by around 20 percent.

SUMMARY

Models of the old and FMVSS 213 bench seats, a vehicle seat and high back booster seat were developed using the multi-body MADYMO software. The initial model was validated against a sled test which was run at 56 km/h. The validated model was considered robust for further parametric analyses. Parametric studies were conducted at 48 km/h by changing the overall and base angle of the high back booster seat and the belt angle. These changes resulted in an optimized solution where the best angles from the high back booster in combination with the best belt angle improved the performance of the ATD based on injury metrics measured on the ATD. This is shown in Figures 15.

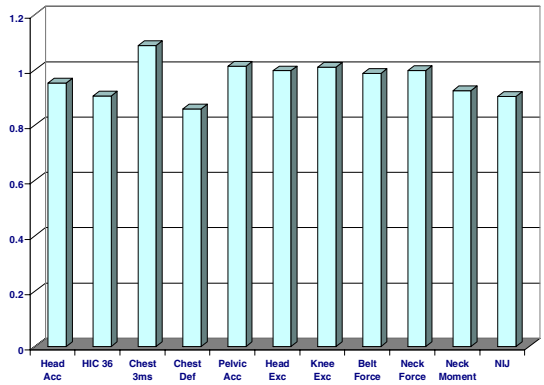

Fig 15. Comparison between the baseline and the optimized model (normalized by the baseline model)

It should be noted that different injury parameters of the ATD in the optimized seat was normalized by the ATD injury parameters of the baseline seat. A value of 1 would show that the ATD in the baseline and optimized high back booster seat had the same response, where as a value less than 1 would show better response from the ATD in the optimized seat.

From Figure 16 it can be seen that all response values, except for the chest acceleration, were lower than that of the baseline model. Although the chest acceleration for the ATD in the optimized seat was greater than that of the baseline model, it did not exceed the IARV limit.

Further analyses were conducted by changing the environment by replacing the old FMVSS 213 bench seat model with the new FMVSS bench seat model and a vehicle seat model. These analyses compared the response of the ATD in these different environments and in general it was seen that for the change in environment from the old FMVSS 213 bench to the new FMVSS 213 bench the injury parameters like the head and chest acceleration reduced but the pelvic accelerations increased. This was also observed when the vehicle seat was used. Analyses were also conducted to understand the effects of top tether use. This analysis showed that that there was a benefit in using the top tether with the high back booster seat and benefited most in the vehicle seat environment.

CONCLUSIONS

- This study showed that by optimizing the seating posture of the ATD and by optimizing the belt positioning over the ATD better performance can be achieved from the ATD
- An optimized angle for high back booster seat base angle of 5° in combination with the overall angle of 100° and with a belt angle of 40° achieved better performance from the ATD when compared to the baseline model.
- Also achieved as part of this study was a comparison of the ATD in different environments, old FMVSS 213 bench seat, new FMVSS 213 bench seat and a vehicle seat.
- This study also showed that it was beneficial to a use of a top tether with a high back booster.

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REFERENCES

[1] http://www.nhtsa.dot.gov/people/injury/childps/RxFlyer/RxFlyer4.html. Protect your kids in the car.

National Highway Traffic Safety Administration, Emergency Nurses Association, American College of Emergency Physicians; 1997.

[2] http://www.aap.org/family/01352.htm. Selecting and Using the Most Appropriate Car Safety Seats for Growing Children: Guidelines for Counseling Parents (RE9618). American Academy of Pediatrics; 1996.

[3] Kulowski K, Rost W. Intra-abdominal injury from safety belts in auto accidents. Arch Surg 1956;73:970-971.

[4] Garrett JW, Braunstein PW. The seat belt syndrome. J Trauma 1962;2:220-238.

[5] Agran P, Dunkle D, Winn D. Injuries to a sample of seatbelted children evaluated and treated in a hospital emergency room. J Trauma 1987;27:58-64.

[6] Winston FK, Durbin DR, Kallan M, Moll E. The Danger of Premature Graduation to Seat Belts for Young Children. Pediatrics 2000;105:1179-1183.

[7] Durbin DR, Arbogast KB, Moll EK. Seat Belt Syndrome in Children: A case report and review of the literature. Pediatr Emerg Care 2001;17:474-477.

[8] Arbogast KB, Durbin DR, Kallan MJ, Menon RA, Lincoln AE, Winston FK. The role of restraint and seat position in pediatric facial fractures. J Trauma 2002;52:693-698.

[9] Durbin, D., Bhatia, E., et. al., Partners for Child Passenger Safety: A Unique Child- Specific Crash Surveillance System, Accident Analysis & Prevention 33: 407-412; 2001.

[10] Durbin, D, Kallan, M., Winston, F., Trends in Booster Seat Use Among Young Children in Crashes, Pediatrics, Vol 108, No. 6, Dec. 2001.

[11] Elliot, M, Kallan M, Durbin, D, Winston, F, Effectiveness of child safety seats vs. seat belts in reducing the risk for death in children in passenger vehicle crashes, Archives of Pediatrics and Adolescent Medicine, June 2006;160(6):617-21.

[12] Durbin, D.R, Elliott M, Winston FK. Belt-positioning booster seats and reduction in risk of injury among children in vehicle crashes. JAMA 2003 Jun 4;289(21):2835-40.

[13] Winston, F., Chen, I., et. al., Shifts in Child Restraint Use According to Child Weight in the United States From 1999 to 2002, 47th Annual Proceedings AAAM, 2003.

[14] http://www.nhtsa.dot.gov/CPS/CSSRating/Index.cfm

[15] Menon, R., Ghati, Y. et. al., Evaluation of Restraint Type and Performance Tested with 3- and 6-year-old Hybrid III Dummies at a Range of Speeds, Paper 2004-01-0319, Society of Automotive Engineers, Warrendale, PA. 2004

[16] Sherwood, C., Shaw, C., van Rooij, L., Kent, R., Gupta, P., Crandall, J., Orzechowski, K., Eichelberger, M., Kallieris, D., Prediction of Cervical Spine Injuries Risk for 6-Year-Old Child in Frontal Crashes, 46th Annual Proceedings AAAM, 2002

[17] Menon, R., Ghati, Y., Roberts, S., Performance Evaluation of Various High Back Booster Seats Tested at 56 Km/h using a 6-Year-Old Hybrid III Dummy, 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Washington DC, July 2005

[18] 49 CFR Part 571 Federal Motor Vehicle Safety Standards: Child Restraint Systems: Final Rule, June 24, 2003.

[19] Theory Manual, MADYMO V6.1, TNO Automotive, April 2003.

[20] Pipkorn, B, Eriksson, M., A Method to Evaluate the Validity of Mathematical Models, 4th European MADYMO Users Meeting, 2003.

APPENDIX A - Validation Results

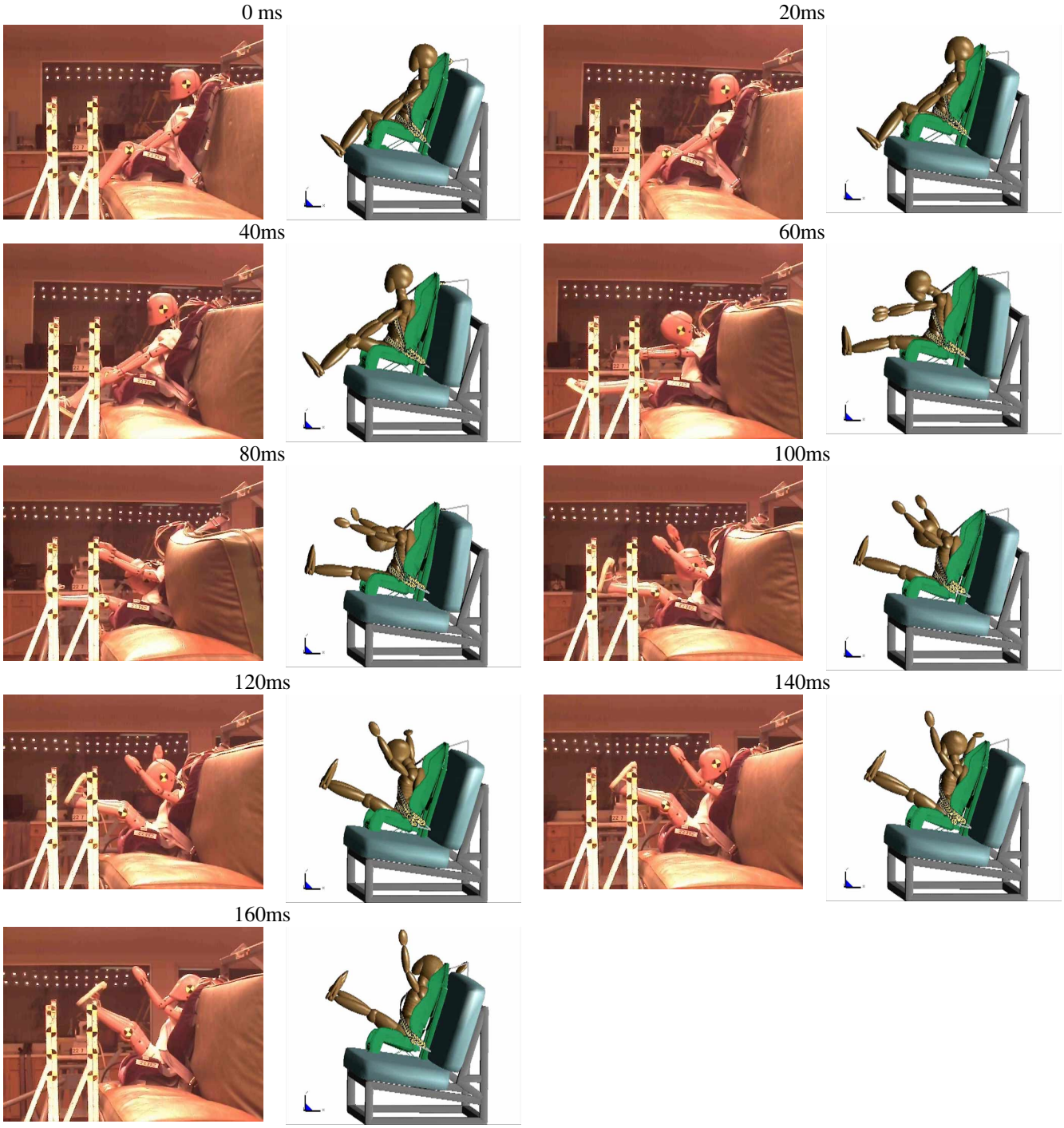


Figure A.1 Kinematic comparison between experimental sled test and model

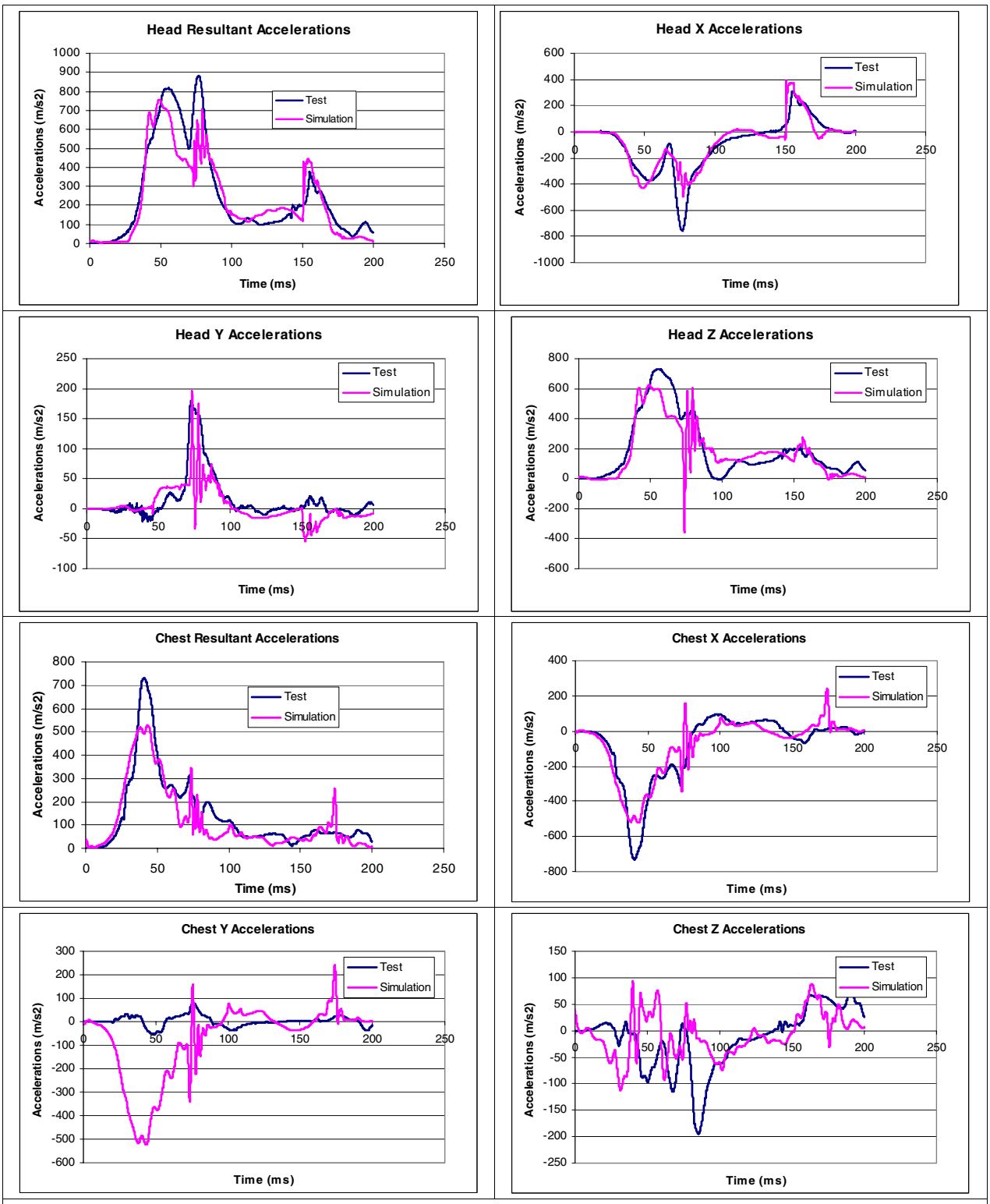
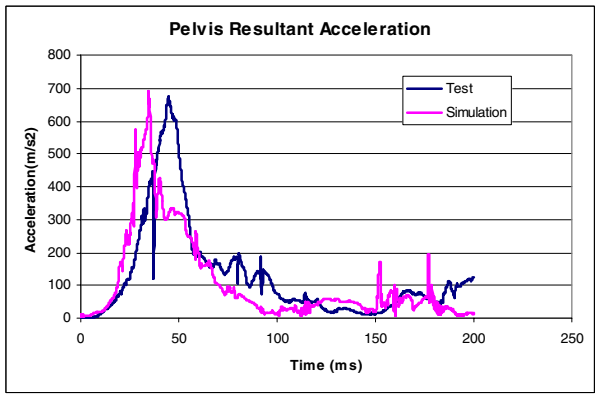
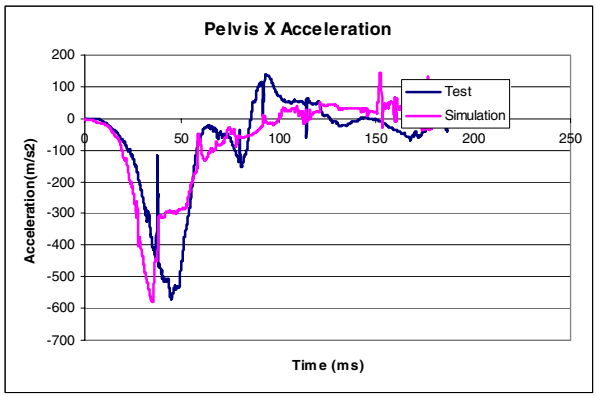
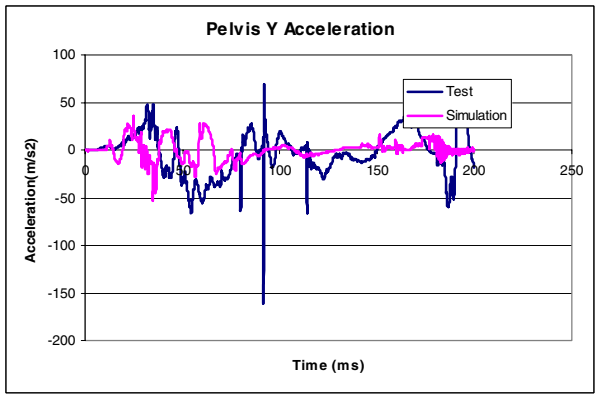
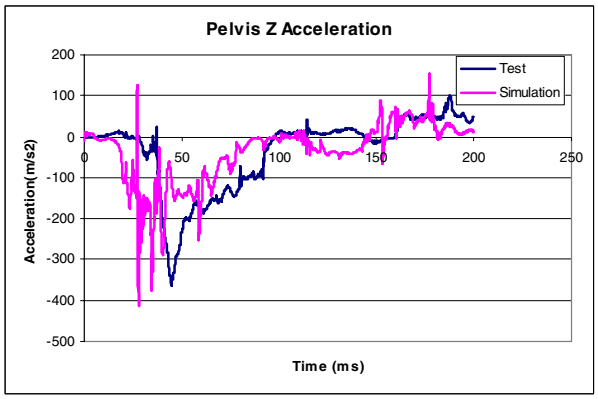


Figure A.2 Response curves from test and simulation









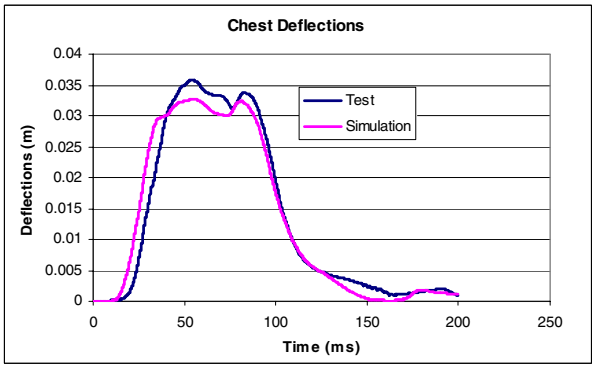


Figure A.2 (cont) Response curves from test and simulation

APPENDIX B

Table B.1.
Comparison of the injury values with and without top tether use for the three different environments

	Units	IARV	Old FMVSS 213 Bench		New FMVSS 213 Bench		Vehicle Seat	
			No Top Tether	With Top Tether	No Top Tether	With Top Tether	No Top Tether	With Top Tether
Head Acceleration	**m/s^2**	**-**	789	740	792	772	595	597
HIC	**-**	**1000**	623	648	796	768	526	586
Chest Acceleration 3MS	**m/s^2**	**600**	550	521	453	456	493	473
Pelvic Acceleration	**m/s^2**	**-**	486	502	606	687	860	860
Neck Forces	**N**	**-**	3446	3299	3822	3026	2720	2534
Neck Moments	**N.m**	**-**	38	41	45	48	35	33
Chest Deflection	**m**	**0.040**	0.027	0.029	0.034	0.034	0.027	0.026
Head Excursion	**m**	**0.813**	0.438	0.443	0.460	0.463	0.429	0.433
Knee Excursion	**m**	**0.915**	0.612	0.598	0.585	0.579	0.604	0.597
Belt Forces	**N**	**-**	3701	3556	3987	3759	5105	5285
NIJ	**-**	**1**	1.32	1.13	1.56	1.28	0.98	1.09

THE DEVELOPMENT OF AN INJURY COST FUNCTION FOR CHILD PASSENGER SAFETY

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ABSTRACT

The design of the optimal child restraint environment must consider both vehicle system (VS) and child restraint system (CRS) components. The objective of this study was to analyze the contributions from each system using a computer simulation of a rear facing (RF) child restraint involved in frontal crash. A parametric study of the material characteristics of components in each system was performed, resulting in a total of 625 simulations. The results of each simulation were compared using a single Cost Function score based on head acceleration, neck tension, and chest acceleration values. This Cost Function was developed based on injury risk curves combined with monetary cost estimates of these injuries. The analysis found that the vehicle seat cushion, lower LATCH belt, and internal CRS cushion should be designed with higher stiffness values, while the internal harness should be made more compliant. Neck tension was the primary contributor to the total cost function.

INTRODUCTION

The automobile child restraint environment is a function of both the vehicle and the child restraint. To design the optimal child restraint environment, design parameters from both the vehicle system (VS) and child restraint system (CRS) must be considered. In addition, VS parameters must be designed with all occupant sizes and ages in mind, including both children and adults.

The goal of this project was to determine the VS and CRS parameters which have the greatest influence on child restraint safety performance in frontal crashes. A 12 month old child in a rear facing child restraint was studied, but in future work multiple occupant sizes would have to be considered simultaneously.

First, a technique was developed to evaluate the risk of injury to a child based on measured forces and accelerations, which could be recorded during sled tests or computer simulations of sled tests. Multiple outcome measures are available when testing child restraint systems. A cost function must be developed that provides an objective method for combining multiple measurements into a single comparative value. Injury risk curves and estimates of the monetary cost of these injuries were combined to develop an overall injury cost based on the most critical body regions.

Second, a computational model of a 12 month old child in a rear facing child restraint, in a frontal crash, was developed. The model was validated against a sled test.

Finally, the computational model was used to assess the importance of VS and CRS parameters in this model. A parametric study varying the material properties of the vehicle seat cushion, lower LATCH belt, child restraint harness, and child restraint cushion was performed with a total of 625 simulations. The cost function developed earlier was used to rate the relative risks of the variable combinations.

METHODS

Injury Cost Function

The purpose of the Total Cost Function is to quantify the overall cost of injury to the dummy in a given loading condition. The dummy has a large number of injury measures which could be incorporated into the Cost Function. Other output parameters of the system, such as rotation angle or excursion distances, could also be used but quantification of the cost associated with these parameters is difficult. Therefore, the final Cost Function only uses injury measures from the head, neck, and chest body regions.

$$\text{Total Cost} = \text{Cost}_{\text{Head}} + \text{Cost}_{\text{Neck}} + \text{Cost}_{\text{Chest}} \qquad [1]$$

One of the criteria used to certify rear facing child restraints in FMVSS 213 (NHTSA, 2003) is the Head Injury Criteria (HIC_{36}), and this calculated measure was also chosen to best represent the risk of head injury in the Cost Function. The maximum value allowed for HIC_{36} in the FMVSS 213 standard is 1000.

In addition to the HIC_{36} limit, the other injury requirement in dynamic tests of rear facing child

restraints for FMVSS 213 standards is chest acceleration (3ms clip, measured on the spine at the equivalent position of T1), with an allowed peak value of 60 g's. This injury measure was chosen to best represent the risk of injury to the bony thorax, thoracic organs, and abdominal organs.

The neck is also a body region of critical importance for young children. The primary reason for restraining young children in rear facing child restraints is to protect the neck. For adults the neck injury criterion (N_{ij}) is commonly used to assess neck injury risk. The N_{ij} calculation is a combined injury criteria for the upper neck which incorporates both axial forces and sagittal bending moments. There are questions, however, about the biofidelity of the neck in the CRABI 12 month dummies. The CRABI 12 month dummy can measure high extension moments despite limited amounts of actual upper neck bending in a rear facing child restraint (Sherwood et al., 2004). It is hypothesized that the design of the neck, which does not include an atlanto-occipital joint at the neck/head interface, may account for some of these high values. For these reasons, the cost function includes peak Upper Neck Tension rather than N_{ij} as the injury measure to quantify neck injury risk.

The Total Cost Function did not include any kinematic measurement due to the difficulty in relating the rotation angle to a quantifiable injury risk and associated cost. The FMVSS 213 standard does, however, include a limit on the child restraint angle (70º, measured at the dummy's back with respect to vertical). This limit is included as a constraint in the simulations, excluding any simulations if this 70º limit is exceeded.

The next step was to relate each injury measure to a probability of injury risk at different AIS levels. An example of this procedure is shown graphically in Figure 1, using sample HIC injury probability curves. For a given injury measure, the probability of an AIS 1 injury was calculated by subtracting the probability of an AIS 2+ injury from the probability of an AIS 1+ injury (0.9 – 0.57 = 0.33) (Kuchar et al., 2001). This technique provides probability values of receiving each AIS level of injury, and these probabilities sum to 1.

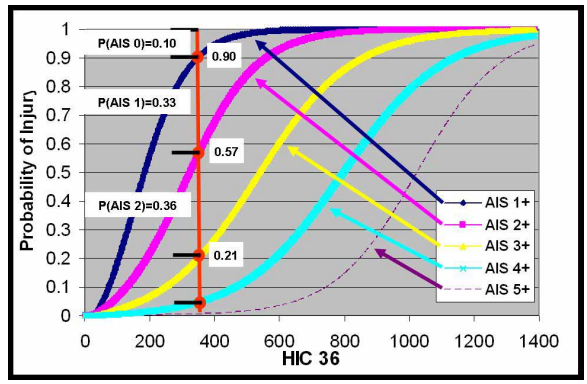

Figure 1. Graph of the method for determining the probability of injury for different AIS levels (data shown for illustrative purposes only).

The probability of injury equations for each injury measure are included in Equations 2-4. The HIC36 curves were scaled from data for the 50th percentile male using a scale factor of 0.5, and the neck tension curves were scaled from data for the 3 year old child using a scaling factor of 0.9 (Eppinger et al., 1999). The chest acceleration curves were scaled from data for the 50th percentile male using a scale factor of 0.833 (Eppinger et al., 1999).

Head Injury Risk

$$\begin{aligned}
&P(AIS \geq 1) = CND,\ \ln(HIC_{36}/0.5),\ Mean = 5.356,\ SD = 1.009\\
&P(AIS \geq 2) = CND,\ \ln(HIC_{36}/0.5),\ Mean = 6.964,\ SD = 0.847\\
&P(AIS \geq 3) = CND,\ \ln(HIC_{36}/0.5),\ Mean = 7.452,\ SD = 0.740\\
&P(AIS \geq 4) = CND,\ \ln(HIC_{36}/0.5),\ Mean = 7.656,\ SD = 0.607\\
&P(AIS \geq 5) = CND,\ \ln(HIC_{36}/0.5),\ Mean = 7.696,\ SD = 0.587
\end{aligned} \qquad [2]$$

Neck Injury Risk

$$\begin{aligned}
&P(AIS \geq 1) = (1+EXP(-(-3.272+0.00268*Fz/0.9)))-1\\
&P(AIS \geq 2) = (1+EXP(-(-3.454+0.00268*Fz/0.9)))-1\\
&P(AIS \geq 3) = (1+EXP(-(-3.655+0.00268*Fz/0.9)))-1\\
&P(AIS \geq 4) = (1+EXP(-(-4.422+0.00268*Fz/0.9)))-1\\
&P(AIS \geq 5) = (1+EXP(-(-5.956+0.00268*Fz/0.9)))-1
\end{aligned} \qquad [3]$$

Chest Injury Risk

$$\begin{aligned}
&P(AIS \geq 2) = (1+e(1.232-0.0576*(Chest3_{ms}/0.833)))-1\\
&P(AIS \geq 3) = (1+e(3.149-0.063*(Chest3_{ms}/0.833)))-1\\
&P(AIS \geq 4) = (1+e(4.343-0.063*(Chest3_{ms}/0.833)))-1\\
&P(AIS \geq 5) = (1+e(8.765-0.0659*(Chest3_{ms}/0.833)))-1
\end{aligned} \qquad [4]$$

where,
CND = Cumulative Normal Distribution
ln = Natural Log
SD = Standard Deviation

The next step was to quantify the "cost" of each level of AIS injury. This was accomplished by using estimates on actual costs (medical, insurance, etc.) using HARM 2000 data (Miller et al., 2001). These estimates were assumed to be valid for children, although the paper was based on adult data. The HARM 2000 data is based on MAIS injury levels at one body region, while the costs for multiple body regions cannot be summed to provide precise estimates of whole-body injury costs. The purpose of this Cost Function procedure is not to provide

accurate monetary cost estimates, but rather to quantify total injury risk in a comparative analysis. The HARM cost estimates are used as scaling factors to compare between AIS injury levels (relating an AIS 2 head injury to an AIS 3 head injury) and between body regions (relating an AIS 2 head injury to an AIS 2 neck injury). To make the HARM estimates dimensionless, each cost estimate was divided by the largest singular cost estimate ($1,617,797 – MAIS 5 Spinal Cord). Table 1 shows the Total Monetary Costs and Scaled Costs, not including Quality of Life adjustments, which were taken from this study using MAIS injury levels for the Brain (HIC_{36}), Spinal Cord (Neck Tension), and Trunk and Abdomen (Chest Acceleration 3ms clip).

Table 1. Harm 2000 Total Monetary Costs and the equivalent dimensionless scaled costs

Body Region	MAIS	Total Monetary Costs	Scaled Costs
Brain	1	$57,858	0.036
	2	$59,911	0.037
	3	$233,250	0.144
	4	$377,577	0.233
	5	$1,058,295	0.654
Spinal Cord	3	$818,588	0.506
	4	$1,366,923	0.845
	5	$1,617,797	1.000
Trunk and Abdomen	1	$8,645	0.005
	2	$58,168	0.036
	3	$89,911	0.056
	4	$153,604	0.095
	5	$198,760	0.123

The cost for each body region was calculated by multiplying the probability of injury at each AIS level with the Scaled Cost value at the corresponding AIS level (Equations 5-7).

$$\begin{aligned} Cost_{Head}=\Sigma_{Head}(&\text{Risk AIS 1})\cdot(\text{Scaled HARM AIS 1})+\\ &(\text{Risk AIS 2})\cdot(\text{Scaled HARM AIS 2})+\\ &(\text{Risk AIS 3})\cdot(\text{Scaled HARM AIS 3})+\\ &(\text{Risk AIS 4})\cdot(\text{Scaled HARM AIS 4})+\\ &(\text{Risk AIS 5})\cdot(\text{Scaled HARM AIS 5}) \end{aligned} \quad [5]$$

$$\begin{aligned} Cost_{Neck}=\Sigma_{Neck}(&\text{Risk AIS 3})\cdot(\text{Scaled HARM AIS 3})+\\ &(\text{Risk AIS 4})\cdot(\text{Scaled HARM AIS 4})+\\ &(\text{Risk AIS 5})\cdot(\text{Scaled HARM AIS 5}) \end{aligned} \quad [6]$$

$$\begin{aligned} Cost_{Chest}=\Sigma_{Chest}(&\text{Risk AIS 1})\cdot(\text{Scaled HARM AIS 1})+\\ &(\text{Risk AIS 2})\cdot(\text{Scaled HARM AIS 2})+\\ &(\text{Risk AIS 3})\cdot(\text{Scaled HARM AIS 3})+\\ &(\text{Risk AIS 4})\cdot(\text{Scaled HARM AIS 4})+\\ &(\text{Risk AIS 5})\cdot(\text{Scaled HARM AIS 5}) \end{aligned} \quad [7]$$

For the purpose of having a more efficient way to calculate the cost for each body region without using normal distribution tables, each of the three components of the total cost function was estimated with a polynomial equation determined by a polynomial curve fitting routine. Both the risk curves for each AIS injury level and the scaled HARM costs were incorporated into these functions (Equations 8-10). The curves were fit with an 8th order polynomial function in each case.

$$\begin{aligned} Cost_{Head} = &-2.824E\text{-}3 + 2.972E\text{-}4*HIC_{36} - \\ &1.403E\text{-}6*HIC_{36}^2 + 4.787E\text{-}9*HIC_{36}^3 - \\ &6.490E\text{-}12*HIC_{36}^4 + 4.628E\text{-}15*HIC_{36}^5 - \\ &1.853E\text{-}18*HIC_{36}^6 + 3.953E\text{-}22*HIC_{36}^7 - \\ &3.503E\text{-}26*HIC_{36}^8 \end{aligned} \quad [8]$$

$$\begin{aligned} Cost_{Neck} = &1.765E\text{-}2 - 4.174E\text{-}5*NeckF_z + \\ &7.674E\text{-}7*NeckF_z^2 - 1.937E\text{-}9*NeckF_z^3 + \\ &2.842E\text{-}12*NeckF_z^4 - 2.017E\text{-}15*NeckF_z^5 + \\ &7.375E\text{-}19*NeckF_z^6 - 1.360E\text{-}22*NeckF_z^7 + \\ &1.006E\text{-}26*NeckF_z^8 \end{aligned} \quad [9]$$

$$\begin{aligned} Cost_{Chest} = &9.468E\text{-}3 + 4.371E\text{-}4*Chest_{3ms} + \\ &8.219E\text{-}6*Chest_{3ms}^2 + 1.243E\text{-}7*Chest_{3ms}^3 - \\ &8.731E\text{-}9*Chest_{3ms}^4 + 2.213E\text{-}10*Chest_{3ms}^5 - \\ &2.877E\text{-}12*Chest_{3ms}^6 + 1.796E\text{-}14*Chest_{3ms}^7 - \\ &4.265E\text{-}17*Chest_{3ms}^8 \end{aligned} \quad [10]$$

Computational Model

The computational model was developed based upon a sled test using the Safety 1st Comfort Ride (Model # 22-400-GRC) child restraint in the rear facing orientation with a CRABI 12 month dummy. The child restraint was attached to a 2001 Ford Windstar bench seat using a lower LATCH belt and a foam spacer. The sled test simulated an FMVSS 213 child restraint test, with a velocity of approximately 48 km/hr (30 mph).

The model simulation was performed in the multibody simulation environment MADYMO 6.1. All model components are rigid bodies with defined mass and inertia. Either ellipsoids or finite element meshes were used to describe the component geometry. While some simplifications are inherent in this modeling technique, the models are computationally efficient and can reasonably simulate global responses to various impacts.

The third row bench seat of a Ford Windstar was modeled as two rigid finite element surfaces with dimensions approximating the actual seat (Figure 3). The interaction between the child restraint and the vehicle seat cushion was modeled with a prescribed force versus deformation relationship. The geometry

of the Safety 1st child restraint was obtained from a 3D measurement of characteristic points on the seat, which were converted into a rigid finite element mesh. This model is also defined as one rigid body.

The child restraint was attached to the vehicle with a lower LATCH belt and a body represented by the foam "noodle" used in the sled test. In many rear facing child restraints a foam noodle or other object must be placed under the base of the child restraint to provide the correct child restraint angle. Without the noodle, the child restraint would be too upright. Since the noodle has minimal initial deformation is no longer under load as the child restraint moves forward during the crash pulse, it was included as a rigid body. The lower LATCH was attached from the LATCH anchorages to fixed points on the child restraint, and was modeled as a multibody belt segment with a non-linear elastic characteristic. The initial pre-tension of the belt was approximately 200 N.

The internal harness is constructed of two shoulder belts which span from above the shoulders to a buckle near the pelvis, two lap belts which span from outside of the thigh to the center buckle, and a single belt which joins the center buckle to the child restraint between the thighs. The belt for the five point restraint is modeled as a multibody element. A multibody belt system consists of a chain of non-linear elastic spring segments. The belt model allows slip between two adjacent belt segments through sliprings. The slip depends on a friction coefficient. At each belt slip ring, a different friction coefficient can be defined to control the slip of belt material between the two adjacent belt segments. Thus no contact models are defined between dummy and belts, but a kinematic constraint is applied at predefined points on the dummy and the child restraint. The harness clip and buckle are modeled as ellipsoid rigid bodies because they do contact the dummy.

A child occupant was modeled using the CRABI 12 month old child dummy model. It is scaled down from the Hybrid III 50th percentile male dummy model. The MADYMO manual reports the dummy to be completely similar in structure to the 50th percentile model. The dummy is a global ellipsoid model that is computationally efficient and can simulate global responses to various impacts.

The positioning of the dummy is executed by simultaneously applying a gravitational force on the seat and dummy while they are positioned right above the backseat of the car. In order to achieve the required initial stiffness on the lower LATCH belt, a separate pre-tensioning system is modeled. These systems are modeled just to apply the required initial force to the belts which occurs during installation. Once the correct amount of tension is applied during the pre-simulation, the belt lengths are locked so that each belt will behave only according to its stiffness characteristics. This pre-simulation is run until an equilibrium state is achieved for dummy and child restraint.

Results for the child seat kinematics are shown in Figure 2, and selected dummy injury measures are included Table 2. Images of the sled test and simulation at several time intervals are shown in Figures 2 and 3. The kinematics between the sled test and model are very similar for both the child restraint and dummy. The angle of the child restraint in the simulation is within 3 degrees of the sled test at all times until approximately 75 ms, at which point all injury values have reached their maxima. At this time, the child restraint in the sled test continues to rotate, but it appears to be partially due to sliding on the vehicle seat, and this movement is not captured in the model.

Table 2. Selected output measures for the sled test and simulation

Injury and Kinematic Measures	Units	Sled Test	Simulation	Percent difference
HIC15		279	221	21%
HIC36		436	340	22%
Head Res Acc, 3ms clip	g's	55.9	48.8	13%
Chest Res Acc, 3ms clip	g's	30.6	44.6	46%
Pelvis Res Acc, 3ms clip	g's	52.5	46.3	12%
Upper Neck Tension	N	1183	973	18%
Rearward rot. Angle @ 55 ms	Deg	8.1	8.8	9%

Figure 2. Sled test images at 0, 30, 60, and 90 ms.

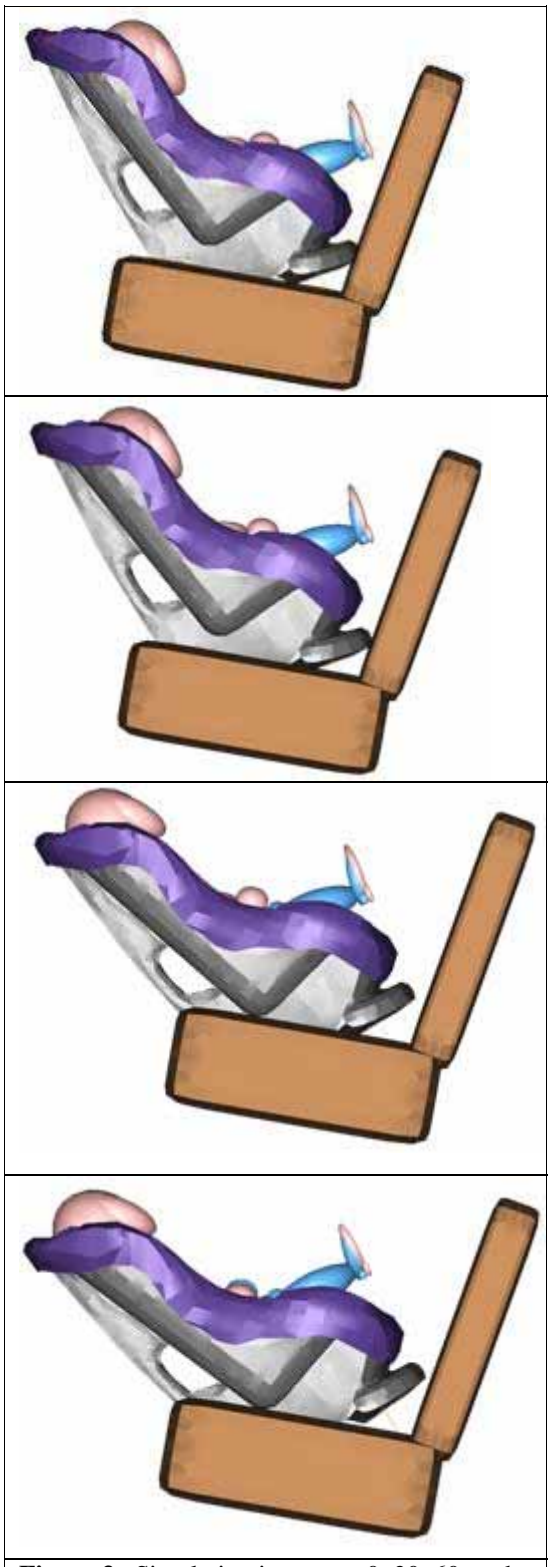

Figure 3. Simulation images at 0, 30, 60, and 90 ms.

The injury values in Table 2 are all within 22% of the sled test values, with the exception of the chest acceleration which was 46% higher in the simulation. In the sled test, the head had a much higher resultant acceleration than the chest (56 g's vs. 30.6 g's). The head and chest values were much closer in the simulation (48.8 vs. 44.6). Because the most common and serious injuries to children are head injuries, more weight was given to the head accelerations when validating the model.

One possibility for the difference between the simulation and the sled test was the deformation of the child restraint shell. The child restraint is designed with stiffening components on the back of the child restraint, but the majority of these do not extend to the portion of the child restraint where the dummy's head is located. The video of the sled test shows that the upper portion of the child restraint flexes, however the effect on the head acceleration is unknown.

Parametric Study

The validated computational model was used in the parametric study with MADYMO 6.2 and MADYMO/AutoDOE 2.3 to set up and run the simulations with the modified variables. The variables used were the Vehicle Cushion Stiffness, LATCH Belt Stiffness, CRS Harness Stiffness, and CRS Cushion Stiffness. The Vehicle and CRS cushion stiffness are defined as functions of Force vs. Displacement. The LATCH Belt and CRS Harness stiffness are defined as functions of Force vs. Strain. The stiffness values were parameterized by scaling the Force values of these functions.

Each variable was evaluated at 5 levels, from 5 times to 1/5th its original value. The variables were distributed logarithmically so the 5 levels were 0.2, 0.44721, 1.0, 2.236 and 5.0. A full factorial design of experiments was used evaluating all of the combinations of the variables. This resulted in a total of 625 simulations. The simulations were run using approximately 1 week of CPU time.

Input and output variables were plotted and compared to each other. When an input variable was plotted against an output variable, average values of all the simulations using that variable level were determined and plotted with lines connecting these average values. When two different output variables were plotted against each other a least squares fit of a straight line was determined and plotted to show a linear trend. It should be noted, however, that trends in the average values include all case simulations, and that these quantities may not reflect the same information when looking for best case scenarios.

The cost variables (head injury cost, neck injury cost, chest injury cost, and total injury cost,) were all divided by the total injury cost of the baseline model (all variables at level 1.) This was done to show the relative change from the baseline cost. These cost values should not be directly compared to injury costs in previous sections of this paper.

RESULTS

The 625 simulations ran to completion with no errors. Visual inspection of the kinematics of each simulation was not done. The minimum, average, and maximum values of the output variables of all 625 simulations are shown in Tables 3-6 below. One simulation exceeded the FMVSS 213 limit of 70 degrees maximum seat back angle. All simulations met the HIC 1000 limit, and most of the simulations fell below the Chest 3ms limit of 60g's.

Table 3. Normalized injury costs for all simulations.

Normalized Cost	Minimum	Average	Maximum
Total	0.316	0.974	3.389
Head	0.071	0.145	0.582
Chest	0.089	0.125	0.215
Neck	0.110	0.705	2.771

Table 4. Relative percentage of injury cost by body region.

Percentage of Normalized Total Cost	Minimum	Average	Maximum
Head	3.4%	15.7%	37.0%
Chest	4.6%	17.7%	39.2%
Neck	32.6%	66.6%	89.5%

Table 5. Injury criteria for all simulations

	Minimum	Average	Maximum
Chest 3ms (g's)	30.3	42.7	72.7
HIC 36	154	299	710
HIC 15	98	207	710
Peak Neck Tens (N)	272	926	2439

Table 6. CRS motion for all simulations

	Minimum	Avg	Maximum
Seat Back Angle (deg)	45	55.1	70.2
Forward Excurs (mm)	690	760	846

Figure 4 shows the Normalized Total Cost of each simulation sorted by rank. The head, neck, and chest cost components of each simulation are also plotted. The total cost was dominated by the neck cost.

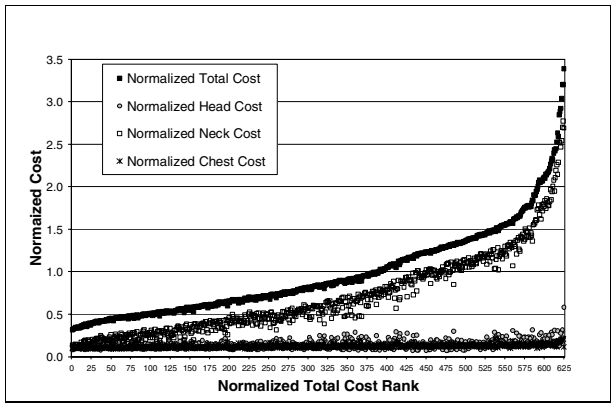

Figure 4. Normalized costs for all simulations.

Figures 5 shows the effect of Vehicle Cushion Stiffness on the Total Cost. The average total cost decreased with both more compliant and stiffer vehicle cushions, although the simulations with the lowest total costs had the stiffest seats. Neck tension had the largest decrease with increasing vehicle cushion stiffness. Chest accelerations tended to increase with increasing vehicle cushion stiffness, while HIC values followed the total cost trend with the baseline value resulting in the highest HIC scores.

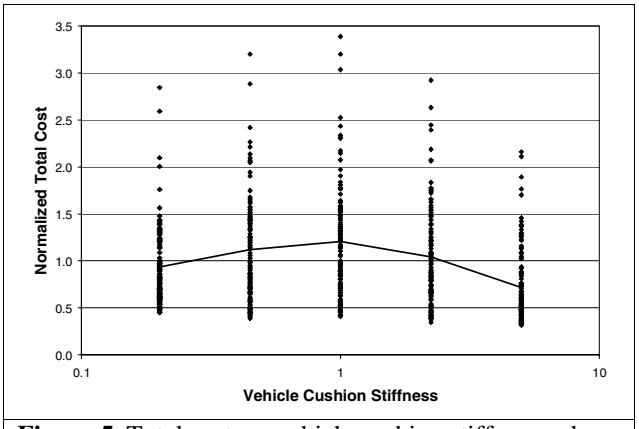

Figure 5. Total cost vs. vehicle cushion stiffness values.

Figure 6 shows the effect of LATCH belt stiffness on injury cost. The average values of total cost, neck tension, Chest G's and HIC all decrease with a more compliant LATCH belt, and increase with a stiffer LATCH belt. The simulations with the lowest total costs and the lowest injury measures occur at all LATCH stiffness levels, however.

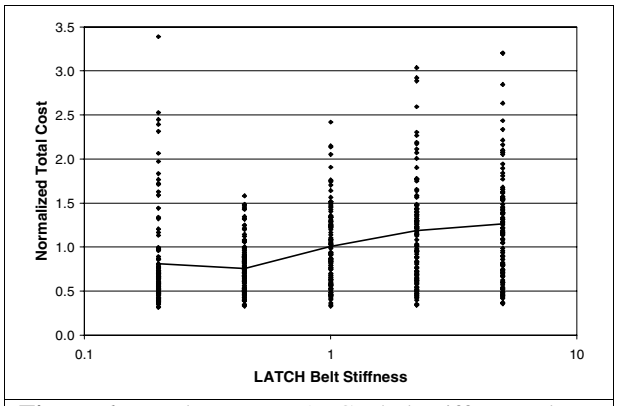

Figure 6. Total cost vs. LATCH belt stiffness values.

A more compliant CRS cushion increases the average values of total cost (Figure 7), neck tension, HIC, and Chest G's. The more compliant cushion allows a differential velocity to develop between the occupant and the CRS. This is similar to having slack in the seat belt of an adult occupant in a frontal collision. This situation should be minimized by having a stiffer CRS cushion.

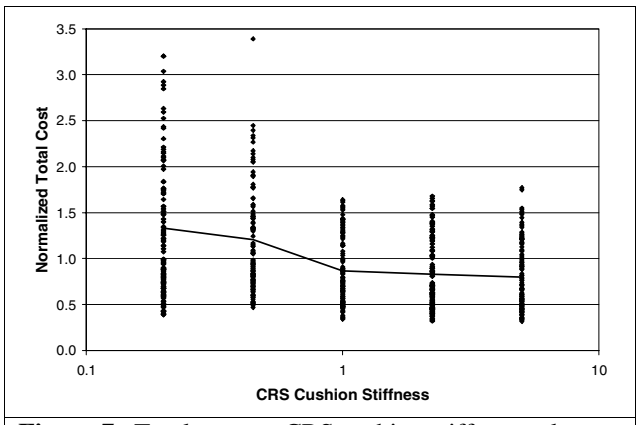

Figure 7. Total cost vs. CRS cushion stiffness values.

A more compliant CRS Harness reduces total cost (Figure 8), neck tension, Chest G's and HIC, although the effect on reducing HIC is minimal. As the occupant moves vertically in the CRS due to its reclined angle, the CRS Harness acts as a spring that couples the occupant to the CRS and ultimately to the vehicle structure. A less stiff spring reduces the applied force on the occupant, but may allow more excursion of the child. This possibility was not analyzed in this study. The effect on HIC is minimal which suggests that HIC is more sensitive to the contact between the head and the CRS, as opposed to the restraining forces applied by the harness.

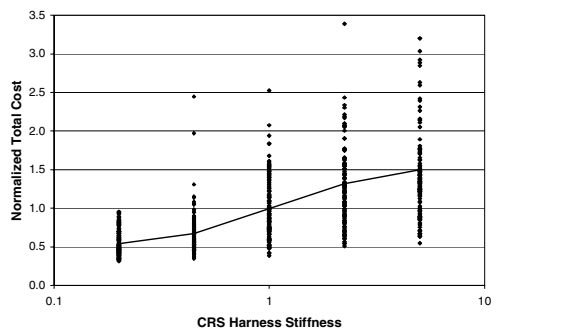

Figure 8. Total cost vs. CRS harness stiffness values.

LIMITATIONS

This parametric study is by no means an accurate reflection of the true vehicle fleet or the different CRS models that are available. The results are used to investigate trends in configurations similar to that of the Safety 1st CRS in a FMVSS 213 condition on a Windstar seat.

The model does not have the detail to show how the CRS interacts with either the metal structure under the vehicle seat cushion, or how the CRS might roll off the front of the seat cushion when it translates too far forward.

The range of the variables chosen for the parametric study was arbitrary. More importantly, it is not known if the range of variation in the vehicle seat cushion underestimates or overestimates the range in the actual vehicle fleet. The outputs are shown to be sensitive to the vehicle cushion based on the ranges chosen. It would be important to know how this relates to the true vehicle fleet.

Seat geometry was also not varied in this study, and a simplified vehicle cushion stiffness model was used. This lumps all of the parameters such as foam stiffness, underlying structure, and overall geometry into one function. Different seat designs may show different results.

The LATCH belt stiffness was varied in this analysis. The LATCH belt was modeled as a line and did not translate with respect to the child restraint. This technique may not capture the more complex interaction as the belt passes through openings in the CRS and slides inside the CRS slot. Therefore the variable of LATCH belt stiffness may actually describe the entire system of attachment between the CRS and the LATCH belt.

Different fixation methods of the CRS were also not explored. Tether systems and other types of fixation may dramatically change the motion of the CRS relative to the vehicle. In addition, the interaction of the child restraint with other vehicle structures (front vehicle seat, front dash) was not included. This interaction and its relationship with excursion is likely a critical factor and must be considered in future research.

All of these assumptions and simplifications should be taken into consideration when evaluating the results of the simulations. Additional sled tests should be used to further test the hypotheses put forth by this parametric analysis.

DISCUSSION

Neck injury is the largest component of the cost function in most of the cases explored in the simulations. The parameter values which were most beneficial were those that limited the neck tension peak value. This differs from research which shows that the most commonly injured body region is the head (Arbogast, 2005). Real world data of child injuries, or child cadaveric research, are needed to further analyze the validity of the cost function, specifically ranking the relative importance of the different injury measures.

Although not addressed specifically in this report, contact with other vehicle structures has the potential to increase the injury risk of rear facing child restraints. The model used for this analysis did not include other interior vehicle structures, and thus judgments about excursion amounts were made without specific data. If, however, it can be assumed that excursion distances should be limited, the following conclusions were made; Vehicle Cushion Stiffness, LATCH Belt Stiffness, and CRS Cushion Stiffness values should all be increased, while the CRS Harness should be made more compliant.

The variable that had the greatest effect on injury cost and neck tension was the CRS harness stiffness. As the occupant moves up the CRS seat back during the crash event, it is restrained by the CRS harness. The stiffness of the CRS harness provides an opportunity for energy absorption by allowing more excursion of the dummy, which results in lower neck tension values. The CRS tested was a convertible CRS which allows for both rear facing and forward facing configurations. The harness may be designed for the forward facing case, resulting in a stiffness that should be reduced to optimize the benefit in the rear facing orientation.

CONCLUSIONS

One of the goals of this project was to develop a procedure for optimizing design variables from both the Vehicle System and Child Restraint System simultaneously, in order to minimize the injury risk to child occupants. This procedure was performed using a one year old dummy in a rear facing child restraint as an initial step in researching this process. A more in-depth, long term research project is required, however, to apply this procedure to the entire spectrum of occupant and restraint combinations. For example, there is little value in optimizing the restraint environment for a 12 month old in a rear facing child restraint without considering the effects on a 6 year old in a booster seat or an adult occupant. Future research on this topic should address the following topics:

1) all occupant ages and sizes
2) all restraint systems (vehicle belt, child restraints)
3) methods for improving the cost function validity by considering real world injury trends
4) realistic models of vehicle seats, including accounting for fleet variations
5) realistic ranges of system design parameters (Vehicle and Child Restraint)
6) child restraint fixation methods not currently used
7) the importance of excursion distances and occupant/child restraint contact with other vehicle structures
8) validation of findings with physical testing

ACKNOWLEDGEMENTS

This work was funded by the National Highway Traffic Safety Administration Contract DTRS 57-03-D-30005. The views expressed are those of the authors and not necessarily those of NHTSA.

REFERENCES

Arbogast, K., Jermakian, J., Ghati, Y., Smith, R., Maltese, M., Menon, R. (2005) Predictors and Patterns of Pediatric Head Injury in Motor Vehicle Crashes. Proc. 2005 IRCOBI Conference.

Eppinger, R., Sun, E., Bandak, F., Haffner, M., Khaewpong, N., Maltese, M., Kuppa, S., Nguyen, T., Takhounts, E., Tannous, R., Zhang, A. Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems – II. National Highway Traffic Safety Administration. November, 1999.

Kuchar, A., Neat, G., Greif, R. (2001) A Systems Modeling Methodology for Evaluation of Vehicle Aggressivity in the Automotive Accident Environment, Paper 2001-01-1172, Society of Automotive Engineers, Warrendale, Pennsylvania.

Miller, T., Romano, E., Zaloshnja, E., Spicer, R. (2001) HARM 2000: Crash Cost and Consequence Data for the New Millennium, Proc. 45th AAAM, pp. 159-184.

National Highway Traffic Safety Administration (2003). "Federal Motor Vehicle Safety Standards: Child Restraint Systems." Federal Register 67(84): 21836-21852.

Sherwood, C, Abdelilah, Y, Crandall, J, Stevens, S, Saggese, J, Eichelberger, M. (2004) The Performance of Various Rear Facing Child Restraint Systems in a Frontal Crash. Proc. 48th AAAM.

INJURIES TO CHILDREN ONE TO THREE YEARS OLD IN SIDE IMPACT CRASHES

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ABSTRACT

Children comprise more than 50% of the rear seat occupants in motor vehicle crashes. Side impact is a particularly harmful crash mode. The National Highway Traffic Safety Administration (NHTSA) has undertaken a study of real-world data to help characterize crash parameters and injury causation of children in side impact crashes. Although there is a paucity of data on children in motor vehicle crashes a detailed analysis of real-world crashes was conducted to determine any potential safety improvements that can be afforded this population of rear seat occupants.

A weighted query of the National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) showed that 9% of child involvements one to three years old were unrestrained, while the Fatality Analysis Reporting System (FARS) showed that 46% of the fatalities in that age group were unrestrained. A NASS-CDS query of side impact crashes with a change in velocity (ΔV) $\geq$ 30 kph was analyzed to determine which body regions were injured. Injury causations were reviewed to determine injury source and severity. Children injured in side impact crashes of this intensity seemed to exhibit a preponderance of head injuries in addition to those to the torso and extremities. Children on the near side in these crashes tended to suffer more severe injuries than far side occupants. Several case studies from the Crash Injury Research and Engineering Network (CIREN) were examined. The cases involved children aged one to three years old who were injured in forward facing child restraint systems (CRS) appropriate for their age. Observations were made about the influence on injury severity of relative seating position (near side, center, far side), crash severity, structural intrusion, and attributes of the child restraint systems. For these cases, the evaluation and applicability of existing countermeasures were considered qualitatively.

INTRODUCTION

Children comprise more than 50% of the rear seat occupants in motor vehicle crashes. The National Automotive Sampling System, in particular the Crashworthiness Data System [NASS-CDS: 1995, 1996, 1998-2005], estimates that more than 2.7 million children ages 0 to 12 years old were involved in motor vehicle crashes in a period covering ten years of data. Figure 1 shows that 53% of 0 to 12 year-olds were involved in frontal crashes followed by 27% in side impact crashes. Rollover and rear end crashes represented the remaining 11% and 9% of crashes, respectively.

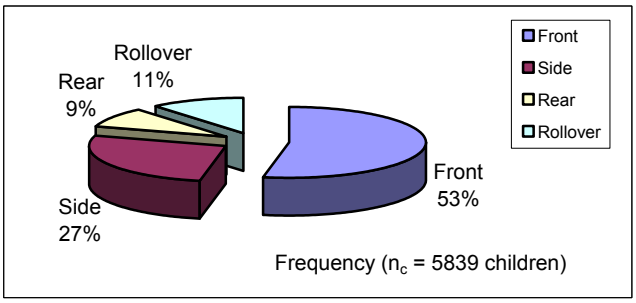

Figure 1: Distribution of crash configurations for all children 0 to 12 years old. Weighted N = 2,732,141 children. NASS CDS: 1995, 1996, 1998-2005

NHTSA has undertaken a study of real-world data to help characterize crash parameters and injury causation of children in side impact crashes. Despite limited data, the detailed analysis of real-world crashes will help to characterize potential safety improvements for rear seat occupants.

For the purpose of this study unweighted data are used. The authors do not draw any conclusions but report the findings based on the data sample. Therefore, in the absence of weighted estimates, the data should be considered a collection of anecdotal data.

National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) and Fatality Analysis Reporting System (FARS)

The initial investigation used the National Automotive Sampling System, in particular the Crashworthiness Data System, and Fatality Analysis Reporting System (FARS). A weighted query of NASS-CDS [data years 1995, 1996, 1998-2004] shows that 13% of children aged 0 to 12 years old involved in crashes were unrestrained. In this time frame, children ages one through three years old had a lower unrestrained rate (9%). In contrast, the Fatality Analysis Reporting System (FARS data years 1994-2003) shows that 46% of side impact fatalities of children aged one through three years old were unrestrained. This implies that 9% of children in this age group who were unrestrained bore significantly more risk of death from side impact crashes than the 91% who were restrained. Continued efforts to encourage proper restraint of vehicle occupants, especially children, appear warranted.

Nonetheless, children are being injured and killed. Further investigations were undertaken to determine how children were being injured in side impact crashes. A NASS-CDS query was performed which identified cases of children aged 0 to 12 years old injured in side impact crashes. The crash parameters include rear seated occupants involved in non-rollover, side impact crashes. Side impact crashes were defined as vehicles with the General Area of Damage variable equal to "right" or "left."

In order to focus on the more serious crash events, a subset of the NASS-CDS data was scrutinized for injury mechanisms and distributions. Children injured in side impact crashes with a change in velocity (ΔV) of 30 kph or more were included. For the children who are the focus of this paper (injured children aged one- to three-years-old), the 28 cases listed at $\Delta V \geq 30$ kph values constitute a relatively small percentage of the overall 117 injured one- to three-year-olds. However, when the data are weighted, these 28 children represent 60% of the one-to three-year-old children receiving a maximum injury of AIS 3 or higher.

At ΔV values of 30 kph or more, there were 552 injuries recorded for the 125 injured children aged zero to twelve years old for an average of 4.4 injuries per child. The injuries were categorized as head, neck, torso, upper extremity, and lower extremity. The distribution is shown in Figure 2. The preponderance of injuries (52%; n=287) was head injuries. Torso and lower extremities injuries each represent 18% of the overall injuries. Upper extremities and neck injuries represent 7% and 5%, respectively.

The subset of data for children one to three years old tells a slightly different story in Figure 3. There were 104 injuries distributed over 28 children (for an average of 3.7 injuries per child).

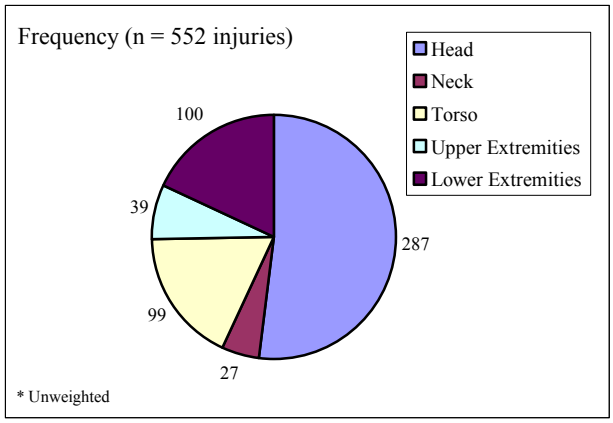

Figure 2: Distribution of injuries among body regions. Side impact crashes. Children 0 to 12 years old. n_c = 125 children. $\Delta V \geq 30$ kph. NASS CDS: 1995, 1996, 1998-2004

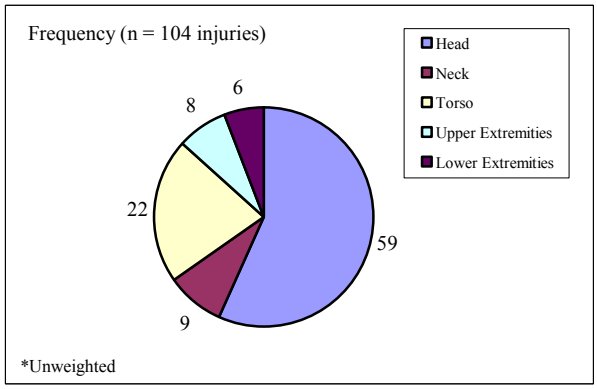

Figure 3: Distribution of injuries among body regions. Side impact crashes. Children 1 to 3 years old. n_c = 28 children. $\Delta V \geq 30$ kph. NASS CDS: 1995, 1996, 1998-2004

The distribution of injury severity across injured body region is shown in Table 1. There were no AIS 6 injuries in this sample.

For the one to three year old subset, head injuries were slightly higher (57%) than the overall population set. The higher fraction of head injuries may be related to relatively high neck loading compared to larger children. According to Weber, there has long been a concern that a child's cervical

spine could be separated as a result of the force on the head when the shoulders are held back in a crash[1]. The other factors to consider are the direction of the impact force, difference in restraint systems (internal harness, 3-point belts, etc.) and the proximity of the nearest surface (often the padded CRS itself).

The percentage of torso injuries is 21% which is similar in proportion to the overall child population. However, for the one to three year old subset, lower extremity injuries were less of an issue--only 6%. Neck injuries represented 9% while upper extremities represented 8% of the injuries for one to three year olds.

Of this injured group of 28 one to three year olds, half were known to be in a forward facing CRS. This population of children in forward facing restraints will be discussed in a later section.

The injuries to the 28 children can be categorized by the contact source that caused the injury. The injury contact sources are defined in the NASS-CDS Coding and Editing manual[1]. The groups are shown in Figure 4. While "flying glass" caused 19 of the 104 injuries (mostly to the head), direct contact with the vehicle interior (47 of the 104 injuries) was the most common injury source. Interior contacts included seat backs, sills, hardware, and other surfaces. Contact with the child seat represented 15 injuries. However, further review is required to determine whether the injury is caused by the child's own CRS (possibly due to contact with an intruding component) or that of an adjacent occupant. Torso injuries were attributed to contact with interior objects/surfaces and other vehicle elements.

Table 1: Distribution of injury severity versus injured body region. Side impact crashes. n_c = 28 children. Children 1 to 3 years old. ΔV ≥30 kph. NASS CDS: 1995, 1996, 1998-2004.

	AIS1	AIS2	AIS3	AIS4	AIS5	Total
Head	49	1	3	2	4	59
Neck	9	0	0	0	0	9
Torso	6	8	2	4	2	22
Upper Extremity	7	1	0	0	0	8
Lower Extremity	5	1	0	0	0	6
Total	76	11	5	6	6	104

Figure 5 correlates these same contact groups with the injury severity level using the Abbreviated Injury Scale (AIS). Minor injuries (AIS1) were attributed to flying glass, the vehicle interior, the child seat and the seat back. However, focusing on the moderate and serious-to-fatal injuries (for known sources), Figure 5 shows that the vehicle seat back and other interior surfaces are the prevailing sources of injuries. Table 2 provides the frequency distribution of injury sources.

The authors choose to compare moderate-to-fatal (AIS2+) injuries with serious-to-fatal (AIS3+) injuries. Moderate (AIS 2) injuries cover a broad spectrum of injuries that may or may not be a threat to life and/or result in long-term outcome issues. Therefore, the AIS2+ frequency count also includes AIS ≥ 3 injuries.

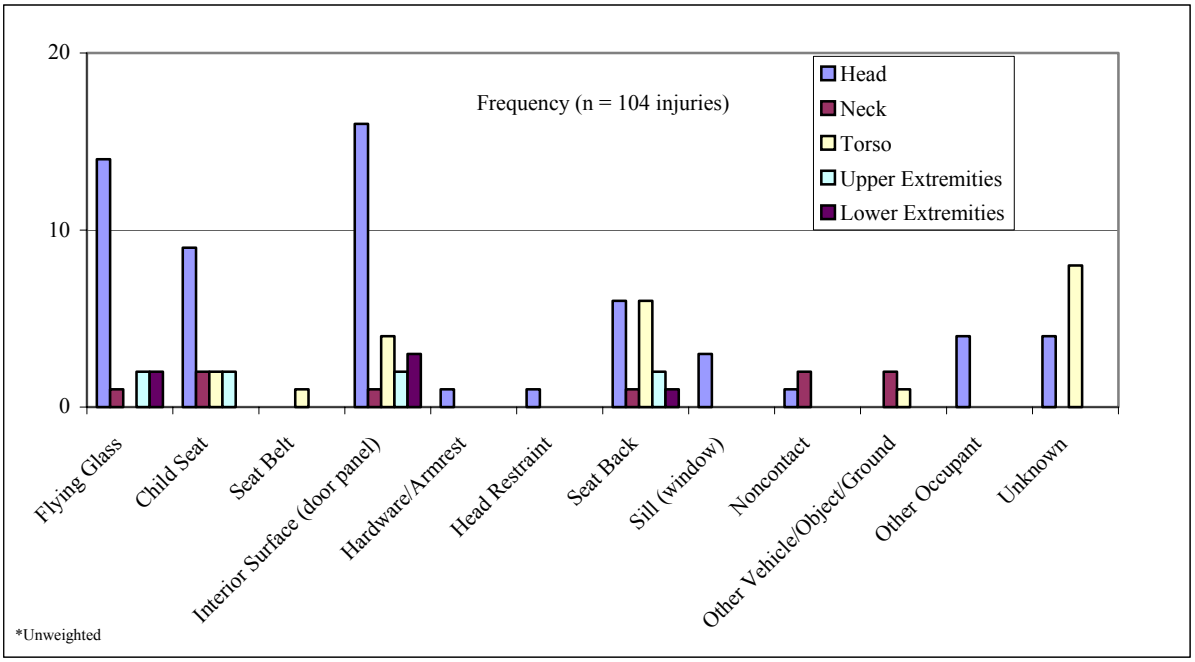

Figure 4: Distribution of injury sources among body regions. Side impact crashes. Children 1 to 3 years old. n_c = 28 children. $\Delta V \geq 30$ kph. NASS CDS: 1995, 1996, 1998-2004

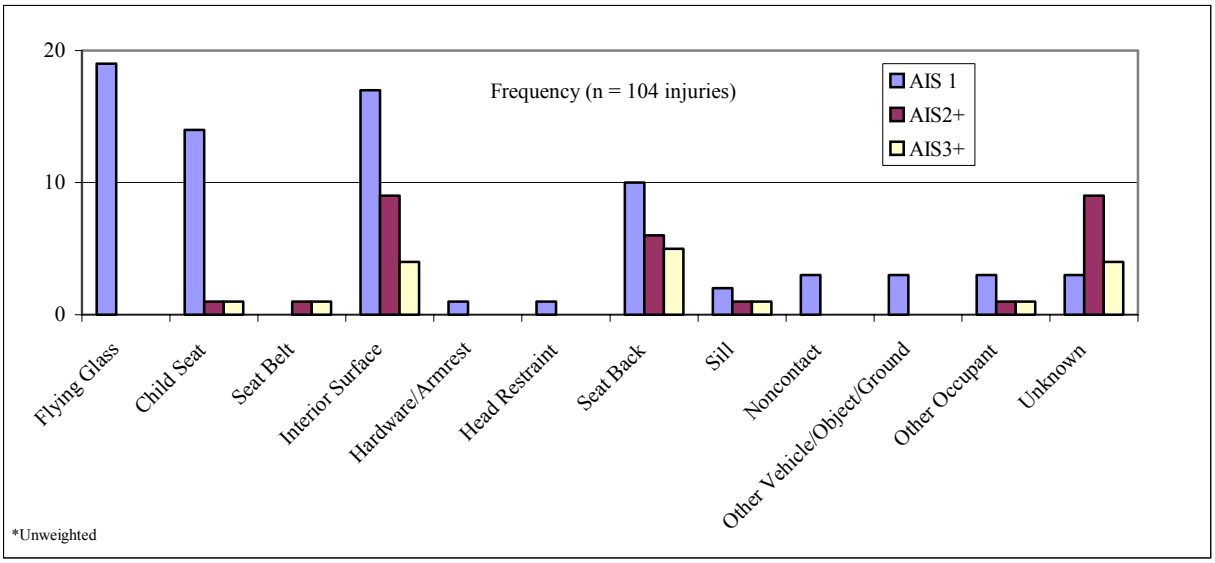

Figure 5: Distribution of injury sources among injury severities. Side impact crashes. Children 1 to 3 years old. n_c = 28 children. $\Delta V \geq 30$ kph. NASS CDS: 1995, 1996, 1998-2004. [Note: AIS2+ also includes AIS≥ 3 injuries]

Table 2: Frequency distribution of injury sources. Side impact crashes. Children 1 to 3 years old. n_c = 28 children. ΔV ≥ 30 kph. NASS CDS: 1995, 1996, 1998-2004

Source	n	Source	n
Flying Glass	19	Seat Back	16
Child Seat	15	Sill (window)	3
Seat Belt	1	Non-Contact	3
Int. Surface	26	Oth/Veh/Grd	3
Hrdw/Arm	1	Other Occupant	4
Head Rest	1	Unknown	12

The frequency of injured regions was also investigated as a function of the relative vehicle impact location. Side impacts were categorized relative to the seating position of the rear seated occupant in question; that is, near side, far side, center, or (in the case of unrestrained children not in a seat) "other." The distribution is shown in Figure 6. Note that these data include all restraint alternatives and will be evaluated in the next segment. The data seem to indicate that head injuries are always prevalent, but that far side occupants are less likely to suffer torso injuries. However, neck injuries are most prevalent with far side occupants then slightly less with near side occupants.

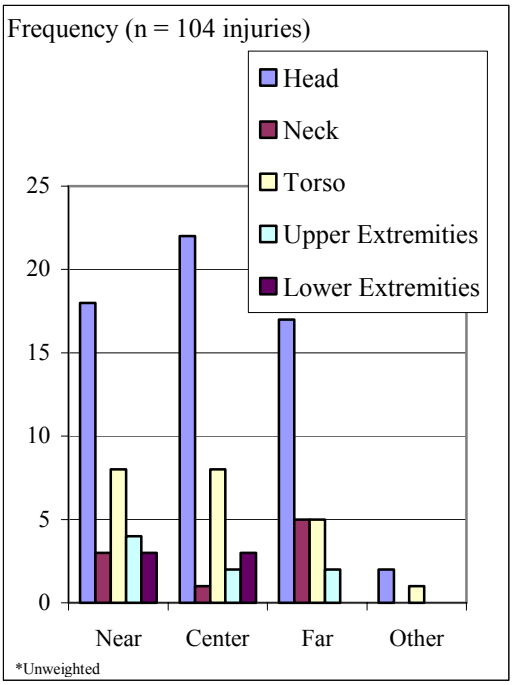

Figure 6: Distribution of relative impact location and injured body region. Side impact crashes. Children 1 to 3 years old. n_c = 28 children. ΔV ≥ 30 kph. NASS CDS: 1995, 1996, 1998-2004

These data can also be looked at in terms of injury severity by relative impact location, as shown in Figure 7. It is encouraging that many of the injuries are at the AIS 1 level, but it becomes evident that a higher percentage of the injuries of near side and center seat occupants are at the higher AIS levels for this dataset. The most significant injuries (AIS 3+) are sustained by near-side and center seated occupants for this dataset.

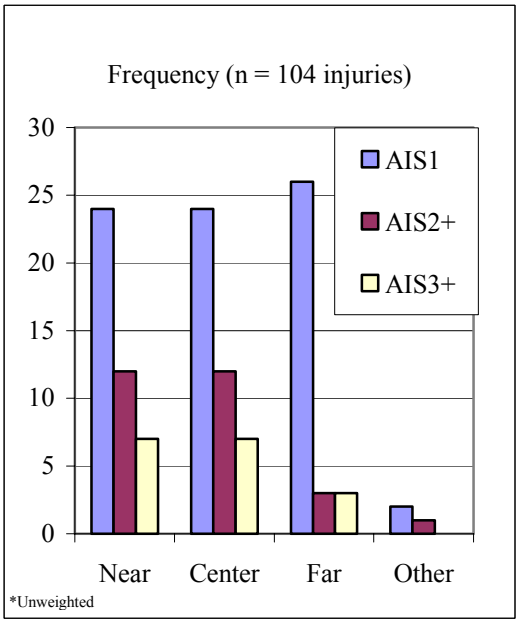

Figure 7: Distribution of relative impact location and injury severity. Side impact crashes. Children 1 to 3 years old. n_c = 28 children. ΔV ≥ 30 kph. NASS CDS: 1995, 1996, 1998-2004 [Note: AIS2+ also includes AIS≥ 3 injuries]

The injury data can be segmented by restraint type. The restraints listed in this NASS-CDS dataset were booster seats, forward facing child restraint systems, lap and shoulder (3 point) safety belts, lap belts only, unrestrained, and other/unknown. The distribution of injured body region is shown in Figure 8. With the limited amount of data across these six alternatives, no clear differences in injury patterns emerge. As a result of this limited sample size of data, the children in forward facing restraints experienced a prevalence of injuries for all body regions. As you review the data, note that the forward facing children represent half of the overall sample. While they represent half of the sample population, there are only 40 (39%) injuries sustained. Thirty five (35) of these injuries are AIS1 and are mainly due to flying glass, child seat, forward seatback and other interior contacts. This sample of restrained children (14) are reviewed in a later section of this paper.

Head injuries are clearly represented within each restraint category. The prevalence of torso injuries is second to head injuries. Although the frequency of upper and lower extremity varies by restraint type, upper extremity injuries are primarily sustained by children in forward facing, lap belt only and other/unknown restraint categories. These data show that children in forward-facing restraints (in this dataset) seem to experience more neck injury than those children in other types of restraints. Given the limited data sample size, more data and further analysis must be conducted better understand the various complexities of the crash events.

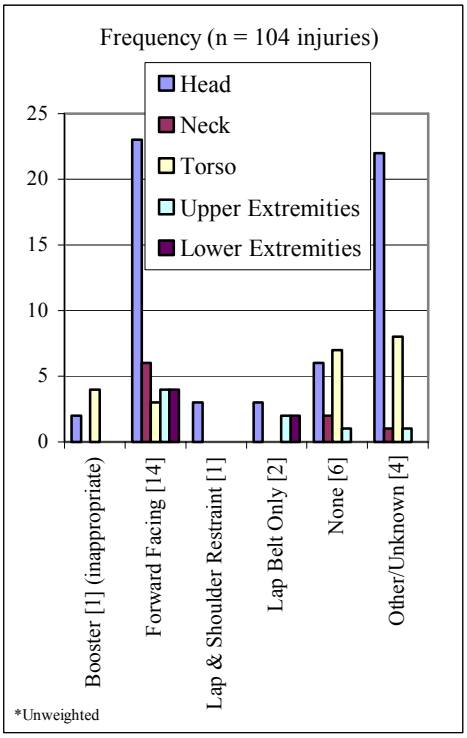

Figure 8: Distribution of restraint type and injured body region. Side impact crashes. Children 1 to 3 years old. n_c = 28 children. ΔV ≥ 30 kph. NASS CDS: 1995, 1996, 1998-2004

Injury severity was also determined based on restraint type, as shown in Figure 9. In this plot, some differences between injury severity and restraint type are evident. While only one case of premature graduation to a booster seat was included, most of that case occupant's injuries were more severe. In contrast, most of the injuries to children in forward facing restraints were AIS 1. The unrestrained and other/unknown cases had higher percentages of injuries above the AIS 1 level.

Of the known restraint types, the most serious (AIS3+) injuries were sustained by a single child inappropriately restrained in a booster seat. This child sustained multiple significant injuries.

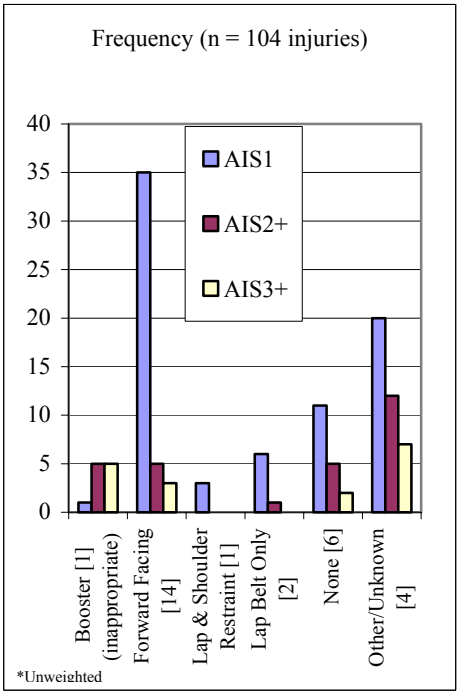

Figure 9: Distribution of restraint type and injury severity. Side impact crashes. Children 1 to 3 years old. n_c = 28 children. ΔV ≥ 30 kph. NASS CDS: 1995, 1996, 1998-2004 [Note: AIS2+ also includes AIS≥ 3 injuries]

Next, it is useful to compare the injury severity distributions for some broad categories of impact speed, ΔV. Figure 10 shows the distribution of AIS level for crashes that occurred over 10 kph increments and those designated as "unknown". Note that these are all ΔV's, including "unknown" values. When accounting for all ΔV's there are 117 injured one to three year old children who sustained a total of 335 injuries. For approximately one-third of the injuries the ΔV is unknown. Of those cases with a known ΔV, again, no clear pattern emerges. While this is surprising in that the impact speed would be expected to have a stronger influence on injury levels, there are enough confounding factors (e.g., the precise location of the intrusion relative to the occupant) that it is not unreasonable to find limited correlation in a relatively small sample.

Minor injuries (AIS 1) occur at each level of impact speed. Moderate to severe injuries (AIS 2+) seem to occur over a broad range of speeds from 20 – 49 kph. The more severe injuries (AIS3+) seem to occur at ΔV of 40-49 kph.

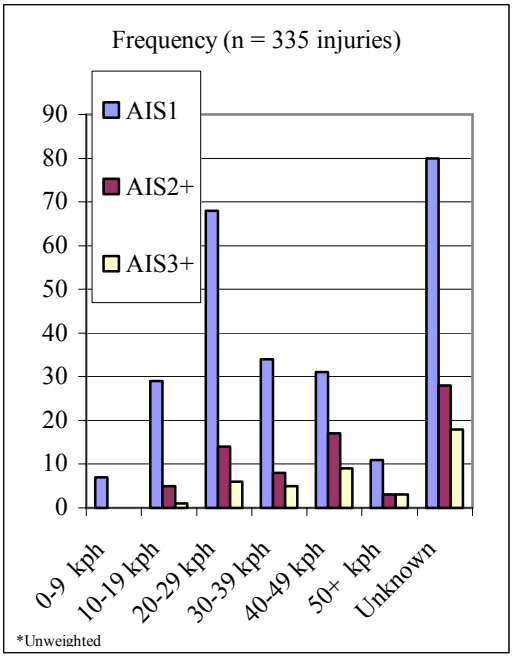

Figure 10: Distribution of ΔV and injury severity. Side impact crashes. Children 1 to 3 years old. n_c = 117 injured children. NASS CDS: 1995, 1996, 1998-2004

Finally, another important aspect of the crash problem is the impact angle or Principle Direction of Force (PDOF). In NASS-CDS, the angles are given as clock angles (e.g., head on force is defined as "12 o'clock"). The dataset was queried to determine the distribution of PDOF for side impact crashes with children in the rear seat. The distribution is shown in Figure 11. If data are grouped by degrees from the longitudinal axis (that is, both 10 o'clock and 2 o'clock represent 60° from longitudinal), then the average impact angle is approximately 70°. If they are grouped by degree from lateral (i.e., 2 o'clock, 4 o'clock, 8 o'clock and 10 o'clock are 30° from lateral), then the average angle from lateral is approximately 30°.

The kinematics of a side impact crash will depend on both the magnitude of the impulse from the bullet vehicle as well as its relative direction. The principal direction of force for side impact crashes tends to be slightly forward of lateral. Figure 12 is a polar coordinate plot depiction of the clock angles of force (12 o'clock being a head-on direction) for side impact crashes in the NASS-CDS database. Side impact crashes are defined as those for which the general area of damage was given as "right" or "left." In the 394 cases of a side impact crash with a one- to three-year-old occupant in the back seat, the most common angles were 10 o'clock and 2 o'clock.

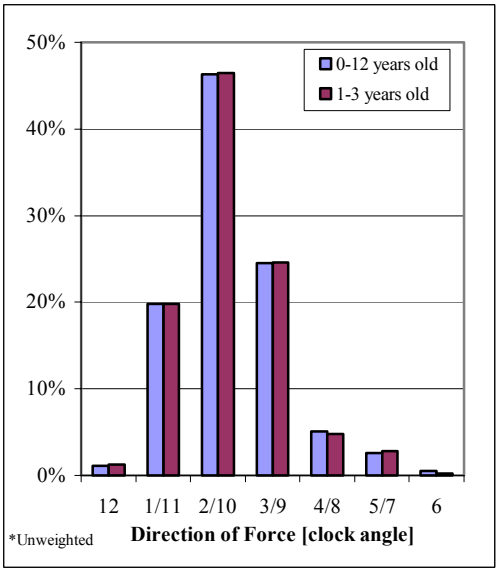

Figure 11: Distribution of Principle Direction of Force. Unweighted side impact crashes (General Area of Damage = Right Side or Left Side). $n_{c\ 1\text{-}3}$ =394 children and $n_{c\ 0\text{-}12}$ =1618 children. NASS CDS: 1996 - 2005.

The data demonstrates that there is typically a longitudinal component in side impact crashes with children. Similar findings were demonstrated in the side impact case studies conducted by Arbogast, et al [3] and Nagabhushana, et al [4].

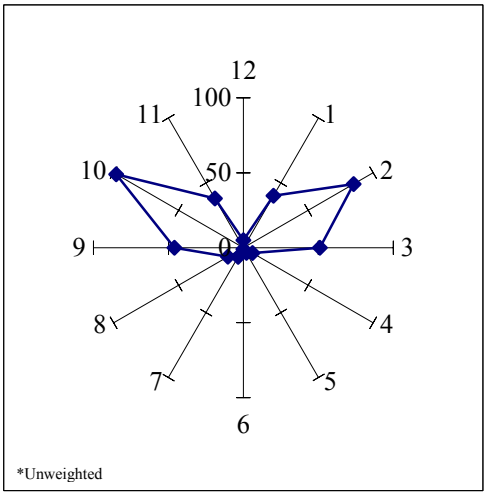

Figure 12: Distribution of principal direction of force [clock angle]. Side impact crashes (General area of damage of "left" or "right") with a rear seat child occupant aged 1 to 3 years old. n_c =394 children. NASS CDS: 1996-2005.

Analysis of Fourteen Children in Forward-Facing CRS

Previously, 28 children ages one to three years old were identified as the subset of children in side impact crashes. Half (14) of these children were restrained in forward-facing restraints. The restraint status of the remaining fourteen children was as listed below. One child was restrained in a booster seat. One was secured with a three-point belt. Two children were restrained with a lap belt only. Nearly half (six) of the 14 children were unrestrained. However, the restraint type was unknown for four children. A similar analysis of the previous section was undertaken to better understand the forward-facing restrained population.

Figures 13 and 14 are the equivalents of Figures 4 and 5 for the restricted (forward facing) dataset. As a general trend, the injuries decrease by more than a factor of two, implying the forward facing child restraints afford significant protection. Certain contact surfaces such as interior surfaces, seat backs, head restraints, and unknown are greatly reduced or virtually eliminated as injury sources. Those injuries that do occur seem to be less severe.

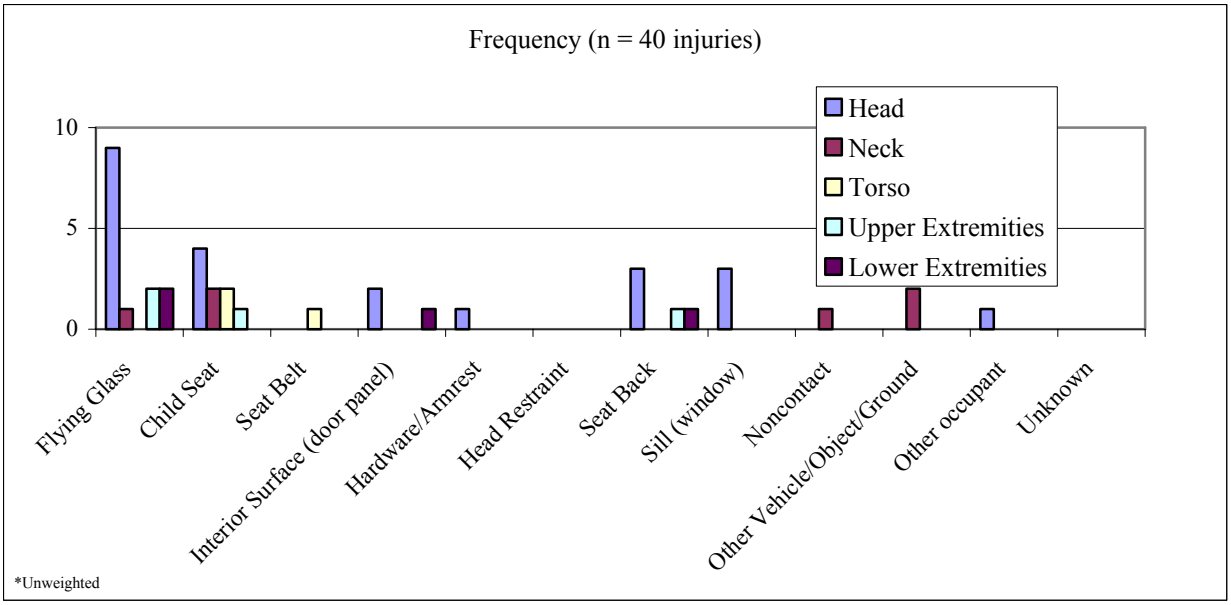

Figure 13: Distribution of injury sources among body regions. Side impact crashes. Children 1 to 3 years old in forward-facing child seats. n_c = 14 children. $\Delta V \geq 30$ kph. NASS CDS: 1995, 1996, 1998-2004

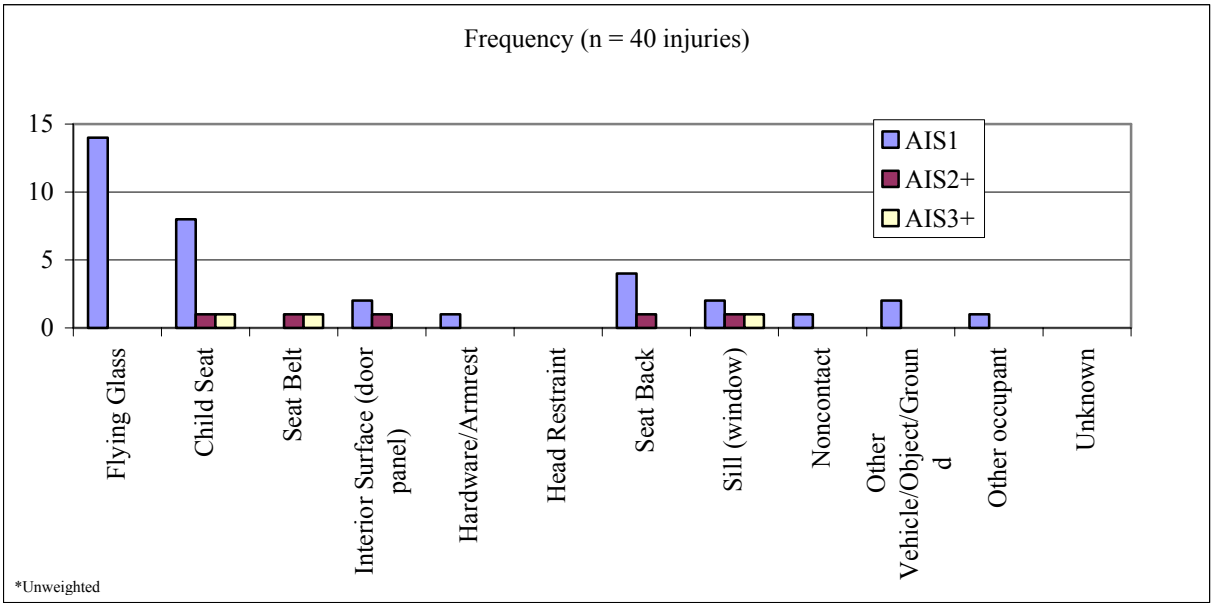

Figure 14: Distribution of injury sources among injury severities. Side impact crashes. Children 1 to 3 years old in forward-facing child seats. n_c = 14 children. ΔV ≥ 30 kph. NASS CDS: 1995, 1996, 1998-2004 [Note: AIS2+ also includes AIS≥ 3 injuries]

Figures 15 and 16 are equivalent to Figures 6 and 7 for the reduced dataset. A comparison of these figures indicates that children in the forward facing restraints are more protected from torso injuries, at least on the near side and in the center when compared to all other restraint alternatives. Figure 16 shows that occupants in forward facing restraints, in the center seat, sustained only minor (AIS1) injuries.

For this dataset the injuries decreased from 104 for 28 children to 40 injuries for 14 children. The reduction in severe injuries of AIS3+ decreased from 17 to 3. The 40 injuries sustained by this sample are mostly AIS1 (35). These injuries were mainly due to sources such as flying glass, the child seat, the seat back, interior surfaces, the window sill, and "other" structures. For the children aged one to three years old identified in this data, the forward facing child restraints seem quite effective.

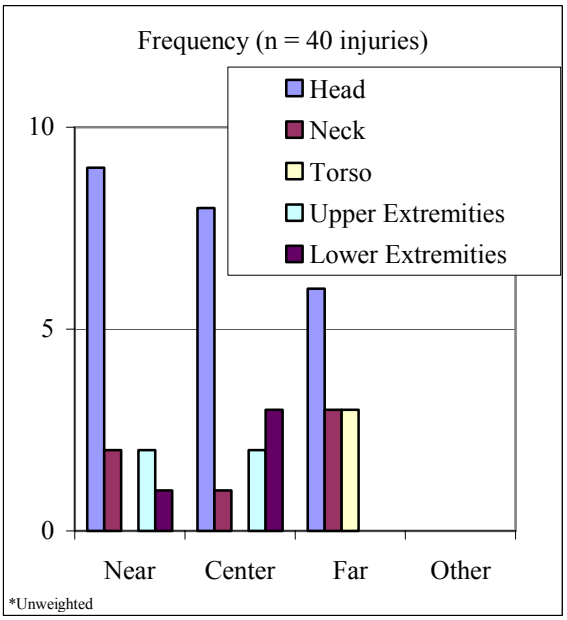

Figure 15: Distribution of relative impact location and injured body region. Side impact crashes. Children 1 to 3 years old in forward-facing child seats. n_c = 14 children. ΔV ≥ 30 kph. NASS CDS: 1995, 1996, 1998-2004

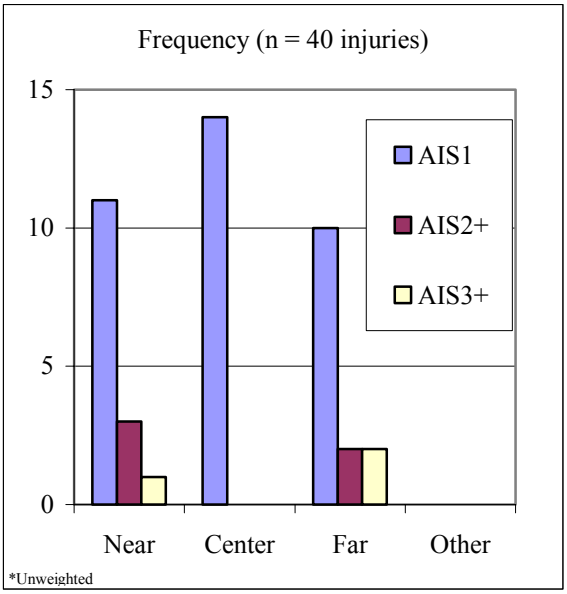

Figure 16: Distribution of relative impact location and injury severity. Side impact crashes. Children 1 to 3 years old in forward-facing child seats. n_c = 14 children. ΔV ≥ 30 kph. NASS CDS: 1995, 1996, 1998-2004 [Note: AIS2+ also includes AIS≥ 3 injuries]

Crash Injury Research Engineering Network (CIREN) Case Studies

The patterns of injury distribution in the NASS-CDS data indicated that this issue of injuries to children from one to three years old in side impact crashes requires closer scrutiny. While the NASS-CDS data gives relevant data, the Crash Injury Research Engineering Network (CIREN) contains more in-depth injury and biomechanical information, although on fewer cases. CIREN currently consists of eight trauma centers which carefully examine injury in various serious motor vehicle crashes. The additional data (such as an evaluation of whether or not the child restraint system was installed properly) becomes useful in understanding injury mechanisms and discussing potential countermeasures.

To ensure the most complete evaluation, CIREN cases were examined in which restraint type was optimal (i.e., forward facing CRS's were chosen), although proper installation was not required. A query of CIREN was run that searched for children aged one through three years (twelve to 47 months) who were restrained in a forward-facing child restraint system, injured in a side impact crash and sustained a Maximum AIS level (MAIS) ≥ 2. Nine cases (in eight separate crashes) were returned and are listed in Table 3[5]. These cases can be accessed as follows:

Table 3: CIREN cases. Side impact crashes injury severity of AIS 2 or more. Children 1 to 3 years old.

Case	Age [months]	ΔV (kph)	Near/Far/ Center	Injury	Installation Annotation
376028346	29	35	Far	AIS 2 spine	No locking clip
874037095	28	48**	Far*	AIS 2 arm fracture	Unknown
377037327	24	42	Far	AIS 2 maxilla fracture	"Highly unlikely" to be appropriate
470047788	33	Unknown	Center	AIS 2 concussion/cuts	Appropriate
33088	46	19	Near	AIS 3 orbit fracture	No locking clip
377039617	31	Unknown	Near	AIS 3 brain hemorrhage	No locking clip, belt in wrong slots
690040270	46	48**	Near*	AIS 3 lung contusion	Appropriate
874034767	40	80	Near	AIS 4 lung contusions	"Proper"
426032502	24	Unknown	Near*	AIS 4 brain hematomas	Appropriate

*other occupants in the same row **Different case occupants from the same crash

Discussion of Injury Patterns and Potential Countermeasures

Near side cases - Five of the nine cases were near side impacts. These crashes have all the vehicle kinematics of center and far side crashes, but also have the most opportunity for direct or indirect contact with intruding vehicle structure. All five of these cases had significant intrusion in the vicinity of the case occupant. They all produced an AIS3+ injury to either the head (including two cases with brain injuries) or the torso (two cases with lung contusions). The Injury Severity Score (ISS) of each child in a near side crash was higher than the other four case occupants.

Four of the five cases experienced right side lateral impacts (See Appendix). Of the five near side cases the principle direction of force (PDOF) was primarily a "pure" lateral impact (three at 80˚and one at 270˚ impact). Only one crash case experienced an impact with a proportionate longitudinal component (PDOF of 50˚). This is not consistent with the NASS-CDS results nor analytical results from other researchers. According to Arbogast et al.[3], a longitudinal component is typically present in most side impact crashes. This difference is likely due to the limited sample size available for case selection in CIREN.

Interestingly, both child restraint systems which were not properly restrained (that is, no locking clip or automatic locking retractor [ALR] was used) resulted in head injury while both lung contusion cases were deemed to have had "appropriate" CRS installation. It appears that improper installation may allow sufficient translation and rotation of the CRS to promote head contact and subsequent injury. While proper installation is always preferable, the advantages of more rigid interfaces between the CRS and the vehicle, such as LATCH, should be further evaluated. According to Arbogast et al.[3], it is suggested that rigid (ISOFIX) LATCH may reduce the risk of rotation.

In contrast, both cases with lung contusions were identified as having appropriate CRS installation as well as significant impact velocity. One CRS was specifically identified as a shield booster. Both case occupants also experienced head injuries and additional internal injuries.

In two of the cases, there were other occupants in the rear seat with the child, but in both cases they were other children restrained in CRS and were not cited as a possible injury source. In contrast, the NASS-CDS study did note some injuries resulting from contact with other occupants. Nonetheless, beyond proper restraint of all rear seat occupants, there are few options for reducing occupant-to-occupant injury mechanism.

Center case - One of the nine cases was a center seat occupant. This young girl suffered head injuries and lower extremity abrasions as the driver's seat was displaced back into her occupant area. This example illustrates that center seat occupants are not immune to the effects of intrusion resulting from external load forces. Her ISS score was lower than all near side occupants, but higher than all far side occupants. The intruding driver's seat reinforces the point that every surface in the vehicle interior is a potential injury source. Reducing the likelihood of collapsing forward seats may reduce intrusion into the rear occupant compartment.

Far side cases - The remaining three of the nine CIREN cases were children on the opposite side of the vehicle from the impact. These were all MAIS 2 cases, although the NASS-CDS data in Figure 6 demonstrates that this need not be the case. None of the children in these cases was demonstrably well-restrained. It is possible that there is a connection between the MAIS 2 requirement in the original CIREN query and the propensity for insufficient restraint.

The primary injuries varied from case to case. One child had primarily head injuries. Another had spine injuries. The last had upper extremity injuries. This diversity shows that substantial contact can occur away from the direct intrusion.

Individual Case Analysis

Case-33088

This case involves a 3-year old (46 months), 15 kg (33 lbs.) and 102 cm (40 in.) female seated in the second row right of a 1998 Honda Accord that was involved in a right side collision with a 1997 Dodge Ram pick-up truck. The principal direction of force (PDOF) was 50˚ (two o'clock) with a ΔV calculated at 19 kph (12 mph). The case vehicle damage was mainly confined to the upper rear portion of the second door, upper rear wheel and right C-pillar area (slight override). The case occupant was restrained in a convertible booster CRS by the internal harness. There was potential slack between the vehicle manual 3-point belt and restraint of the CRS due to non-use of a locking clip or use of the automatic locking retractor mode. The occupant was near-side to the impact and moved forward and to the right with respect to the vehicle. The occupant contacted the

upper portion of the intruding door panel (9 cm) with her right malar eminence (cheek bone) as evidenced by door panel scuffing and contusion/abrasion to the malar eminence. This direct compression on the malar eminence resulted in a right zygoma fracture, right maxillary sinus fracture and a right lateral orbit wall fracture. The occupant's MAIS was 3 with an ISS of 10.

Case-376028346
This case involves a 2 year-old (29 months), 17 kg (37 lbs.) male seated in the third row left of a 1997 Dodge Caravan that was involved in a right side collision with a 1991 Hyundai Sonata sedan. The PDOF was 80˚ (three o'clock) with a ΔV calculated at 35 kph (22 mph). The case vehicle damage was distributed down the right side of the vehicle starting behind the front wheel and extending to the rear wheel, vertical damage extended past the midline. The lower sill or rocker panel was fully engaged. The case occupant was restrained in an appropriate forward facing CRS by the internal harness, but the vehicle 3-point belt was improperly routed to restrain the CRS. The occupant was far-side to the impact and moved right and slightly forward with respect to the vehicle. The improper belt routing allowed the CRS to move right prior to fully engaging the 3-point belt. The neck/cervical spine underwent lateral extension as the occupant's head moved to the right. This extension placed the brachial plexus under tension causing nerve injury within the plexus. The occupant's MAIS was 2 with an ISS of 4.

Case-377037327
This case involves a 2-year old (24 months), 17kg (37 lbs.) and 91 cm (36in.) female seated in the second row right of a 1990 Honda Accord that was involved in a left side collision with a 1991 Toyota 4-Runner SUV. The PDOF was 280˚ (nine o'clock) with a ΔV calculated at 42 kph (26 mph). The case vehicle damage was distributed across both doors on the left side with B-pillar engagement and minimal rocker panel engagement. The case occupant was restrained in an appropriate forward facing CRS by the internal harness, but the vehicle 3-point belt was likely not locked. The occupant was far-side to the impact and moved left with respect to the vehicle. Slack in the 3-point belt allowed the CRS to rotate to the left. The occupant contacted the center second row seat back as evidenced by a large fabric scuff. The occupant contacted the seat back with the left side of her face. This compression fractured her left maxilla and nose. The occupant's MAIS was 2 with an ISS of 8.

Case-377039617
This case involves a 2-year old (31 months), 17 kg (37 lbs.) and 94 cm (37 in.) female seated in the second row right of a 1994 Honda Civic that was involved in a right side collision with a 1999 Kenworth tractor and trailer. The PDOF was 80˚ (three o'clock) with a barrier equivalent speed calculated at 28 kph (17 mph). The case vehicle damage was distributed across the upper portion of both right side doors and over the rear wheel (slight override). The case occupant was restrained in a forward facing CRS by the internal harness which was not routed through the upper slots. There was potential slack between the vehicle manual 3-point belt and restraint of the CRS due to non-use of a locking clip or use of the automatic locking retractor mode. The occupant was near-side to the impact and moved forward and to the right with respect to the vehicle. The occupant contacted the upper portion of the intruding door panel (11 cm) with the right side of her head just superior to the ear and anterior. The broken window glass lacerated her scalp and face (glass in wound) and the compression of the intruding door resulted in a very small right frontal subarachnoid hemorrhage of the cerebrum. The occupant's MAIS was 3 with an ISS of 10.

Case-426032502
This case involves a 2-year old (24 months), 9 kg (20 lbs.) and 90 cm (36 in.) male seated in the second row left of a 1994 Acura Legend that was involved in a left side collision with a 1993 International tractor and trailer. The PDOF was 270˚ (nine o'clock) with a barrier equivalent speed calculated at 41 kph (25 mph). The case vehicle damage was distributed across both left side doors (horizontally and vertically) and over the rear wheel (significant crush). The case occupant was restrained in a forward facing CRS by the internal harness. The CRS was properly restrained to the vehicle by the 3-point belt. The occupant was near-side to the impact and moved to the left with respect to the vehicle. The occupant contacted the upper portion of the intruding door panel (50 cm) with the left side of his head in the temporal region. The intruded door panel also loaded the left side of the CRS. The compressive contact of the upper door on the occupant's head produced a subdural hematomas in the left cerebrum and cerebellum. The left scalp was contused and lacerated. The occupant's thorax and abdomen was compressed by the reinforced side of the CRS causing lung contusions on the lower lobe of the left lung and a small spleen laceration. The occupant's MAIS was 4 with an ISS of 29.

Case-470047788
This case involves a 2-year old (33 months), 15 kg (33 lbs.) and 97 cm (38in.) female seated in the second row center of a 1998 Ford Contour that was involved in a left side collision with a 1985 International tractor and trailer. The PDOF was 280˚ (nine o'clock) with a barrier equivalent speed calculated at 37 kph (23 mph). The case vehicle damage was distributed across both left side doors and over the front wheel with rocker panel and roof engagement (significant crush). The case occupant was properly restrained in a forward facing CRS by the internal harness. The CRS was properly restrained to the vehicle by the 3-point belt. The occupant was center to the impact and moved to the left with respect to the vehicle. The occupant contacted the intruding door panel (28 cm) with the left side of her head just superior to the eyebrow and across the temple resulting in a laceration and concussion. The occupant's MAIS was 2 with an ISS of 8.

Case-874034767
This case involves a 3-year old (40 months), 16 kg (35 lbs.) and 97 cm (38 in.) male seated in the second row right of a 1997 BMW 318 that was involved in a right side collision with a 1997 Cadillac Seville. The PDOF was 80˚ (three o'clock) with a ΔV calculated at 80 kph (50 mph). The case vehicle damage was distributed from behind the right front wheel to past the rear wheel. The rocker panel and doors were fully engaged. The case occupant was restrained in a backless booster CRS by the available manual 3-point belt. The occupant was near-side to the impact and moved forward and to the right with respect to the vehicle. The occupant contacted the intruding door panel (60 cm) with his right thorax and head resulting in bilateral lung contusions and a concussion. The intruding door panel also loaded the CRS compressing the occupant's pelvis resulting in a fracture. The occupant's MAIS was 4 with an ISS of 24.

Case-690040270 (Occupant #1)
Case-874037095 (Occupant #2)
This case involves two children in the same vehicle. The occupants are in a 1994 Toyota Corolla that is involved in a right side collision with a 1988 Ford Ranger compact pick-up truck. The PDOF was 80˚ (three o'clock) with a ΔV calculated at 48 kph (30 mph). The case vehicle damage was distributed across the both right side doors and over the rear wheel (slight override).

Occupant 1 is a 3-year old (46months), 16kg (36 lbs.) and 111 cm (44 in.) male seated in the second row right. Occupant 1 was restrained in a booster seat with a shield using the manual 3-point belt. The occupant was near-side to the impact and moved forward and to the right with respect to the vehicle. The occupant contacted the upper portion of the intruding door panel (40 cm) with the front right side of his head just superior to his hairline resulting in a scalp laceration. The intruded door panel loaded the CRS and compressed occupant 1's thorax as he contacted the CRS's shield resulting in a right lung contusion with hemo and pneumothorax. The upper abdomen was also compressed resulting in a small liver laceration and small kidney laceration. The occupant's MAIS was 3 with an ISS of 17.

Occupant 2 is a 2-year old (28 months), 15kg (34 lbs.) female seated in the second row left. Occupant 2 was restrained in a forward facing CRS using the internal harness. The CRS was properly restrained in the vehicle using the manual 3-point belt. The occupant was far-side to the impact and moved forward and to the right with respect to the vehicle. Occupant 2's arm contacted the shielded booster (occupant 1) to her right resulting in a right distal ulna fracture 2 cm proximal to the wrist joint. The occupant's MAIS was 2 with an ISS of 5.

LIMITATIONS OF STUDY

This study used data from NASS-CDS years 1995, 1996, 1998-2004. Due to the small sample size, the authors did not segment the data to evaluate vehicle type, older versus recent model year, etc.

For the purpose of this study unweighted data are used. The authors do not draw any conclusions but report the findings based on the data sample. Therefore, in the absence of weighted estimates, the data should be considered a collection of anecdotal data.

The NASS-CDS data, by their nature, are limited in detail of the description of injury mechanisms. The CIREN data are limited by the relatively small number of cases. While neither set is complete in every aspect, together they do suggest common themes in the injury mechanisms of one to three year old children in side crashes.

The CIREN inclusion criteria are based on serious injury resulting from automobile crashes. The typical CIREN case involves significant impacts and usually multiple events. Such cases are often deemed catastrophic, but as we have seen all occupants in these cases survived and some with only AIS2 injury.

DISCUSSION

The NASS-CDS and CIREN databases give useful information about the injury patterns of children one to three years old in side impact crashes. The authors chose to investigate subgroups of data with more severe crashes and injury levels and identified some important trends. Head injuries were prevalent in these severe crashes. Further, while restraint is crucial in minimizing overall injury due to the severity of the crash, the loads applied by the restraint resulted in injury, usually in the torso.

In the side impact cases reviewed for this paper the majority of the significant injuries resulted from contact with an intruding door surface. The upper door in the area of the window sill was often the source for direct head contact. Upper and mid-door contacts were noted often with the door intrusion loading the occupant's CRS and resulting in thoracic injury. Although the door intrusion was not directly coded as the source, without these loading conditions energy transfer would not have been as significant. These injury scenarios where the intruding door contacts the CRS will have the injury contact typically assigned to the CRS. For the occupants in these cases, increased padding of the upper door area and/or within the CRS might have mitigated the severity of the injury sustained. Along with increased padding, methods to decrease the door panel intrusion by transferring more of the impact force longitudinally to the surrounding structures (pillars and rocker panel) of the door could help decrease the amount of intrusion into the occupant's position.

Interaction between vehicles was seen as a contributing factor in several of the more severe cases reviewed. Improved classification and/or measuring techniques are required to better research this issue in future cases. This study required analysis of photographs to estimate underride or override characteristics due to a lack of hard-coded fields for side plane impacts in the current NASS-CDS investigation process. The side impact data reviewed indicated injurious impact angles with more oblique approach than pure lateral.

Incorrect or poor CRS installation is not a new problem, but continues to be a possible contributing factor for injury in side impact crashes. Many of the cases reviewed produced evidence of poor CRS installation, which either leads to increased motion of the CRS or increased excursion of the child from the CRS. The increased CRS movement and/or child excursion can be of sufficient amount to place the child in contact with a rigid structure. The threat of injury is increased even farther when the occupant is put in motion due to poor restraint and rigid structures are intruding resulting in even less ride-down space.

DISCLAIMER

The views expressed in this paper are not necessarily those of the National Highway Traffic Safety Administration.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Weber, K., "Crash Protection for Child Passengers: A Review of Best Practice," University of Michigan Transportation Research Institute Research Review, July-September 2000, Vol. 31, No. 3.

[2] United States Department of Transportation, National Highway Traffic Safety Administration, "National Automotive Sampling System, Crashworthiness Data System, 2000 Coding and Editing Manual", NHTSA, Washington, D.C..

[3] Arbogast, K., Ghati, Y., Yoganand, G., Menon, R., Tylko, S., Tamborra, N., and Morgan, R.,"Field Investigation of Child Restraints in Side Impact Crashes," Journal of Injury Prevention, 6:351-360, 2005.

[4] Nagabhushana, V., Park, J., Kuznetsov, A., and Morgan, R., "Side impact Risk for Small-Size Children Final Report," Volume 1 and II, NHTSA Technical Report No. DOT HS 810699, U.S. Department of Transportation, *In press*.

[5] CIREN cases may be accessed at: http://www-nrd.nhtsa.dot.gov/departments/nrd-50/ciren/CIREN.html

Appendix: Summary of CIREN Case Studies

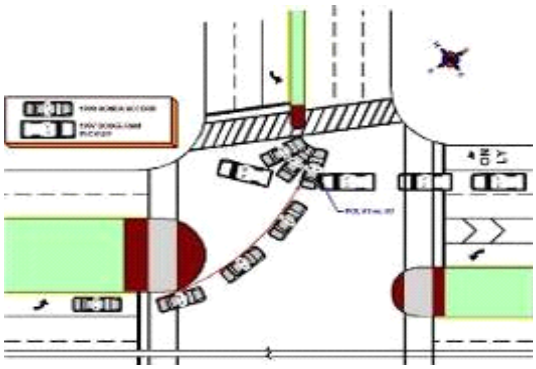
Case	Age [months]	ΔV [kph]	PDOF	Child's ISS	Near/ Far/ Center	Injury	Proposed Injury Causation and Possible Countermeasures
376028346	29	35	80	4	Far	AIS 2 spine	Causation: Lateral flexion of the cervical spine with tension on the brachial plexus produced a nerve root injury. More like a whiplash effect rather than contact between neck and CRS, exacerbated by improper CRS installation causing excessive CRS movement. **Countermeasures: Secure CRS installation**
874037095	28	48**	80	5	Far*	AIS 2 arm fracture	Causation: contact between arm and sibling's CRS **Countermeasures: CRS padding**
377037327	24	42	280	8	Far	AIS 2 maxilla fracture	Causation: Head contact with back of front seat, exacerbated by improper CRS installation causing excessive CRS movement.. **Countermeasures: Interior padding, secure CRS installation**
470047788	33	Unknown	280	8	Center	AIS 2 concussion Facial lacerations	Causation: Intruded door panel (28cms) made contact with occupant's face causing complex laceration and concussion. CRS restrained and appropriate. **Countermeasures: Interior padding, airbags**
33088	46	19	50	10	Near	AIS 3 orbit fracture	Causation: Head contact with intruding door (9cms), exacerbated by improper CRS installation causing excursion and/or rotation. **Countermeasures: Interior padding, secure CRS installation, airbags covering door portion**
377039617	31	Unknown	80	10	Near	AIS 3 brain hemorrhage	Causation: Head contact with intruding upper door panel (11cms), exacerbated by improper CRS installation causing excessive CRS movement **Countermeasures: Interior padding, secure CRS installation, airbags covering door portion.**
690040270	46	48**	80	17	Near*	AIS 3 lung contusion AIS 2 liver laceration AIS 2 scalp avulsion	Causation: Head contact with intruded window sill (40 cms), thorax contact with booster shield reinforced by the intruded door. **Countermeasures: Interior padding, airbags, more appropriate CRS selection.**
874034767	40	80	80	24	Near	AIS 4 lung contusions AIS 2 pelvic fracture AIS 2 loss of consciousness	Causation: Thorax and head contacted intruded door panel (62cms), pelvis pinned by intruded door panel and CRS, resulting in fracture **Countermeasures: Interior padding, airbags, appropriate CRS selection.**
426032502	24	Unknown	270	29	Near*	AIS 4 brain hematomas, AIS 3 lung contusion, AIS 2 spleen laceration	Causation Head contact to upper portion of intruded door panel (50 cms) and thorax contact with CRS reinforced by the intruded door panel. **Countermeasures: Interior padding, CRS padding, airbags**

*Other occupant in the rear seat **Two different occupants in the same crash

Case Number: 33088

Vehicle Exterior:

Scene Diagram:



The collision between Vehicle 1 and Vehicle 2 occurred when the driver of the northbound Vehicle 1 attempted to turn left at the intersection as Vehicle 2 was traveling southbound through the intersection. Vehicle 2 struck Vehicle 1's right side plane with its front end. After the impact, Vehicle 1 rotated clockwise to final rest position in the intersection, facing north. The final rest position of Vehicle 2 was in the intersection, facing southwest. Vehicle 1 was towed from the collision scene due to the damage sustained in this collision. Vehicle 2 was driven from the collision scene.

Near-Side Occupant

Case Vehicle Information:

V1: Honda-Accord, 4-door sedan, hardtop-1998

DOF: 2 O'clock

Delta-V: Total: 19 Km/h (12 Mph)

Lateral: 14 Km/h (9 Mph)

Longitudinal: 12 Km/h (7 Mph)

Location of Impact: Right Side

Maximum Intrusion: >=8 to <15 cm, Second Right

Max. Intrusion Corresponding Component (s):

(1) C-pillar (2) Second seat back (3) Door panel (side)

Vehicle 2 Information:

V2: Dodge-Ram, Large pickup-1997

Case Occupant Information:

46mo old, Female, height-40" and Weight-33 lbs

Seating Position: Second right

Restrain Status: Lap and shoulder belt

Child Seat Type: Booster seat

Was Occupant Injured due to Intrusion? Yes

Components:

(1) C-pillar

(2) Door panel (side)

Other Occupant (s) in Case Vehicle:

DRIVER: 21yr old, Female , MAIS 1

Restrain Status: Lap and shoulder belt

Front right: 21yr old, Female, MAIS 1

Restrain Status: Lap and shoulder belt

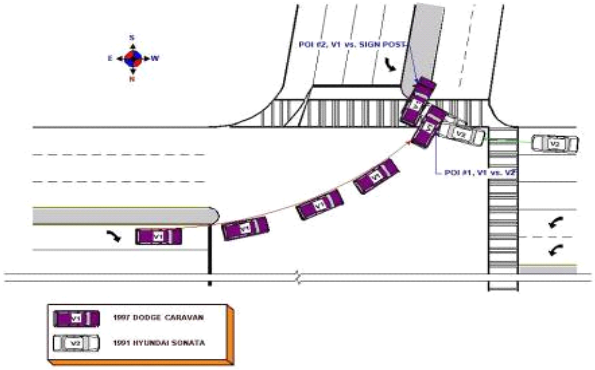
Case Occupant Associated Injuries:

Body Region	Injury Source	Injuries
Face	**Right side interior surface**	**(AIS 3): Orbit fracture open/displaced/comminuted**
Face	Right side interior surface	(AIS 1): Facial Skin laceration minor
Face	Right side interior surface	(AIS 1): Eyelid contusion

Case Number: 376028346

Vehicle Exterior:

Scene Diagram:



The collision between the two vehicles occurred when the driver of Vehicle 1 attempted to make a left turn at the intersection and Vehicle 2 was traveling through the intersection. Vehicle 2 struck Vehicle 1's right side plane with its front end (angle configuration). After the impact, Vehicle 1 was pushed sideways with the left side leading and contacted a sign post with the left side of the vehicle. Vehicle 1 came to a final rest position, facing southwest in the median of the south leg of the intersection. Vehicle 2 came to a final rest position, up against the right side of Vehicle 1, facing southeast. Vehicles 1 and 2 were towed from the collision scene due to the damage sustained in this collision.

Far-Side Occupant

Case Vehicle Information:

V1: Dodge-Caravan, Minivan-1997

DOF: 3 O'clock

Delta-V: Total: 35 Km/h (22 Mph)

Lateral: 35 Km/h (22 Mph)

Longitudinal: : 6 Km/h (4 Mph)

Location of Impact: Right Side

Maximum Intrusion: >=30 to <46 cm, Front Right

Max. Intrusion Corresponding Component (s):

(1) B-pillar

Vehicle 2 Information:

V2: Hyundai-Sonata, 4-door sedan, hardtop-1991

Case Occupant Information:

29mo old, Male, height-U" and Weight-37 lbs

Seating Position: Third left

Restrain Status: Lap and shoulder belt

Child Seat Type: Convertible seat

Was Occupant Injured due to Intrusion? No

Other Occupant (s) in Case Vehicle:

DRIVER: 27yr old, Male, MAIS 1,

Restrain Status: Lap and shoulder belt

Second left: 5yr old, Female, MAIS 1

Restrain Status: Lap and shoulder belt

Second right: 6yr old, Female, MAIS 1

Restrain Status: Lap and shoulder belt

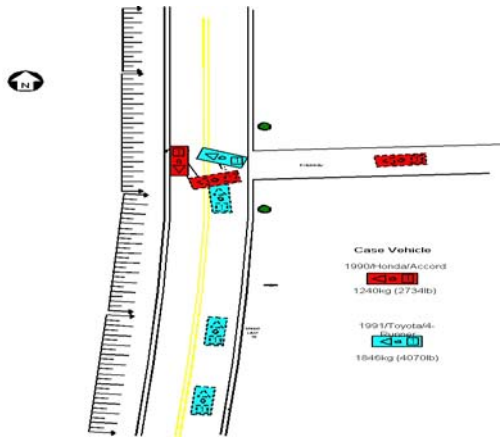
Case Occupant Associated Injuries:

Body Region	Injury Source	Injuries
Spine	Other non contact injury source	(AIS 2): Cervical Spine Brachial plexus

Case Number: 377037327

Vehicle Exterior:

Scene Diagram:



Vehicle #1 (Case vehicle, 1990 Honda Accord 4 door) was traveling westbound on a negative 1 percent drive-way intending to travel southbound. Vehicle #2 (1991 Toyota 4-Runner Utility) was traveling northbound on a two lane positive 6 percent grade(slightly curved to the left) roadway with a posted speed limit of 40mph. As V1 entered the roadway, it intended to make a left turn to travel southbound when it was impacted on the left side by the front of V2. V1 and V2 both traveled in a north-west direction before traveling to final rest. The roadway was dry and it was sunny and clear at the time of the crash.

Far-Side Occupant

Case Vehicle Information:

V1: Honda-Accord, 4-door sedan, hardtop-1990

DOF: 9 O'clock

Delta-V: Total: 42 Km/h (26 Mph)

Lateral: 41 Km/h (25 Mph)

Longitudinal: 7 Km/h (4 Mph)

Location of Impact: Left Side

Maximum Intrusion: >=30 to <46 cm, Front Left

Max. Intrusion Corresponding Component (s):

(1) Side panel - forward

Vehicle 2 Information:

V2: Toyota-4-Runner, Compact utility-1991

Case Occupant Information:

24mo old, Female, height-36" and Weight-37 lbs

Seating Position: Second right

Restrain Status: Lap and shoulder belt

Child Seat Type: Unknown child safety seat type

Was Occupant Injured due to Intrusion? No

Other Occupant (s) in Case Vehicle:

DRIVER: 35yr old, Female, MAIS 2

Restrain Status: Lap and shoulder belt

Front right: 28yr old, Female, Not Injured

Restrain Status: Lap and shoulder belt

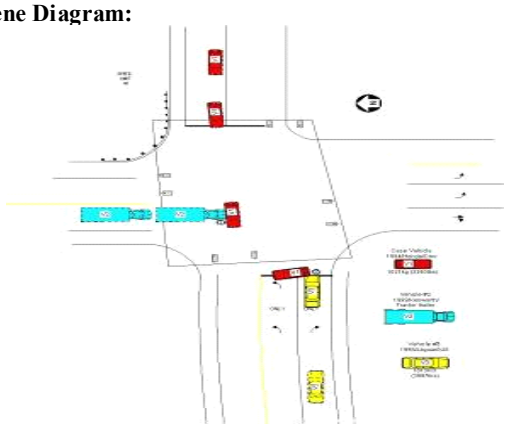
Case Occupant Associated Injuries:

Body Region	Injury Source	Injuries
Face	**Seat, back support**	**(AIS 2): Maxilla fracture closed**
Face	**Seat, back support**	**(AIS 2): Facial Skin laceration major**
Face	Seat, back support	(AIS 1): Nose fracture closed
Face	Seat, back support	(AIS 1): Eyelid contusion

Case Number: 377039617

Vehicle Exterior:

Scene Diagram:



This crash occurred in the afternoon hours. The roadway was dry with adverse weather conditions. This crash occurred at a four legged intersection properly controlled by overhead traffic control standards. The case vehicle was initially traveling westbound in the outer travel lane on a three lane- roadway. The non-case vehicle, a 1999 Kenworth Tractor-trailer, was traveling southbound in the inner travel lane. Both vehicles entered a four-legged intersection resulting in an angle collision between the case and non-case vehicles. The initial impact caused Vehicle #1 to rotate clockwise resulting in an impact (second event) with a stopped 1998 Jaguar XJ8.

Near-Side Occupant

Case Vehicle Information:

V1: Honda-Civic/CRX/Del Sol, 4-door sedan, hard-top-1994

DOF: 3 O'clock

Delta-V: Total: U Km/h

Lateral: U Km/h Longitudinal: U Km/h

Location of Impact: Right Side

Maximum Intrusion: >=15 to <30 cm, Front Right

Max. Intrusion Corresponding Component (s):

(1) Door panel (side)

Vehicle 2 Information:

V2: Kenworth-Median/Heavy Truck, 1999

Case Occupant Information:

31mo old, Female, height-37" and Weight-37 lbs

Seating Position: Second right

Restrain Status: Lap and shoulder belt

Child Seat Type: CSS

Was Occupant Injured due to Intrusion? Yes

Components:

(1) C-pillar

(2) Door panel (side)

(3) Window frame

Other Occupant (s) in Case Vehicle:

DRIVER: 38yr old, Female, Not Injured

Restrain Status: Lap and shoulder belt

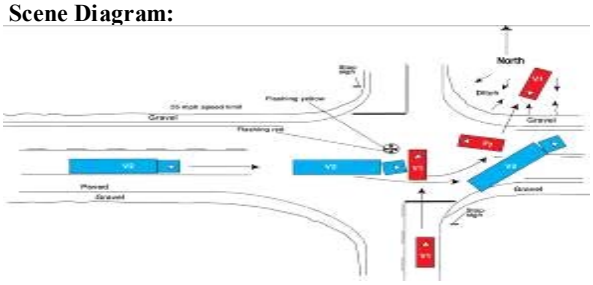
Case Occupant Associated Injuries:

Body Region	Injury Source	Injuries
Face	Flying glass	(AIS 1): Facial Skin laceration minor
Head	**Right side interior surface**	**(AIS 3): Cerebrum subarachnoid hemorrhage**
Head	Right side interior surface	(AIS 1): Scalp laceration minor

Case Number: 426032502 **Near-Side Occupant**

Vehicle Exterior:

Scene Diagram:



V1 (case vehicle), a 1994 Acura Legend, 4-door sedan was traveling north in the northbound lane of a two-lane, two-way bituminous roadway and was approaching a four-leg intersection. V2, a 1993 International tractor-trailer (one trailer) was traveling east in the eastbound lane of the intersecting, two-lane, two-way bituminous roadway. It was daylight, clear weather, and the roadways were dry and free of defects. V1 came to a stop at the four-leg intersection. For an unknown reason, the driver of V1 pulled into the intersection with the intention of moving straight across the intersection and was struck on the left-side by the front of V2. V1 moved laterally and rotated counter-clockwise and exited the northeast corner of the intersection. V1 came to rest off the roadway facing southwest.

Case Vehicle Information:

V1: Acura-Legend, 4-door sedan, hardtop-1994

DOF: 9 O'clock

Delta-V: Total: U Km/h

Lateral: U Km/h Longitudinal: U Km/h

Location of Impact: Left Side

Maximum Intrusion: >=46 to <61 cm, Second Left

Max. Intrusion Corresponding Component (s):

(1) Door panel (side)

Vehicle 2 Information:

International H-Med/Heavy Truck, 1993

Case Occupant Information:

24mo old, Male, height-35" and Weight-20 lbs

Seating Position: Second left

Restrain Status: Lap and shoulder belt

Child Seat Type: Convertible seat

Was Occupant Injured due to Intrusion? Yes

Components: (1) Door panel (side)

Other Occupant (s) in Case Vehicle:

DRIVER: 35yr old, Female, MAIS unknown

Restrain Status: Lap and shoulder belt

Second right: 4yr old, Male, MAIS 1

Restrain Status: Lap and shoulder belt w/CRS

Case Occupant Associated Injuries:

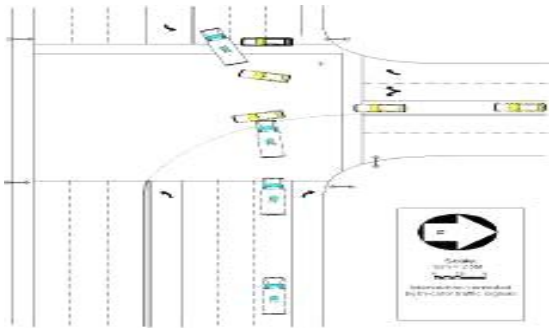
Body Region	Injury Source	Injuries
Abdomen	Left side interior surface	(AIS 2): Spleen laceration minor
Face	Left side interior surface	(AIS 1): Gingiva (gum) contusion
Head	**Left side hardware or armrest**	**(AIS 4): Cerebellum hematoma/hemorrhage**
Head	**Left side interior surface**	**(AIS 4): Cerebrum hematoma/hemorrhage**
Head	Left side hardware or armrest	(AIS 1): Scalp abrasion
Head	Left side hardware or armrest	(AIS 1): Scalp contusion/subgaleal hematoma
Head	Left side hardware or armrest	(AIS 1): Scalp laceration minor
Thorax	Left side interior surface	(AIS 3): Lung contusion unilateral
Upper Extremities	Left side interior surface	(AIS 1): Upper Extremity Skin abrasion

Case Number: : **470047788**

Center Occupant

Vehicle Exterior:

Scene Diagram:



This crash occurred at the three leg intersection of two urban roadways. The east/west roadway consists of seven, undivided, lanes of travel. The north/south roadway consists of five, undivided, lanes and connects to the north side of the larger east/west street. The incident occurred during daylight hours under clear, dry conditions. The case vehicle (V1) was traveling southbound approaching the intersection in the left turn lane intending to turn left. The opposing vehicle (V2) was traveling westbound in the number one lane. As V1 maneuvered into the intersection it was struck on its left side by the front of V2. V1 was pushed directly right to its final rest while V2 skidded straight to its final rest.

Case Vehicle Information:

V1: Ford-Contour, 4-door sedan, hardtop-1998

DOF: Unknown

Delta-V: Total: U Km/h

Lateral: U Km/h Longitudinal: U Km/h

Location of Impact: Left Side

Maximum Intrusion: >=30 to <46 cm, Front Left

Max. Intrusion Corresponding Component (s):

(1) B-pillar (2) Roof side rail

Vehicle 2 Information:

International H-Med/Heavy Truck, 1985

Case Occupant Information:

33mo old, Female, height-38" and Weight-33 lbs

Seating Position: Second middle

Restrain Status: Lap and shoulder belt

Child Seat Type: Convertible seat

Was Occupant Injured due to Intrusion? Yes

Other Occupant (s) in Case Vehicle:

DRIVER: 47yr old, Male, MAIS 5

Restrain Status: Lap and shoulder belt

Second right: 37yr old, Female, MAIS 2

Restrain Status: Lap and shoulder belt

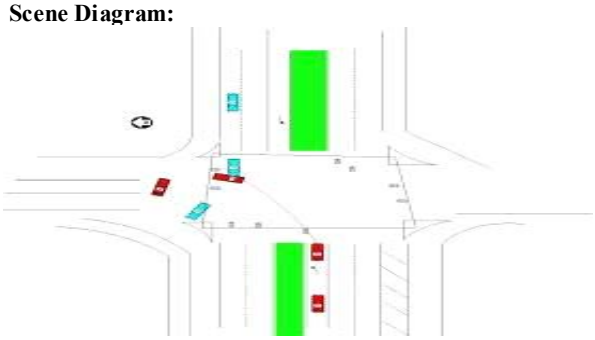
Case Occupant Associated Injuries:

Body Region	Injury Source	Injuries
Face	**Left side window sill**	**(AIS 2): Facial Skin laceration major**
Face	Left side window sill	(AIS 1): Facial Skin laceration minor
Head	**Left side window sill**	**(AIS 2): Cerebral Concussion**
Head	Left side window sill	(AIS 1): Scalp laceration minor
Lower Extremities	Seat, back support	(AIS 1): Lower Extremity Skin contusion
Upper Extremities	Seat, back support	(AIS 1): Upper Extremity Skin abrasion

Case Number: 690040270 **Near-Side Occupant**

Vehicle Exterior:

Scene Diagram:



This crash occurred in the afternoon hours. The roadway was wet with adverse weather conditions. This crash occurred at a four legged intersection properly controlled by overhead traffic control standards. The case vehicle was initially traveling eastbound in the left hand turning lane (lane 3) on a six lane-divided roadway. The non-case vehicle was traveling westbound in the outer curb lane. The case vehicle attempted a left hand turn and was struck by the non-case vehicle within the intersection.

Case Vehicle Information:

V1: Toyota-Corolla, 4-door sedan, hardtop-1994

DOF: 3 O'clock

Delta-V: Total: 48 Km/h (30 Mph)

Lateral: 47 Km/h (29 Mph)

Longitudinal: 8 Km/h (5 Mph)

Location of Impact: Right Side

Maximum Intrusion:

(1) >=30 to <46 cm, Front Right

(2) >=30 to <46 cm, Second Right

Max. Intrusion Corresponding Component (s):

(1)Door panel (side) (2)Door panel (side)

Vehicle 2 Information:

V2: Ford-Ranger, Compact pickup-1988

Case Occupant Information:

46mo old, Male, height-44" and Weight-35 lbs

Seating Position: Second right

Restrain Status: Lap and shoulder belt

Child Seat Type: CSS

Was Occupant Injured due to Intrusion? Yes

Other Occupant (s) in Case Vehicle:

DRIVER: 82yr old, Female, MAIS 1

Restrain Status: Lap and shoulder belt

Second left: 3yr old, Male, MAIS 2

Restrain Status: Lap and shoulder belt w/CRS

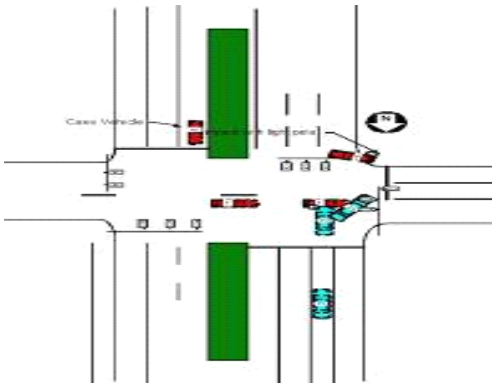
Case Occupant Associated Injuries:

Body Region	Injury Source	Injuries
Abdomen	Child safety seat	(AIS 2): Liver laceration minor
Abdomen	Child safety seat	(AIS 2): Kidney contusion minor
Abdomen	Child safety seat	(AIS 1): Adrenal gland contusion minor
Face	Right side window sill	(AIS 1): Facial Skin laceration minor
Head	Right side window sill	(AIS 2): Scalp laceration major
Lower Extremities	Right side interior surface	(AIS 1): Lower Extremity Skin contusion
Thorax	**Child safety seat**	**(AIS 3): Lung contusion unilateral**

Case Number: 874034767

Vehicle Exterior:

Scene Diagram:



Vehicle #1 (case vehicle, 1997 BMW 318i) was initially traveling northbound and attempted a left turn at a four legged intersection. Vehicle #2 (non-case Vehicle, 1997 Cadillac Seville) was initially traveling southbound in the opposite direction of the case vehicle. Vehicle #1 entered the intersection and was struck on the passenger side by the front of the non-case vehicle. After impact Vehicle #1 rotated clockwise and traveled to final rest after impacting a light standard. It should be noted that the roadway was dark with no street lights and the surface was dry and the weather was clear at the time of the crash.

Near-Side Occupant

Case Vehicle Information:

V1: BMW-3Series, 4-door sedan, hardtop-1997

DOF: Unknown

Delta-V: Total: 80 Km/h (50 Mph)

Lateral: 79 Km/h (49 Mph)

Longitudinal: 14 Km/h (9 Mph)

Location of Impact: Right Side

Maximum Intrusion: >=61 cm, Second Right

Max. Intrusion Corresponding Component (s):

(1) Door panel (side)

Vehicle 2 Information:

V2: Cadillac-Seville, 2-door sedan, hardtop, coupe-1997

Case Occupant Information:

40mo old, Male, height-38" and Weight-35 lbs

Seating Position: Second right

Restrain Status: Lap and shoulder belt

Child Seat Type: Booster seat

Was occupant Injured due to Intrusion? Yes

Components:

(1) Door panel (side)

Other Occupant (s) in Case Vehicle:

DRIVER: Female, MAIS unknown

Restrain Status: Lap and shoulder belt

7yr old, Male, MAIS unknown

Restrain Status: Unknown

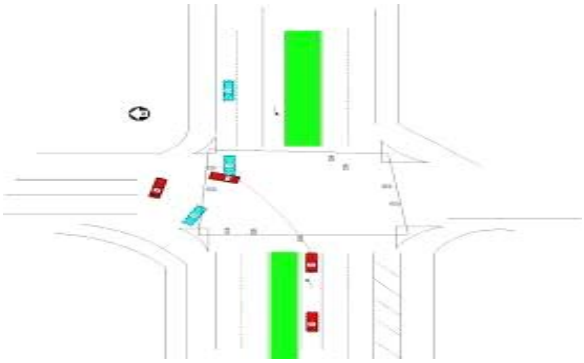
Case Occupant Associated Injuries:

Body Region	Injury Source	Injuries
Face	Right side interior surface	(AIS 1): Facial Skin laceration minor
Face	Right side interior surface	(AIS 1): Gingiva (gum) laceration
Head	Right side interior surface	(AIS 1): Scalp contusion/subgaleal hematoma
Lower Extremities	Child safety seat	(AIS 2): Pelvis fracture closed
Thorax	**Right side interior surface**	**(AIS 4): Lung contusion bilateral**

Case Number: 874037095

Vehicle Exterior:

Scene Diagram:



This crash occurred in the afternoon hours. The roadway was wet with adverse weather conditions. This crash occurred at a four legged intersection properly controlled by overhead traffic control standards. The case vehicle was initially traveling eastbound in the left hand turning lane (lane 3) on a six lane-divided roadway. The non-case vehicle was traveling westbound in the outer curb lane. The case vehicle attempted a left hand turn and was struck by the non-case vehicle within the intersection.

Far-Side Occupant

Case Vehicle Information:

V1: Toyota-Corolla, 4-door sedan, hardtop-1994

DOF: 3 O'clock

Delta-V: Total: 48 Km/h (30 Mph)

Lateral: 47 Km/h (29 Mph)

Longitudinal: 8 Km/h (5 Mph)

Location of Impact: Right Side

Maximum Intrusion:

(1) >=30 to <46 cm, Front Right

(2) >=30 to <46 cm, Second Right

Max. Intrusion Corresponding Component (s):

(1)Door panel (side) (2)Door panel (side)

Vehicle 2 Information:

V2: Ford-Ranger, Compact pickup-1988

Case Occupant Information:

28mo old, Female, height-U" and Weight-33 lbs

Seating Position: Second left

Restrain Status: Lap and shoulder belt

Child Seat Type: CSS

Was Occupant Injured due to Intrusion? No

Other Occupant (s) in Case Vehicle:

DRIVER: 82yr old, Female, MAIS 1

Restrain Status: Lap and shoulder belt

Second right: 3yr old, Male, MAIS 3

Restrain Status: Lap and shoulder belt w/CRS

Case Occupant Associated Injuries:

Body Region	Injury Source	Injuries
Upper Extremities	**Other restraint system component**	**(AIS 2): Ulna fracture closed**
Upper Extremities	Other restraint system component	(AIS 1): Upper Extremity Skin laceration minor

Four Years of Enhanced Child Restraint Data Collection in NASS CDS

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Paper Number 07-0235

ABSTRACT

In 2002, the National Highway Traffic Safety Administration's (NHTSA's), National Automotive Sampling System (NASS) improved its child safety data collection for the Crashworthiness Data System (CDS) by having each primary sampling unit (PSU), location, dedicate one data encoder to child safety issues. In turn, NASS data encoders took the PSU source data and created the CDS data entries. These CDS data were obtained via crash scene and vehicle inspections supplemented with occupant interviews and medical records, when available. Consequently, the NASS encoders were trained extensively on child safety seat technologies, as well as their installation and placement, and new variables and attributes were defined. The new variables and attributes allow encoders to describe fully the child safety seat within the vehicle during the crash, from post crash occupant interview and vehicle inspection. The expanded data compiles real-world crashes involving child occupants, providing a unique data set useful to NHTSA as well as the whole child occupant protection community.

This paper presents a description of the new data collection process, the new variables, and a first look at the analyses possible with the new data set.

BACKGROUND

Each year CDS collects detailed information on a nationally representative, random sample of police-reported, tow away traffic crashes involving passenger cars, light trucks, and vans. The bulk of this detailed information supports research into the crashworthiness of passenger vehicles, biomechanics of occupant trauma, and the development of test procedures and criteria. CDS data also supports the rationale for and development of motor vehicle safety standards and consumer information programs related to occupant protection.

INTRODUCTION

Beginning in 2002, the child safety data collection was revised for NASS CDS data sets. As before, child safety seat type may be identified, however, the archaic coding and formatting inconsistencies have been removed from the enhanced data sets. This was accomplished by encoding a more thorough understanding of the child safety restraint systems and the injury patterns for the restrained or inadequately restrained child.

NASS CDS has kept pace with newer technologies, and is continually assessed, and, when necessary, improved for its information collection practices. From these assessments, child restraint data collection methodologies have changed; most recently of note is the latest modification to the child restraint interview form (Murianka, 2005). This modification considered 4 years of real world data collection practices resulting in the development of a more appropriate tool for encoders to rely upon when eliciting information regarding a restrained child occupant.

With these modifications, the quality of the data continues to improve so that child safety seat information is continually considered and accurately reported.

This paper is designed to introduce the child safety community and the public to the child safety CDS enhancements expected to be released. It also provides guidance with respect to companion resources for the data.

The new child safety data sets since 2002 have not been made available to the public yet because an exhaustive quality control must be exercised for release of NASS, which has not yet been completed. For the purposes of this paper, however, the authors provided exhaustive quality control on the data presented. Although a true statistical analysis may not be undertaken owing to the small case counts available for study, an anecdotal demonstration of the new variables is possible. In sum, the paper only deals with data that would be ready for release;

however, the entire data set must be released together in accordance with practices followed by The National Center for Statistics and Analysis governing the NASS data. The variables and attributes populating the data set have been in place and approved since 2002.

Changes Since 2002

In 2002, the Child Restraint Interview Form was changed from a 1-page document to 12 pages, due to the addition of numerous questions, which would help the field researcher/analyst determine specifics about a child seat and its use when the child seat involved in the crash was no longer available and a telephone interview was the only option. It is fairly common for the child seat involved in the crash to be destroyed, thereby creating a situation where the parent/caregiver must rely on memory and familiarity of the child restraint in answering questions regarding its type and use. To avoid reuse subsequent to a crash, the destruction of the child seat is an accepted practice.

In 2005, the Child Restraint Interview Form was again revised eliminating many of the questions (answers to which were not coded in CDS) in order to assist better the field researchers in their information gathering as well as not to burden crash occupants unnecessarily. The current interview consists of 4 total pages, one of which is a graphic reference of child seat types providing a visual for in-person interviews when the child seat is no longer available.

In the summer of 2005, it was decided that a core group of field researchers would be selected, who would be assigned as "primary" researchers on child seat cases at their respective site. The impetus for this was two fold: specific trainings could be tailored to the needs of those conducting child seat interviews and inspections, resulting in the coding of fewer "Unknown" and "Other" data attributes

The CDS currently has 27 field researchers, a representative from each of the 27 field research teams, dedicated to crashes selected at their site involving a child restraint. In the spring of 2006, this core group of researchers received special child restraint training, which focused on interviewing techniques, and hands-on inspection of crash-involved child restraints.

Child restraint cases make up a small portion of all cases collected each year in CDS, as shown in Table 1. Note that in 2005, 4,481 cases were coded with only 234 cases involving one or more child restraints. Further, note that there are sometimes more than one child seat involved in a given crash case. For example, in 2005, there were 293 child seats involved in the 234 cases. The yearly totals dating back to 1999 are also listed in Table 1. The new data provides for better understanding of these seats and how they performed.

PROCEDURES

The CDS program utilizes trained field researchers to collect details on a limited number of crashes involving new and rapidly changing occupant protection technologies. In 2002, new and updated data collection methodologies related to child occupant restraints were incorporated into the NASS, CDS, Electronic Data Collection System. Major revision to certain data collection and coding tools were incorporated, for example., enhanced Child Restraint Interview Form, child seat make/model pick-list, as well as detailed information regarding the child seat installation using the vehicle belt system or Lower Anchors and Tethers for Children (LATCH).

An in-depth, 8-hour child restraint and safety belt training was provided to all field researchers prior to the 2002 data collection year. This training built upon the introductory/initial child seat and safety belt training each researcher receives during their basic training. A child seat and safety belt update training session has been provided to all field researchers during every year-end training through 2005.

In the most recent data year available, 2005, the CDS had 27 field research teams and 76 field researchers collecting data from about 4,500 crashes, 234 of which involved a child restraint. The CDS currently collects and codes crash information involving over 600 data elements obtained during on-site crash scene inspections and exterior and interior vehicle inspections. In-person and over the telephone interviews are also conducted with individuals involved in the crash and pertinent injury and medical records are obtained for those occupants injured and who sought medical treatment. Interviews with crash victims entail questions dealing with pre and post-crash events as related to all occupants of the vehicle. Details regarding each occupant, for example, seating position, restraint type available, and use, along with any available medical/injury information, are collected and coded into each case.

Data Summarization

The usage of child restraints is of paramount importance; however, many misconceptions exist with respect to the selection, installation, age appropriateness, and finally graduation to an adult restraint system. Historically and as a convenience child safety advocates have used singular measures of age, height, or weight. It must be considered, however, that the current demographic make up of the children in the United States does not fit one profile. For this reason, NHTSA provides guidelines for appropriate usage by age, weight, and seating position.

The children reported in the NASS CDS enhanced reporting were separated into age categories specified by the authors. This segmentation was based upon a rough age range for graduation to the booster seat and subsequent movement to vehicle-installed restraint systems. The restraint usage categories were assessed based upon the child safety seat type and the manual restraint usage. Age, manual restraint usage and child safety seat type are variables found in the NASS CDS Coding Manual (DOT, 2000), as well as the electronic case access. The child safety seat type variable in NASS CDS identifies type of child safety system relevant to the case child occupant. If the child was unrestrained, as dictated by the manual restraint usage, then the child was categorized as unrestrained.

New or Enhanced Variables

With the advent of the expanded data sets, the new understanding and fuller reporting could be captured in unique research data sets. Previously, the NASS CDS reported any child seat information with general occupant demography. In the new data set, the presence of a child safety seat is reported at the occupant level and acts as a flag. This flag indicates that relevant information will be placed in the child safety seat data set. The child safety data set contains information relevant to the placement of the seat with respect to the vehicle seating positions, orientation, and position of occupant. In addition, the presence and design of LATCH, child restraint harness, and harness chest clip are reported.

Child Occupant Demography with respect to Age and Restraint Usage

The enhanced data sets allow for finer disaggregation of the data with respect to demography. One modification has been to the units of age, as shown in Table 2.

In children less than three years old, development from month to month becomes more meaningful when assessing the crash outcome. Further, the gradation, with respect to biomechanical tolerance, from birth to one year old is more crucial than the 12-month increments after the age of three years. Table 2 segments child occupants, without respect to their restraint usage, into months from birth through two years and years for children 3 through 12 years.

Few automotive manufacturers continue to produce child restraints specifically designed for their vehicles. Although limited data exists regarding the benefit of proprietary versus commercially produced child safety seat systems, and while the benefit of children placed in any child safety system has been proven, integration of the technology makes sense conceptually. Nevertheless, restraint usage must be a key consideration in analyzing child safety.

For example, the child who benefited from one of the child safety seat types, and was less than ten years old, was considered to be restrained. If the child was 10 through 12 years at the time of the crash, and was deemed to be restrained by virtue of the manual restraint usage, an active restraint usage characterization reported in NASS CDS, then the child was said to be restrained. Finally, children who were restrained by some other means than a child safety system were considered restrained by an age inappropriate device. It must be recalled that the child safety seat couples with the vehicle restraint system, at the most generic level, as specified by NHTSA. For this reason, both the manual restraint usage, an observation of active restraint usage, and the child safety seat usage must be considered when determining the restraint status of a child.

Results for newborn children through 3 years old keep with the messages suggesting that caregivers are restraining smaller children. As previous mandates dictated, restraint by any means would be better than no restraint at all. In keeping with this mandate nearly one-third of children benefited from a caregiver who took some action. This by no means assures the occupant outcome and this will be addressed in subsequent sections of this paper.

For children 4 through 7 years old, it should be noted that two issues exist with segmentation of few years of data. The cell size may suffer because the children of this age range are not being injured or merely because the sampled cases did not have vehicles transporting this age group. In studying this group, this must be considered. Unrestrained children do

increase from the previous age range, as well as those who are inappropriately restrained. The inappropriately restrained children may have been subjected to a premature graduation from a child restraint to a vehicle-installed restraint system.

The children of age 8 and 9 years were segmented because this marks a graduation of many children regardless of their readiness. Questions of peer pressure and parental involvement may also be suggested as potential reasons for this decrease.

The oldest age group, 10 through 12 years, was retained for comparative purposes in this section only. These were deemed to be the group that would be subject to a generally justifiable graduation to a vehicle-installed restraint system.

It should be noted that children of 9 years and less were reported to have used a child safety seat. Children above this age were reported to have used a vehicle-installed restraint or were unrestrained, as seen in Table 3.

With benefit of greater training and experience, NASS CDS researchers may discern the subtleties of seemingly similar child restraints. This information may be coupled with manual restraint usage data to understand better the restraint usage habits of children from birth through 12 years old.

Based upon the enhanced and tailored training of NASS researchers and stringent quality control standards, several conclusions may be reached based upon the child safety seat disaggregation. First, young children are generally placed in age-appropriate child safety seats, and these are used according to manufacturer recommendations. Further, children of 4 through 7 years old, follow a similar pattern. With an eye toward cell size and children of ages 8 through 9 years not being captured in the sampling design of NASS CDS, approximately 8 percent of children are unrestrained. More than 90 percent of this age group is transported in some sort of restraint system. Less than one percent of this age group makes use of an age appropriate system. In trying to understand such findings, this leaves researchers with the question of early graduation versus robustness of children of this age warranting graduation.

Prior to 2002, older formatting was retained and accurate characterization of booster seats was not possible. Additionally, archaic child seat types were eliminated and better definitions were provided for the child restraints, per Table 4.

In the new data set, improved descriptions have become available with respect to harness design. Previously, analysts imagined configuration of the child restraints based upon the child safety seat. Currently, it is possible to identify harness, clip, tether, and latch design, as seen in Table 5.

Placement of Child Safety Seat

Another variable allowing for better characterization of the child safety seat is the placement variable, as shown in Table 6. This allows for the precise location of the child seat with respect to the vehicle interior.

In cases where a placement was other than the seat, consultation of other relevant variables might be necessary to understand fully the circumstance. Further, as with any other interview tool, the researchers must rely upon cooperation from the crash occupant and their ability to elicit appropriate information from the interviewee.

With nearly 90 percent of child restraints reported on the vehicle seat, installation issues may be ebbing. However, concern rests with the remaining ten percent that were found on the floor or an unknown location. The unknown location may stem from the absence of a vehicle/child restraint inspection, or lack of crash occupant interview. It should be noted that this is only one element that might be considered when assessing improper restraint usage and installation. Prior to 2002, improper restraint usage was reported in the data set, as determined by the CDS researcher based upon experience. The enhanced variables and attributes allow the data user to characterize proper restraint usage by interpreting the encoded child safety seat data encoded.

Orientation of the child with respect to the safety seat is a further enhancement to this description. The child orientation may be described, per Table 7.

The orientation might be used to signal problems of child placement. For instance, with the accompanying variables describing the child seat make and model, it might be possible determine the validity of the caregiver's installation of the car seat and the child within the car seat.

Child Safety Seats and Occupant Injury Severity

Historically, the use of child restraint systems has been the preferred child protection. During recent years, the idea of some restraint system being better

than nothing has been considered. By consensus, however, unrestrained children are the most vulnerable, per Table 8.

Among children, birth through 12 years old, less than ten percent are unrestrained. Further, less than one percent of the child occupant population sustains critical or maximum injuries. The unrestrained children sustain the majority of MAIS 5 and 6 injuries. This is followed by those children who graduate early to lap and shoulder belts.

Table 9, provides evidence for the age appropriate restraint usage. Among occupants restrained by a child safety seat, less than one percent sustains MAIS 5 or 6 injuries. More than 50 percent of those occupants sustaining critical and maximum injuries were restrained by an unknown type of child restraint. This reinforces the message in support of age-appropriate child restraints.

SUMMARY

As introduced in Murianka (2005), the enhanced data sets were unavailable for the public at the time of publication. However, in December 2006, these data sets were made available to the authors under the condition of use for the quality-controlled segments of the data set. The exhaustive review of the child safety data made this possible. At this moment, the remaining portions of the data set are undergoing rigorous quality control to ensure accurate codification of the data, as dictated by NASS data release practices.

At this stage in data collection, the child safety data contained in the enhanced data set may be considered for anecdotal representation. Although weighting factors accompany each record as set forth by the sampling design, reliance on the differences in frequency amongst any of these attributes would be reckless owing to the small cell sizes found upon disaggregating the data. With the accumulation of added years of data, tests of significance might be applied to reach meaningful conclusions.

The data eventually will allow the safety community to identify child passenger restraint usage. Among those children who benefit from child safety systems additional data will be available relevant to the technologies used, the child seat and vehicle interaction, and the occupant interaction with the child safety system.

CASE AVAILABILITY

As previously, electronic case files may be accessed via the NHTSA website, Electronic Case Access Screen. The hyperlink is as follows: http://www-nrd.nhtsa.dot.gov/departments/nrd-30/ncsa. This allows users to obtain elements that might not be available in the 11-file SAS data sets, also available on the NHTSA website.

REFERENCES

Association for Advancement of Automotive Medicine, Abbreviated Injury Scale (AIS) 1990 - Update 98, Barrington, 1998.

United States Department of Transportation, National Highway Traffic Safety Administration, National Automotive Sampling System, Crashworthiness Data System, 2002-2005, NHTSA, Washington, D.C.

United States Department of Transportation, National Highway Traffic Safety Administration, "National Automotive Sampling System, Crashworthiness Data System, 2000 Coding and Editing Manual", NHTSA, Washington, D.C.

Table 1: Number of Cases Coded in NASS CDS, Unweighted Data			
YEAR	**Total # of CDS Cases**	**Child Seat Cases**	**# of Child Seats Coded**
1999	4,274	182	230
2000	4,307	210	248
2001	4,090	188	220
2002	4,589	225	279
2003	4,754	219	276
2004	5,624	271	351
2005	4,481	234	293

Table 2: NASS CDS Occupants, in Years and Months, 2002 - 2005			
Age in Years	**Age in Months**	**Total Occupants, Raw**	**Total Occupants, Weighted**
0	1 - 3	72	26,618
0	4 - 6	70	27,091
0	7 - 9	72	37,646
0	10- 12	155	79,896
1	13 - 15	35	12,848
1	16 - 18	64	27,452
1	19 - 21	55	25,211
1	22 - 24	333	137,374
2	25 - 27	1	387
2	28 - 30	3	452
2	31 - 33	0	0
3	34 - 47	296	112,849
4	48 - 59	259	95,566
5	60 - 71	267	95,520
6	72 - 83	275	127,092
7	84 - 95	270	96,869
8	96 - 107	274	148,051
9	108 - 119	273	116,490
10	120 - 131	268	142,111
11	132 - 143	260	75,132
12	144 - 155	280	156,002
Total		3,582	1,540,659

Table 3 Annualized NASS CDS Occupants, in Years and Months, NASS CDS					
Restraint Usage	**Birth through 3 Years**	**4 through 7 Years**	**8 through 9 Years**	**10 through 12 Years**	**Total**
Unbelted	7,638	12,157	5,226	11,952	36,973
Child Safety Seat	101,888	24,712	625	0	127,225
Lap and Shoulder Belt	6,380	49,329	48,864	71,087	175,660
Other or Unknown	6,051	17,563	11,421	10,273	45,307
Total	121,957	103,762	66,135	93,311	385,165

Table 4: Annualized Child Safety Seat Usage, Children Birth through 9 Years, NASS CDS, 2002 - 2005				
Child Safety Seat	**Birth through 3 Years**	**4 through 7 Years**	**8 through 9 Years**	**Total**
Convertible Seat, CSS	40,511	1,881	0	42,393
Forward Facing Only, FSS	13,797	5,881	150	19,828
Infant Seat, ISS	13,944	0	0	13,944
Booster Seat, BSS	12,356	13,463	468	26,287
Integrated Seat, INT	359	167	0	526
Special Needs, SNSS	0	20	0	20
Booster/Forward Facing Seat, BSS/FSS	0	31	0	31
Booster Seat/ Convertible Facing Seat, BSS/CSS	3	0	0	3
Other or Unknown	23,646	4,770	7	28,422
Total	104,616	26,214	625	131,455
Note: Child Safety Total is slightly different owing to rounding, and variable and attribute combination				

Table 5: Description of Design Aspects Available in Enhanced NASS CDS			
Table 5a: Attributes Relevant to Harness	**Table 5b: Attributes Relevant to Clip**	**Table 5 c: Attributes Relevant to Tether**	**Table 5d: Attributes Relevant to Latch**
Three point	No clip available (OR Not Designed with Harness Retainer Clip)	No tether available (OR Not designed with Tether)	No LATCH available (OR Not designed with LATCH)
Five Point	Clip available (OR Designed with Harness Retainer Clip)	Tether available (OR Designed with Tether)	LATCH available (OR designed with LATCH)
T-Shield	Unknown	Unknown	Unknown
Tray Shield			
Shield			
No harness/shield available (OR Not designed with harness/shield)			
Unknown			

Table 6: Annualized Child Seat Placement, Birth through 12 Years, NASS CDS 2002 - 2005				
Child Safety Seat	**Seat**	**Floor**	**Other or Unknown**	**Total**
Convertible Seat, CSS	50,237	101	73	50,411
Forward Facing Only, FSS	21,434	194	48	21,676
Infant Seat, ISS	13,897	317	111	14,324
Booster Seat, BSS	29,306	5	143	29,454
Integrated Seat, INT	1,039	0	160	1,198
Special Needs, SNSS	20	0	0	20
Booster/Forward Facing Seat, BSS/FSS	39	0	0	39
Booster Seat/ Convertible Facing Seat, BSS/CSS	7	0	0	7
Other or Unknown	19,446	0	12,535	31,981
Total	135,424	617	13,070	149,110
Note: Child Safety Total is slightly different owing to rounding, and variable and attribute combination				

Table 7: Annualized Child Seat Orientation, Children Birth through 12 Years, NASS CDS, 2002 - 2005					
Child Safety Seat	**Rear Facing**	**Forward Facing**	**Supine**	**Other or Unknown**	**Total**
Convertible Seat, CSS	5,128	41,429	0	3,854	50,411
Forward Facing Only, FSS	0	21,360	0	316	21,676
Infant Seat, ISS	13,643	344	150	187	14,324
Booster Seat, BSS	0	27,716	0	1,738	29,454
Integrated Seat, INT	0	1,198	0	0	1,198
Special Needs, SNSS	0	20	0	0	20
Booster, Forward Facing Seat, BSS/FSS	0	39	0	0	39
Booster Seat/ Convertible Facing Seat, BSS/CSS	0	7	0	0	7
Other or Unknown	2,540	8,715	0	20,727	31,981
Total	21,310	100,827	150	26,822	149,110
Note: Child Safety Total is slightly different owing to rounding, and variable and attribute combination					

Table 8: Annualized Child Safety Seat Usage, by Maximum Injury Severity, Children Birth through 9 Years, NASS CDS, 2002 - 2005									
Child Safety Seat	Uninjured MAIS 0	Minor MAIS 1	Moderate MAIS 2	Serious MAIS 3	Severe MAIS 4	Critical MAIS 5	Maximum MAIS 6	Other or Unknown MAIS 7, 9	Total
Unrestrained	15,868	16,062	2,299	1,319	469	197	41	718	36,973
Child Safety Seat	99,159	22,229	706	207	190	81	43	4,610	127,225
Lap and Shoulder Belt	121,652	49,983	2,250	476	137	105	18	1,034	175,654
Other or Unknown	28,401	11,156	830	205	60	13	11	4,631	45,307
Total	265,079	99,429	6,086	2,207	856	396	113	10,992	385,159

Table 9: Annualized Child Safety Seat Usage, by Maximum Injury Severity, Children Birth through 9 Years, NASS CDS, 2002 - 2005									
Child Safety Seat	**Uninjured MAIS 0**	**Minor MAIS 1**	**Moderate MAIS 2**	**Serious MAIS 3**	**Severe MAIS 4**	**Critical MAIS 5**	**Maximum MAIS 6**	**Other or Unknown MAIS 7 or 9**	**Total**
Convertible Seat, CSS	32,804	6,418	72	45	5	11	2	3,037	42,393
Forward Facing Only, FSS	14,508	5,008	77	94	124	13	0	5	19,828
Infant Seat, ISS	11,948	1,783	125	10	20	32	25	0	13,944
Booster Seat, BSS	20,579	5,536	98	21	44	3	0	6	26,287
Integrated Seat, INT	463	40	9	11	0	0	0	3	526
Special Needs, SNSS	20	0	0	0	0	0	0	0	20
Booster/Forward Facing Seat, BSS/FSS	31	0	0	0	0	0	0	0	31
Booster Seat/ Convertible Facing Seat, BSS/CSS	0	3	0	0	0	0	0	0	3
Other or Unknown	21,589	4,832	347	37	10	24	20	1,564	28,422
Total	101,943	23,621	727	218	203	81	47	4,615	131,455
Note: Child Safety Total is slightly different owing to rounding, and variable and attribute combination.									

REVIEW OF THE DEVELOPMENT OF THE ISO SIDE IMPACT TEST PROCEDURE FOR CHILD RESTRAINT SYSTEMS

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ABSTRACT

Side impacts are frequent and can pose a hazard for children travelling at the struck side in passenger cars. Although the number of seriously injured children has decreased during the last decades, there is still a considerable risk especially for head, neck and thorax injuries.
ISO/TC 22/SC12/WG 1 (working group on child safety inside passenger cars) has been working on the definition of a side impact test procedure for child restraint systems for a number of years, taking into account other side impact test procedures for CRS (child restraint system) already implemented in some countries.
This paper is a comprehensive summary of accident data (from USA and Europe), boundary conditions to be recognised for the definition of a side impact test procedure for CRS (crash worthiness, geometry, etc.) and current side impact test procedures. Special emphasis is given to the design specification for a suitable test procedure with respect to loading conditions and test severity based on full-scale test data. The paper is based on a recent ISO Technical Report, which is a comprehensive base for the future ISO test procedure development.

INTRODUCTION

ISO/TC 22/SC12/WG1 has been working on the definition of a side impact test procedure for child restraint systems. After meeting the deadline for finalisation of a third DIS (Draft International Standard) version and with disapprovals (by a small margin) of the previous two DIS votings, it was decided to finalise the current project with a Technical Report and to restart the process of developing an international standard.
The aim of this report is to summarise the work done within ISO, and to collect additional relevant information to form a solid base for the restarted project.
This paper repeats the most important parts of the Technical Report. In addition the current status of the ISO side impact test procedure for CRS standardisation is summarised.

ACCIDENT STATISTICS

The severity of injuries in side impacts depends on the seating position. It can be noticed that the severity of injuries is much higher for children sitting on the struck side than sitting on the non-struck side. The share of injuries on the non-struck side is comparable to frontal impacts, while the

injury probability is much higher in struck side accidents, see Figure 1.

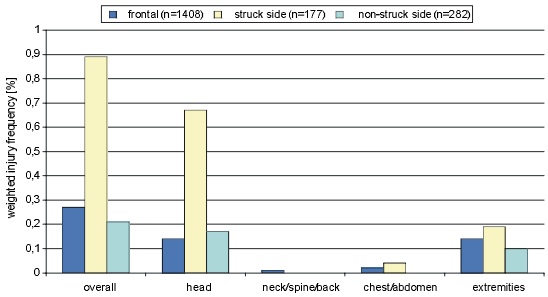


Figure 1. Injury frequency depending on the impact direction [Arbogast, 2004].

Even when analysing all lateral impact accidents the relative number of children suffering MAIS 2+ injuries is much higher than for other impact directions, see Figure 2.

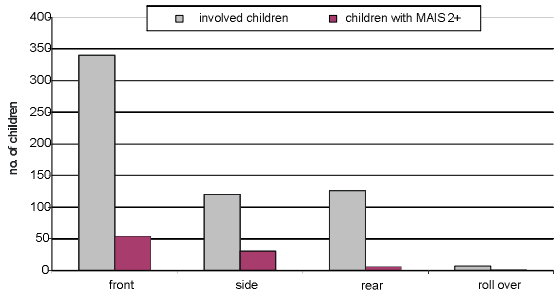


Figure 2. Share of different impact directions [Langwieder, 2002].

Regarding the different body regions the risk for severe injuries decreases from the head down to the legs. The frequently observed injuries of arms and legs are not of high severity, but may cause long term impairments. The focus for investigations concerning improvements of CRS should be on the head, neck and thorax, see Figure 3.

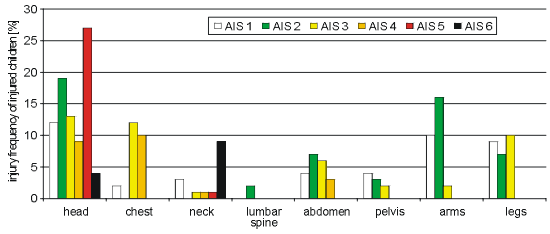


Figure 3. Injury risk of different body regions of 68 injured children in side impacts [Langwieder, 1996].

Looking at the development of injuries in lateral impacts from 1985 to 2001 in Germany it is obvious that the injury probability decreased since 1985 while the risk to suffer neck injuries increased and the chest remained unchanged, see Figures 4, 5 and 6.

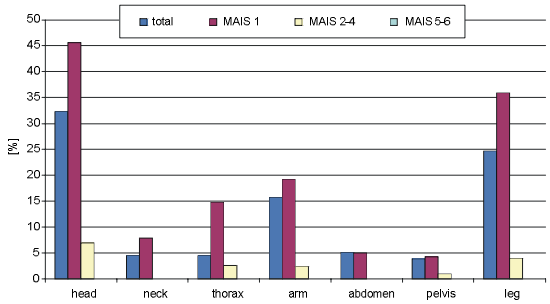


Figure 4. Injury probability of different body regions in side impact accidents between 1985 and 1990 [Otte, 2003].

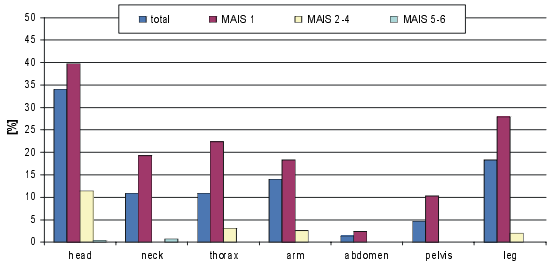


Figure 5. Injury probability of different body regions in side impact accidents between 1991 and 1996 [Otte, 2003].

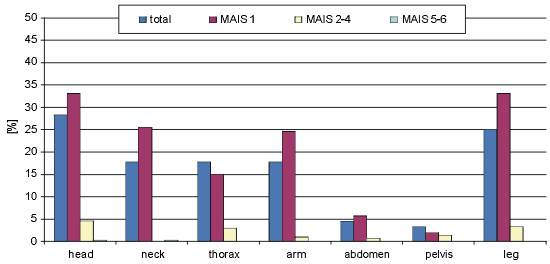


Figure 6. Injury probability of different body regions in side impact accidents between 1997 and 2001 [Otte, 2003].

The presented accident shows that side impact accidents are severe ones especially for those children sitting at the struck side. Especially head, neck and chest need to be protected.
In a study of the Swedish accident situation Jakobsson et al. [Jakobsson, 2005] did not find any moderate-severe (AIS2+) head injuries in children using rear-facing (RF) CRS involved in lateral impact accidents, while children using forward facing (FF) booster seats or the car belt only suffered from moderate-severe injuries (AIS2+) in side impacts. Comparing the injury risk for RF and FF CRS in frontal and lateral impact accidents of NASS Data (US American accident data base) of the years 1988 to 2003 Crandall et al. [Crandall, 2005] observed a ratio of 4.32 in favour of RF seats. The ratio was felt to be larger than expected.

SIDE IMPACT TEST METHODS FOR CARS

The full-scale test methods have been validated against the real world accident conditions in the specific regions. We can therefore utilise these test methods in the development of the child side impact test procedure.

European Side Impact Test Methods

In Europe the compulsory side impact test method is described in ECE R95. In addition Euro-NCAP defined a side impact test procedure, which is similar to ECE R95.

ECE R95 - A moveable deformable barrier (MDB) strikes the test car with a velocity of 50 km/h in an angle of 90°. The barrier has a weight of 950 kg and a width of 1500 mm. The deformable element has a ground clearance of 300 mm. The centre line of the MDB should match with the X position of the hip point of the 95-percentile dummy (R-point). A Euro SID dummy is positioned in the driver's seat. No child dummies are prescribed for ECE R95.

Euro-NCAP Lateral Test - The Euro-NCAP side impact test protocol is in most parts similar to that of ECE R95. The most important differences to ECE R95 are that an ES2 dummy is used in the front driver's position and child dummies are used in the rear. The two following opportunities for the CRS installation are possible:

- P1.5 on the struck side and P3 on the non struck side;
- P1.5 on the middle rear seat and P3 on the struck side.

If a head protection system is available in the car, it can be tested in a pole test. The car travels with a velocity of 29 km/h laterally into a rigid pole with a diameter of 254 mm. No child dummies are used in this test.

US Side Impact Test Methods

The compulsory side impact test method in the US is defined in FMVSS 214 and 201. In addition consumer tests are defined by US-NCAP and IIHS.

FMVSS 214 - A crabbed barrier hits with a velocity of 54 km/h the stationary test car, see Figure 7. Because of the 27° angle of the barrier the velocity has a theoretical component of 48 km/h in the car Y-direction and 25 km/h in car X-direction. The X component should simulate that the struck car is moving in normal lateral accidents. The barriers face has a width of 1676 mm and a ground clearance of 279 mm. The "bumper part" of the deformable element has a ground clearance of 330 mm. The mass of the trolley is 1368 kg. US SID dummies are used at the front and rear struck side seat. No child dummies are tested according to FMVSS 214.

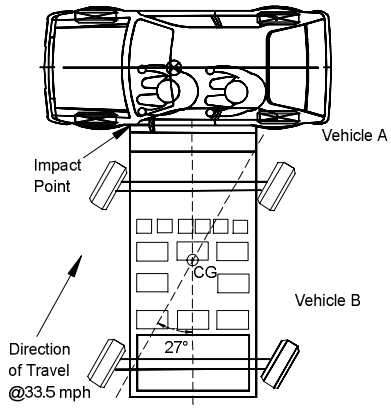


Figure 7. Impact configuration according to FMVSS 214 [NHTSA, 2003].

FMVSS 201 describes a pole test, which formed the basis for the Euro-NCAP pole test described above.

US-NCAP Lateral Test - The US-NCAP side impact test procedure is analogous to the FMVSS 214 protocol. The main difference is that the impact speed is 5 mph higher in the NCAP test compared to FMVSS 214. This means an impact velocity of 62 km/h representing 55 km/h in car Y direction and 30 km/h in X direction.

IIHS Lateral Test - The Insurance Institute for Highway Safety (IIHS) defined a more severe side impact procedure, which should represent accidents with SUV.
A trolley with a mass of 1500 kg hits the car in a purely lateral impact with a velocity of 50 km/h. The ground clearance of the barrier face is 379 mm, while the ground clearance of the bumper element is 430 mm. The shape of the barrier element shall comply with the front end shape of SUV's, see Figure 8. Two SID-II dummies are used in the front and rear seats on the vehicle's struck side. No child dummies are used in the IIHS side impact test.

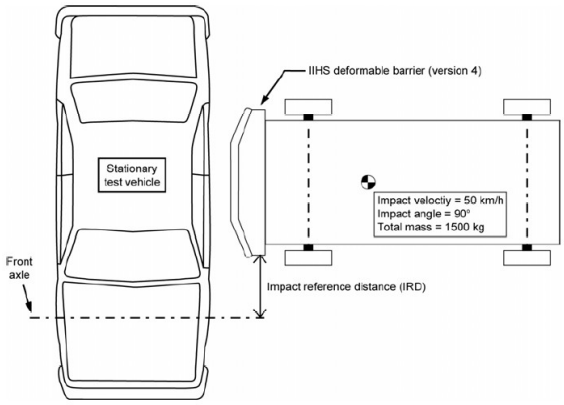


Figure 8. Test configuration in IIHS side impact test [IIHS, 2005].

Japanese Side Impact Test Method

In Japan, ECE R95 (see above) is used for compulsory side impact tests. J-NCAP utilises Euro-NCAP side impact test method (see above) with some changes. The most important within this context are:

- Test speed is 55 km/h;
- No child dummies are prescribed.

Australian Side Impact Test Method

The compulsory side impact test for cars in Australia is defined by ADR72, which is equal to ECE R95 (as described above). The Australian consumer test programme (ANCAP) follows in most parts the protocols of Euro-NCAP (see above). However, no child dummies are tested in the rear seat.

CHILD RELATED PROPERTIES OF CAR SIDE IMPACT TEST METHODS

In several full-scale crash tests according to ECE R95 performed in the last ten years, dynamic lateral intrusions of front and rear doors were measured. The sample includes super minis, family cars, executive cars and mini multi-purpose vehicles of the model years from 1990 until 2004. Both two-door and four-door cars are included. In the last tests the revised deformable barrier face according to EEVC/WG 13 was used. In all test the lateral intrusion of the inner part of the doors was measured with a string potentiometer or a cross tube positioned at the middle of the door. Intrusion velocities were calculated from the intrusion time history diagrams. For comparison, car-to-car test results are analysed too.

Door Intrusion Depth

The maximum intrusion depth of the front door varies from 180 mm to 310 mm, whereas the newer vehicles have lower intrusions (Figure 9).

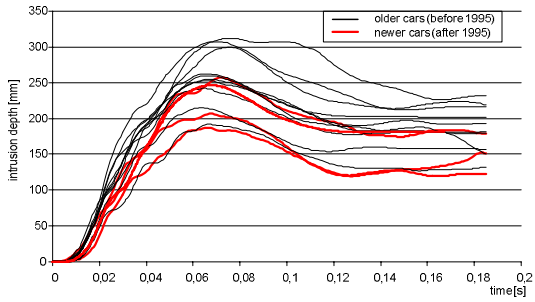


Figure 9. Front door intrusion depth in according to ECE R95 [Johannsen, 2005].

It can be seen that the maximum intrusion depth of the rear door varies from 170 mm to 280 mm, which indicates that the intrusion depth is lower at the rear door compared with the front door (Figure 10).

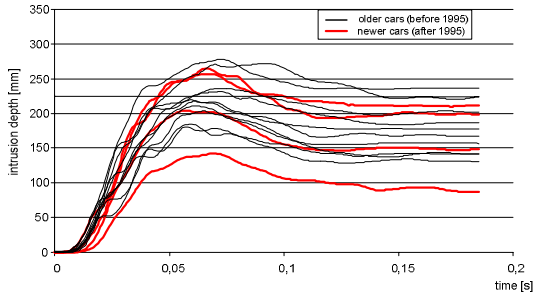


Figure 10. Rear door intrusion depth in side impact tests according to ECE R95.

Door Intrusion Velocity from ECE Tests

Regarding the intrusion velocity a comparable result can be observed. The intrusion velocity is again lower at the rear door compared with the front door.

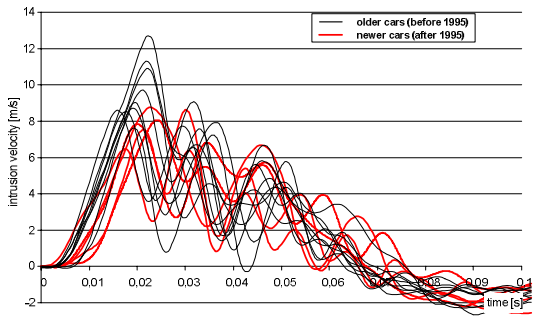


Figure 11. Front door intrusion velocity in tests according to ECE R 95 [Johannsen, 2005].

The intrusion velocity at the front door shows a range between 8 and 13 m/s (Figure 11), while the

intrusion velocity at the rear door varies between 7 and 13 m/s (Figure 12).

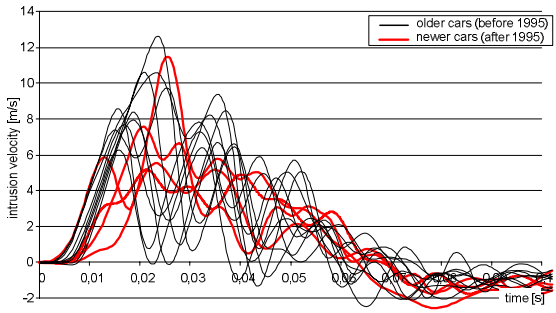


Figure 12. Rear door intrusion velocity in side impact tests according to ECE R95.

Taking into account the difficulties in positioning of the intrusion measurement device especially in smaller cars, a mean difference in intrusion velocity between front and rear door of 10% can be observed (Figure 13). The difference could be caused either by vehicle design or the test procedure with the centre of impact located more in the front.

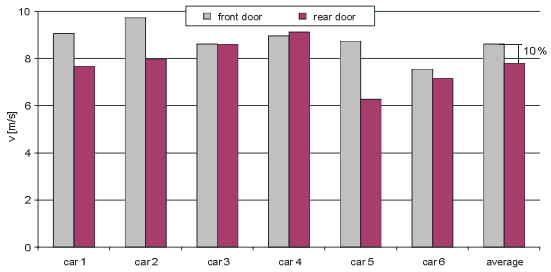


Figure 13. Comparison of maximum intrusion velocity for front and rear seat.

Door Intrusion Velocity in Car-to-Car Tests

For the development and assessment of a new European side impact test procedure several car-to-car and MDB-to-car side impact tests were conducted on behalf of EEVC/WG13 [Ellway, 2005]. These data help to analyse real-world side impact accidents, as passenger cars were used as the striking vehicles.
The intrusion measurement data presented below are acquired by acceleration based measurements for the Camry tests (except the AEMDB V2 test) and the Corolla car-to-car tests. For the other tests string potentiometers were used. The intrusion was measured close to the position of the thoraxes of driver and rear seat passenger but without interferences. When comparing acceleration based and string potentiometer based intrusion measurements, Ellway came to the conclusion that the first one tends to deliver higher residual velocity towards the end of the impact.
Figure 14 shows front door intrusion velocity of the inner door panel of an Alfa Romeo 147 running at 24 km/h which was struck by a Toyota Corolla travelling at 48 km/h. In a second test an Alfa Romeo 147 was struck by a Land Rover Freelander. While intrusion velocity in the Toyota test was approximately 6.5 m/s, the Land Rover Freelander caused an intrusion velocity of more than 12 m/s.

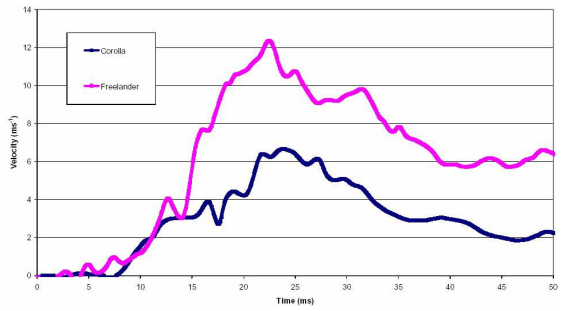


Figure 14. Comparison of front door intrusion velocity in car-to-car and SUV-to-car test [Ellway, 2005].

Looking at the rear door intrusion velocity of the inner panel these recorded approximately 7.5 m/s in the Corolla test compared to 10.5 m/s in the Land Rover Freelander test, see Figure 15.

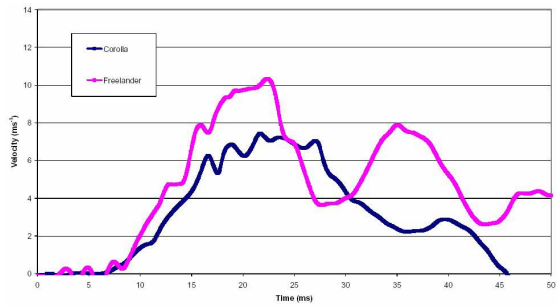


Figure 15. Comparison of rear door intrusion velocity in car-to-car and SUV-to-car test [Ellway, 2005].

Tests with a Toyota Camry, an executive saloon, showed again considerable differences between car-to-car (in this case a Ford Mondeo was used) and SUV-to-car tests. The intrusion velocities at the front door were approximately 5 m/s for the Mondeo and 9.5 m/s for the Freelander respectively, see Figure 16. For the rear door the intrusion velocities varied between 7 m/s (in the Ford test) and 10.5 m/s (in the Land Rover test, see Figure 17).

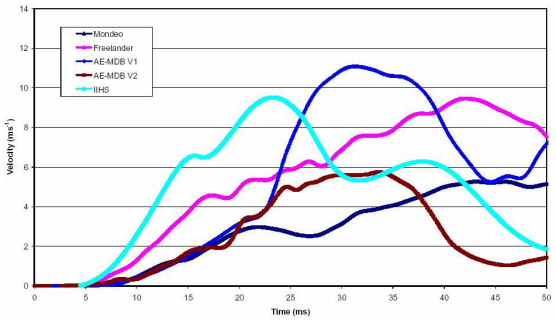


Figure 16. Comparison of front door intrusion velocity in different side impact tests with a Toyota Camry [Ellway, 2005].

The MDB tests were carried out utilising a barrier face stiffness and geometry (increased ground clearance) different from that of ECE R95. In addition the sled mass was increased to 1,500 kg. These measures should help to represent a more realistic accident severity.

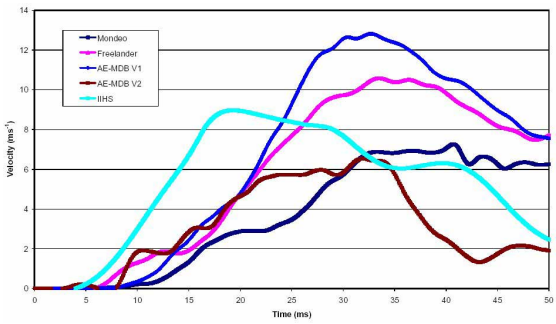


Figure 17. Comparison of rear door intrusion velocity in different side impact tests with a Toyota Camry [Ellway, 2005].

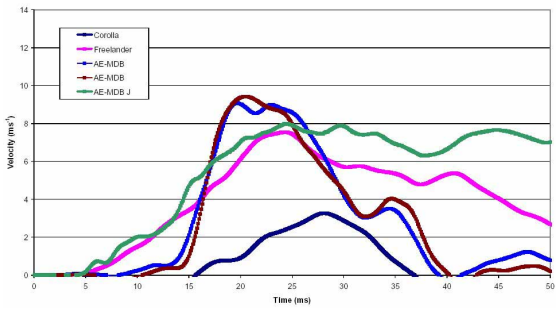


Figure 18. Comparison of front door intrusion velocity in different side impact tests with a Toyota Corolla [Ellway, 2005].

In the tests with a Toyota Corolla considerable differences between front and rear door are visible, see Figure 18 and Figure 19. While the intrusion velocity in the Corolla-to-Corolla test were relatively low for the front seat (approx. 3.5 m/s compared with 6 m/s at the rear door) this was contrary to the situation for all other tests.

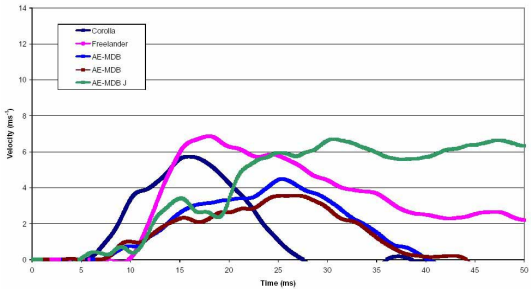


Figure 19. Comparison of rear door intrusion velocity in different side impact tests with a Toyota Corolla [Ellway, 2005].

Struck Car Acceleration and Velocity Change

In addition to the intrusion of the side structure the struck car experiences a lateral acceleration.

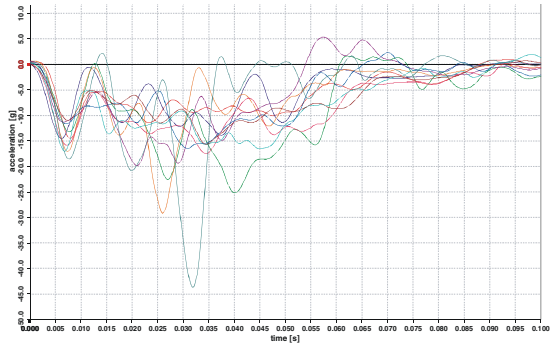


Figure 20. Acceleration of the struck car in ECE R95 tests [Nett, 2003].

Taking into account the theoretical velocity change for cars of an average weight in ECE R95 tests the struck car will be accelerated up to 22 km/h (Figure 20), which is in line with the derived velocity change from the vehicle acceleration time histories shown in Figure 21.

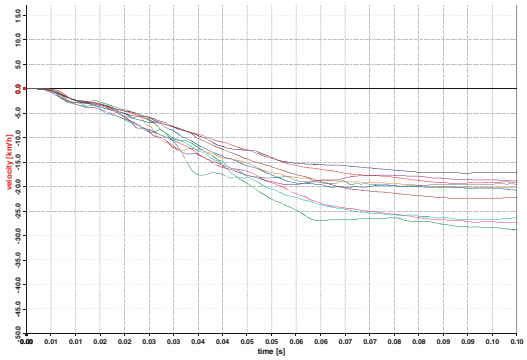


Figure 21. Velocity change of the struck car in ECE R95 tests [Nett, 2003].

Deformation Profiles

The comparison of static deformation of the struck vehicle from front to rear shows at first an increasing crush over a distance of about 500 mm, then a

more or less constant crush over a distance of about 900 mm and then a decreasing trend (Figure 22).

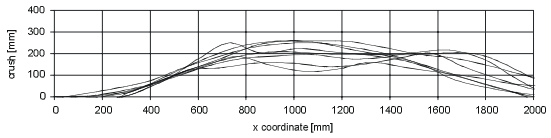


Figure 22. Static crush of different cars in ECE R95 tests [Johannsen, 2005].

The static crush in the EEVC/WG13 tests as described above show a comparable static crush as mentioned above, see Figure 24 and Figure 26. The crush distribution across the vehicle height shows significant differences; see Figure 23 and Figure 25. Again the influence of properties of the striking vehicle can be observed.

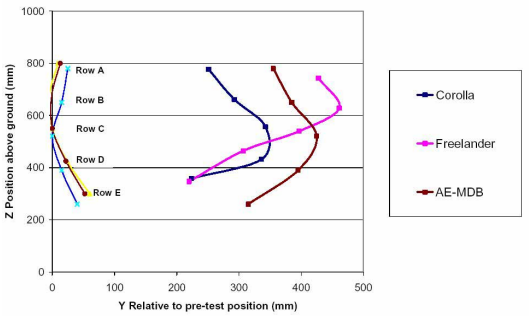


Figure 23. Static crush of Alfa 147 in several side impact tests (in Z-direction) [Ellway, 2005].

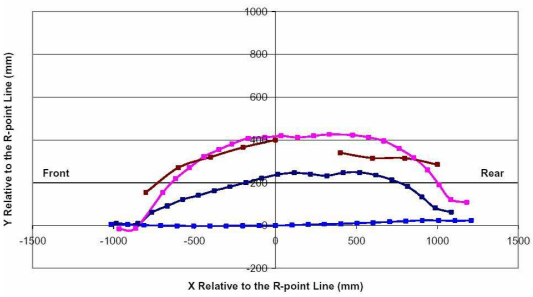


Figure 24. Static crush of Alfa 147 in several side impact tests (in X-direction row A) [Ellway, 2005].

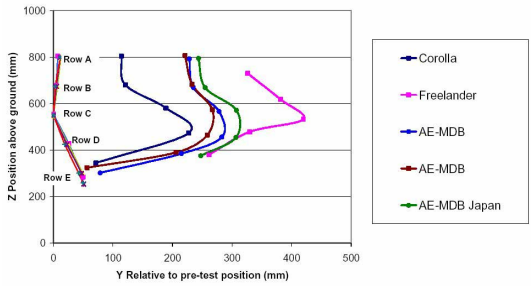


Figure 25. Static crush of Toyota Corolla in several side impact tests (in Z-direction) [Ellway, 2005].

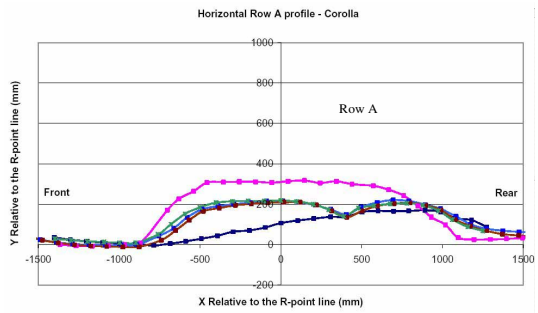


Figure 26. Static crush of Toyota Corolla in several side impact tests (in X-direction row A) [Ellway, 2005].

Dynamic Force-Deflection Characteristics of Door Interior

In addition to the dynamic behaviour, the geometric boundary condition of passenger cars, such as the lateral distance between seat and side structure, the height of the window sill in relation to the CR-point, and the stiffness of the side structure, are important.
The stiffness of the door trim, analysed in pendulum tests, showed considerable differences for different car models and different impact locations, see Figure 27.

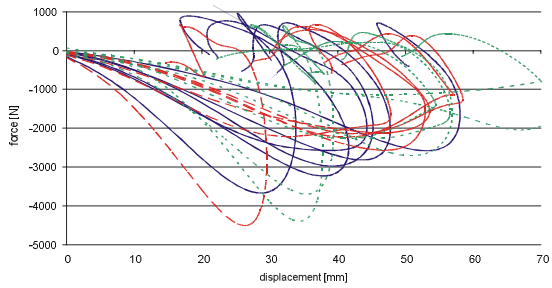


Figure 27. Door trim force-deflection of different locations at different doors [Nett, 2003].

Door window sill height and distance to door trim

Investigation of Nett [Nett, 2003] showed a lateral distance of the CRS centreline to the side structure of 300 mm and a window sill height of 500 mm. The average window sill height with respect to the CR point is approximately 500 mm, Figure 28.

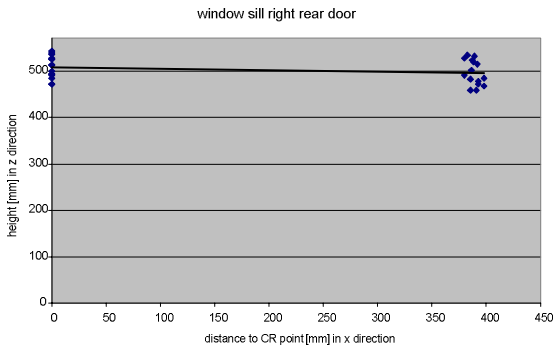


Figure 28. Height of the window sill in different cars [Nett, 2003].

The CRS centreline has an average distance to the inner door trim of approximately 300 mm [Nett, 2003], Figure 29.

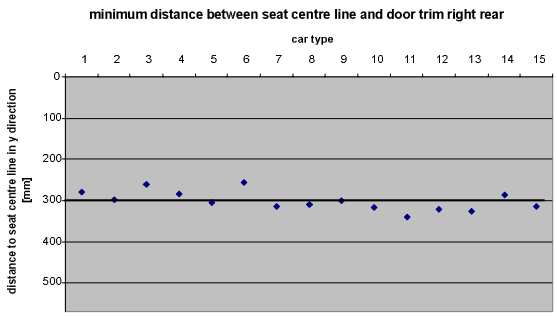


Figure 29. Lateral distance between CRS centreline and inner door trim [Nett, 2003].

REQUIREMENTS FOR THE SIDE IMPACT TEST PROCEDURE

The requirements of the ISO side impact test procedure for child restraint systems can be divided into the sections; test severity, validation, and field of application.

Test Severity

The test severity is defined by sled acceleration, intrusion depth and intrusion velocity (as far as intrusion is simulated), but also by geometrical measurements such as the panel height, distance of the CRS to the panel etc.
Analysis of full-scale side impact tests shows that the performance of current cars has been significantly improved during the last years. However, there are still old cars on the road and the test severity of the full-scale test is subject to several discussions as it is felt to be too moderate. One example for higher severity tests is the IIHS test procedure, where the mass of the barrier as well as the stiffness and shape of the barrier face, causes a more aggressive contact with the car in comparison to ECE R95 and FMVSS 214 test conditions.

Whilst there are no validated biomechanical load limits for children in side impact tests, the dummy readings resulting from the side impact test procedure should correlate with those measured in full-scale side impact tests.
Summing up the results presented in the section "Child Related Properties of Car Side Impact Test Methods" and the statements above, the following properties defining the test severity apply to a majority of cars in use:

- Intrusion velocity range: 7 – 10 m/s
- Intrusion depth: approx. 250 mm
- Sled acceleration range: 10 – 15 g
- Door panel height: approx. 500 mm
- Distance between door and CRS centre line: approx. 300 mm

In addition the padding specification needs to be fully defined.

Validation

For the validation of the test procedure, the test severity as well as the CRS definition according to the scope (see below) needs to be approved. Concerning the test severity, accident statistics show that the most important body region to protect is the head. Therefore it is necessary to put special emphasis on the validation of head loads and the capability of child restraints to contain the head inside the CRS during the test.

Field of Application

Besides the differences of forward facing and rear-facing the fixation of the CRS and the child can be different. The following types can be found in today's world markets: belt fixed CRS with integral harness for the child (FF mainly 5-point-harness, RF mainly 3-point-harness), booster with/without backrest (CRS and child restrained with car belt), ISOFIX connection of CRS and car with integral harness for the child. For the belted CRS the usage of tensioning devices, which reduce the belt slack of the car belt, are becoming more popular. The side impact test procedure has to be able to cope with all these different CRS types. In addition it is important that all these seats are tested with comparably realistic severity.

HISTORICAL OVERVIEW

Based on a side impact test procedure developed by TUB (Technical University of Berlin) within the EC funded project Brite ATASED (Advanced Technologies for Automotive Seat Evaluation and Design) TUB started testing CRS in lateral impacts. These tests were conducted in a double-sled arrangement, where the first sled impacted the

second one. This double sled approach represents the deceleration and intrusion as recognised in car side impact tests. In the beginning a real car door was mounted on the striking sled, which impacted a CRS mounted on a car seat (see Figure 30).

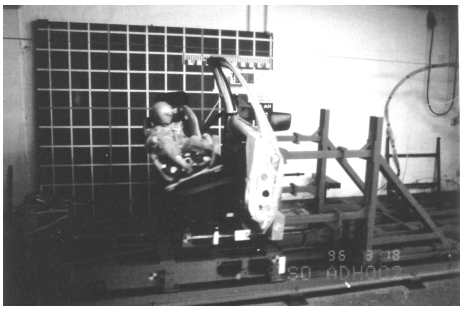


Figure 30. Double sled test set-up with car door and car seat.

In a later evolution a flat panel was used to represent the door and the CRS was mounted at an ECE R44 test bench. See Figure 31.

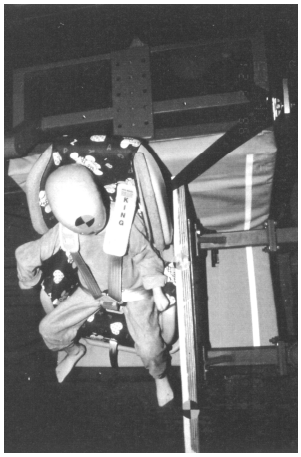


Figure 31. Double sled test set-up with flat panel and ECE R44 test bench.

It was then proposed by TRL (Transport Research Laboratory) to represent the intrusion with a hinged door. The hinged door was impacted by a 100 kg pendulum mass. Because of the relatively low mass the intrusion depth and intrusion velocity could not be reproduced in a satisfactory manner. Both depended on the CRS fixture, CRS weight etc. However, the principle idea of the hinged door concept seemed to be a good compromise of reproducing vehicle acceleration and intrusion.
To reduce the complexity of the hinged door procedure, the Nordic European countries proposed to use a curved panel as a door, which is fixed at the concrete block. The intrusion velocity in this approach is defined by the initial sled velocity. As the intrusion velocity in lateral impacts is higher than the lateral velocity change of the struck car, the Nordic countries proposed to use a suitable intrusion velocity as initial sled speed. The sled was then decelerated during the contact with CRS and dummy to meet the intrusion depths requirement. This procedure was realised by TNO with a flat panel.
Another proposal, coming from MPA Stuttgart, was to impact the CRS by a panel without reproducing the vehicle movements.

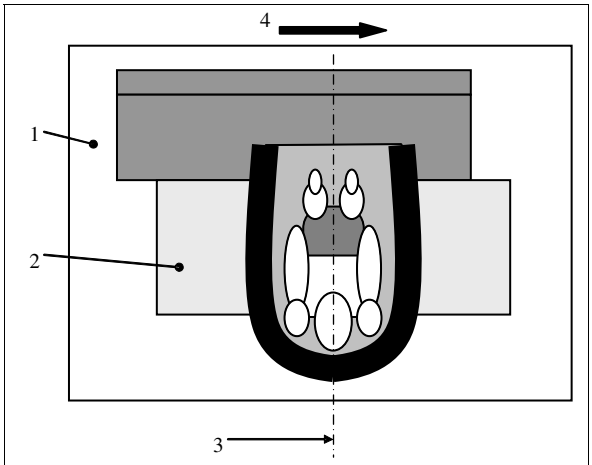
CURRENT SIDE IMPACT TEST PROCEDURES FOR CHILD RESTRAINT SYSTEMS

This clause gives a brief summary of the existing side impact test procedures for child restraint systems.

ISO/DIS 14646 / TRL Test Procedure

The child restraint working group of ISO (ISO/TC22/SC12/WG1) started in 1994 the development of a side impact test procedure for child restraint systems. Most of the procedures described in previous section were proposed and discussed within the responsible task group. Finally in the end of the nineties the decision was taken to use a derivative of the hinged door concept as proposed by TRL.
The main problem recognised with the original hinged door concept was the considerable influence of the CRS on intrusion velocity and intrusion depth. This was mainly caused by the relatively low impactor mass. Finally the activating method of the intruding panel was not defined in the protocol but corridors for intrusion velocity and an intrusion depth was fixed.
Due to the proposed hinged door method it is important to define the worst-case conditions. The contact velocity between the CRS (child dummy, respectively) and the intruding panel depends on the angular velocity of the panel and the distance of the CRS (defined by the position of the head) to the hinge line. In order to test rear-facing and forward facing CRS with the same test severity, it is necessary to use different hinge line positions with respect to the CR point. Within ISO it was decided to test in worst-case conditions, which means with the maximum intrusion close to the dummy's head, requiring the hinge line far from the dummy's head.
The draft standard was subject to two subsequent DIS votes. After failing the first one, it was decided to improve the draft standard for rear-facing CRS, while defining the details for forward facing CRS in a second part. For the second vote only the part covering RF CRS was presented, the second part should be published as a Technical Report. However the standard proposal was disapproved also during the second DIS vote (by a small margin).

Description of the ISO Test Method - The main property of the ISO 14646 test procedure is the hinged door concept where an ECE R44 test bench is mounted at an angle of 90° on a sled. To avoid interactions between the intruding panel and the test bench backrest, the latter one is displaced by 100 mm, see Figure 32.

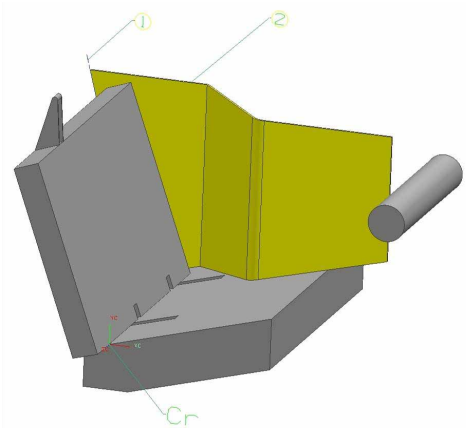


Key

1	Sled
2	ECE R.44 test bench
3	CRS centreline
4	Travel direction

Figure 32. General test setup in ISO/DIS 14646.

The hinge line of the intruding panel is perpendicular to the seat cushion by means of an angle of 15° to the ground. The simulated intrusion should realise an intrusion depth of 250 mm and a maximum intrusion velocity of 9 m/s.
The panel shape was subject to several discussions within the responsible task group. After initially testing with a flat panel, curved and shaped panels were developed and tested. The main advantage of a shaped panel is the fact that it is possible to define a maximum intrusion, which is not the case with a flat panel. Finally a double shaped panel according to Figure 33 was developed.
During the sled deceleration the hinged door intrudes. The CRS is positioned with a distance of 300 mm of its centreline from the hinged door. The test procedure takes into account the worst-case scenario for both, RF and FF CRS, by positioning the hinge at the side of the feet of the child dummy. The sled deceleration is defined by a delta-v corridor representing an overall delta-v of 25 km/h. The hinged door concept transfers the translational into a rotational intrusion. The middle angular velocity for RF CRS of 13 rad/s corresponds to a translational intrusion velocity at the point of the head of about 12 m/s.
The test procedure according to ISO/DIS 14646 was implemented at TRL.



Key

1	Panel hinge line
2	Hinged panel

Figure 33. Seat bench construction with panel for RF configuration of ISO/DIS 14646.

Voting Results - The draft ISO standard was disapproved in both DIS votes. Numerous comments were provided for both votes.
In the first vote ISO/DIS 14646 was disapproved by five countries (France, Italy, Japan, Netherlands, US). The main reason for the disapproval was the missing validation, especially for the test set up for FF CRS.
During the second vote, again five countries disapproved the proposal. This time France, Germany, Japan, Philippines and Sweden voted against the draft especially because of separate parts describing the test methods for FF and RF seats, and again the missing validation, especially regarding reproducibility.

TNO Test Procedure

The TNO procedure is based on an earlier stage of the ISO 14646. The main difference to ISO is the utilisation of a flat panel and a different padding. In principle the TNO procedure was intended to be used for both, RF and FF CRS, in worst-case conditions, but the set up for FF worst-case has not been realised yet.

TUB Test Procedure

The test procedure developed by the Technical University Berlin is again based on the hinged door concept. TUB started the development in 1999 based on the resolutions and decisions taken by ISO WG1.
The main differences with respect to ISO 14646 are different hinge line orientation, different panel shape and different panel padding. In addition the backrest and upper belt anchorage point in FF configuration are both moveable in the Y direction and firmly connected with the intruding panel representing the seat and B-pillar displacement in

full-scale crash tests. The lower ISOFIX anchorages are free to move in Y-direction.
The hinge line in the TUB method is vertical to the ground allowing the same hinge to be used for both test set-ups. The single shaped panel is padded with a thicker and softer material compared to the ISO procedure.
The TUB test procedure was selected to be used for the NPACS Programme (New Programme for the Assessment of Child Restraint Systems) at the end of 2005.

ADAC Test Procedure

The ADAC (Germany Motoring Club) tests take place in a body-in-white of a VW Golf [Gauss, 2002]. The body-in-white is mounted on a sled at an angle of 80° and is equipped with a fixed door. The angle of 80° should cause an additional head movement in frontal direction. Therefore it is more difficult to pass the head containment criterion for FF CRS. The body in white is mounted in the same way to the sled for FF and RF CRS. In the ADAC procedure a fixed door is used, i.e. no intrusion is simulated. The sled is decelerated from an initial velocity of 25 km/h at a level of 15 g. The main advantage of this test procedure is that it is considerably simpler, enabling good performance with respect to reproducibility.

Australian Standard AS/NZS 1754 Test Procedure

In Australia and New Zealand two different kinds of side impact tests for homologation of child seats have to be used. One test is on a test bench, which is mounted at 90° on a sled, without any door and the second test is with a fixed door, again at 90° angle. The first test assesses for dummy ejection in lateral impacts and has been in the standards for over 20 years while the latter test assesses the head containment capabilities of the CRS. For the door-less tests, selected TNO P series dummies are used for forward facing seats and boosters, while a TARU Theresa dummy is used for infant restraints. Selected TNO P series dummies are used for the tests in which the door is utilised. The sled is calibrated to undergo a velocity change of not less than 32 km/h, with a deceleration of 14 – 20 g. The door used was based on research work from the Child Restraint Evaluation Program with changes to construction of the angle on the top half of the door. This side impact testing with the door was introduced in to the 2004 version of the standard.

Australian CREP Test Procedure

The consumer information testing in Australia is known as the Child Restraint Evaluation Program (CREP). There have been three rounds conducted and published. There are two side impact tests, one at 90° and the other at 66° (previously 45°), both with a fixed door structure in place. The test conditions are the same as AS/NZS 1754 (see above), however there are additional assessment criteria. Selected TNO P Series dummies are used for testing. In some instances they are modified to increase their seated height.

CURRENT STATUS AND FUTURE RESEARCH FOR ISO 29062

The restarted project has been accepted as a new work item proposal as ISO 29062.According to the ISO rules the standard must be published before November 2009.
The current focus of the subgroup developing the final standard is the definition of appropriate corridors addressing repeatability and reproducibility as well as the validation of the test procedure taking into account the application of the procedure, the test severity etc.

Corridor Specification

The current corridors for sled delta-v and the angular velocity are shown in Figures 34 and 35

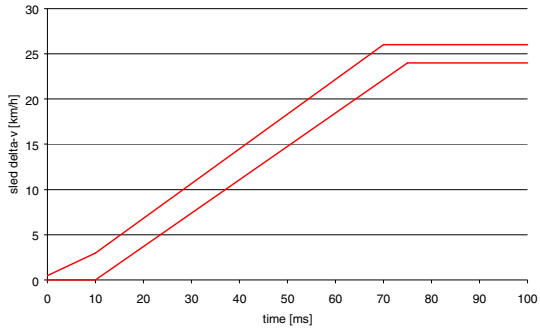


Figure 34. Sled delta-v corridor.

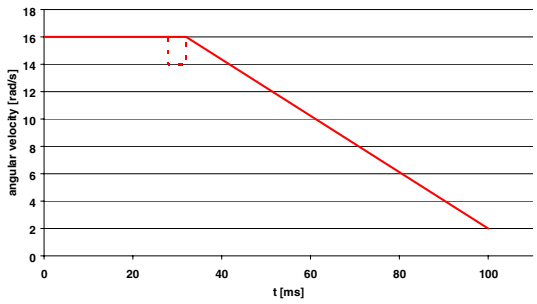


Figure 35. Angular velocity corridor for FF CRS.

The combination of both corridors was felt to offer too much variety. For analysing the effect of the allowed tolerance numerical simulations utilising MADYMO with a generic FF CRS were performed (see Figure 36).

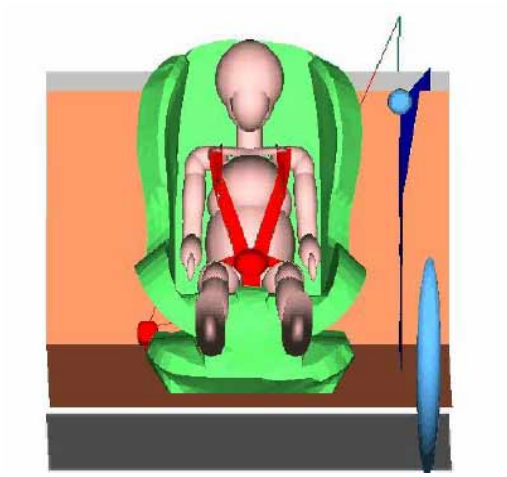


Figure 36. Set-up for the analysis of the corridors [Rooij, 2005].

The contact velocity between panel and CRS was used as an indicator for the dummy readings as the used CRS model did not allow reliable assessment of the dummy readings.

These simulations show that the procedure is sensitive to the timing of the door angular velocity while the maximum value of the door velocity and the sled pulse show only a minor influence on the test results, see Figures 36 and 37.

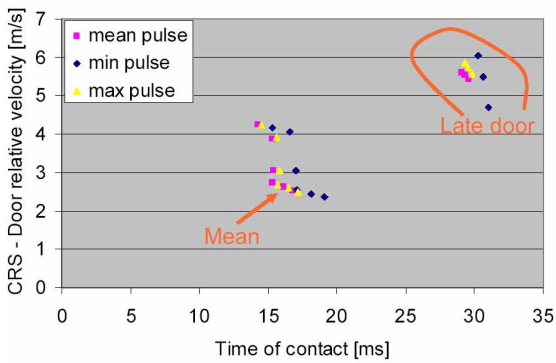


Figure 37. Influence of door timing and sled pulse on the contact velocity.

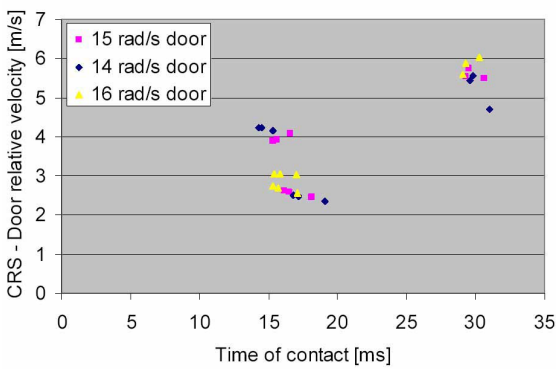


Figure 38. Influence of door timing and panel speed on the contact velocity.

The future revised corridors should address the timing issue recognised above but has to be feasible.

Test Severity

The test severity of the current drafted standard is mainly based on cars of the eighties and nineties. Due to considerable changes in new cars adoption of the test severity might be necessary.
Intrusion velocity and door panel height are the main parameters currently under discussion. For styling reasons the window sill height, especially at the rear seat, changed considerably during the last years. An increased door panel height results in higher dummy readings but reduces the challenges concerning the head containment for high-back booster seats.
The data presented above show a considerably lower intrusion velocity for newer cars compared with older ones. This behaviour is caused by improved vehicle design. For defining a sustainable test procedure it is necessary to keep this development in mind.

Forward Component

The US side impact test procedures for cars (FMVSS 214 and US-NCAP) as well as the ADAC side impact test procedure for CRS represent a forward component of the sample car. The drafted standard describes a purely lateral impact. Currently advantages and disadvantages of including a forward component are investigated. European accident statistics indicate that perpendicular and angled side impact accident happen with an equal share while the purely lateral ones seem to be more severe.
The next steps are to include US accident data, to analyse the velocity change in US-NCAP tests and to assess the influence of including a forward component to the dummy readings.

CONCLUSIONS

Accident statistics prove that side impact accidents are dangerous for children travelling at the struck side in passenger cars. Although the number of seriously injured children has decreased during the last decades, there is still a considerable risk especially for head, neck and thorax injuries. Comparing RF and FF CRS there are indications in the accident statistics that rear facing seats protect children better in side impact than forward facing child restraint.
Side impact test procedures for cars, which are designed to represent average accident conditions, are mainly MDB tests with a barrier travelling either perpendicular to the struck car or at a crabbed angle. In addition to the direction

differences in barrier weight, speed, geometry and stiffness exists. The most severe test procedure seems to be the IIHS side impact test procedure simulating an SUV striking the test car.
When analysing test results of ECE R95 side impact tests it becomes evident that injures are caused by the combination of both structural intrusion and vehicle acceleration. The intrusion is defined by intrusion shape, intrusion depth and intrusion velocity. In addition geometrical properties (such as door panel height, distance between side structure and CRS etc.) of the struck car have a considerable influence. An appropriate side impact test procedure for CRS should be capable to reproduce the following properties:

- Intrusion velocity range: 7 – 10 m/s
- Intrusion depth: approx. 250 mm
- Sled acceleration range: 10 – 15 g
- Door panel height: approx. 500 mm
- Distance between door and CRS centre line: approx. 300 mm

In addition the padding specification needs to be fully defined.
In addition the test procedure should be repeatable and reproducible and should offer the possibility to test all kinds of CRS at a comparable severity level.
The proposed side impact test method for CRS according to ISO DIS 14646 reproduces vehicle acceleration by a sled and intrusion by a hinged panel. It has been disapproved in two votes; mostly because concerns that additional validation of the procedure would have been necessary.
As a consequence of the disapprovals of the proposed ISO procedure, and taking into account the alternative method development, ISO/TC22/SC12/WG1 adopted the following resolution in November 2005:
"Considering the disapproval of DIS 14646-1.2, and the recent information that NPACS have just decided to use a method similar to the TUB method for side impact CRS rating, WG 1 decided to change direction of the ISO work in recognition of the NPACS decision." *(Excerpt of resolution 180, adopted at the 34th meeting in Arlington (USA), 2005-11-17.)*

BIBLIOGRAPHY

Arbogast, K.B.; Chen, I.; Durbin, D.R.; Winston, F.K.: Injury Risks for Children in Child Restraint Systems in Side Impact Crashes, IRCOBI Conference, Graz 2004

Crandall, J.; Sherwood, C.: Factors Influencing the Performance of Rear Facing Restraints in Frontal Vehicle Crashes, 3rd International Conference – Protection of Children in Cars, Munich, 2005

Ellway, J D on behalf of EEVC/WG13; The Development of an Advanced European Mobile Deformable Barrier Face (AE-MDB), ESV conference 2005, Paper Number 05-0239

National Highway Traffic Safety Administration (NHTSA); §571.214 FMVSS 214, 2003

Gauss, C.; Klanner, W.; Das Kindersitz-Testverfahren der europäischen Automobilclubs im Vergleich zur Euro NCAP Bewertung. Innovative Kinderschutzsysteme im Pkw, Cologne, 2002

IIHS: Crashworthiness Evaluation Side Impact Crash Test Protocol (Version IV), 2005. http://www.iihs.org/ratings/protocols/pdf/test_protocol_side.pdf

Jakobsson, L.; Isaksson-Hellmann, I.; Lundell, B.: Safety for the Growing Child – Experience from Swedish Accident Data. 19th ESV Conference, Washington DC, June 2005.

Johannsen, H.; Gehre, C.; Schoeneich, O.; Schindler, V.: Restrained Children in Side Impacts – Crash Tests and Simulation. 1st Conference Protection of Children in Cars, Cologne, 2003.

Johannsen, H.; Huijskens, C.; Schnottale, B.; Schindler, V.: Side Impact Test Procedure for Child Restraint Systems – Review of Existing Methods and Proposal for Continuation. IRCOBI Conference, Prague, 2005.

Langwieder, K.; Hell, W.; Willson, H.: Performance of Child Restrain systems in Real-Life Lateral Collisions. 40th STAPP-Conference, Albuquerque, 1996.

Langwieder K.: Verletzungsfolgen für Kinder als Insasse bei pkw-Unfällen. Innovative Kindersicherungen im Pkw, 2002 (in German).

Nett, R.: Testverfahren zur Bewertung und Verbesserung von Kinderschutzsystemen beim Pkw-Seitenaufprall. Berichte der Bundesanstalt für Straßenwesen, Heft F43, 2003 (in German)

Otte, D.: Injury Risk of Children in Cars. 1st Conference Protection of Children in Cars, Cologne, 2003.

Rooij L. v.; Harkema, C.; Lange, R. d; de Jager, K. d.; Bosch-Rekveldt, M.; Mooi, H.: Child Poses in Child Restraint Systems Related to Injury Potential: Investigations by Virtual Testing, 19th ESV Conference, Washington DC, USA, 2005

IMPLEMENTATION OF ISOFIX AND LATCH EQUIPED AUTOMOTIVE CHILD RESTRAINT SYSTEMS IN AN AIRCRAFT ENVIRONMENT

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ABSTRACT

The increasing trend towards fractional aircraft ownership has seen a rise in the number of babies and children being transported on corporate and private aircraft. Occupant protection policies for children younger than 2 years on aircraft are inconsistent with all other national policies on safe transportation. Children younger than 2 years are not required to be restrained or secured on aircraft during takeoff, landing, and conditions of turbulence. The National Transportation Safety Board 2005-2006 Most Wanted Transportation Safety Improvements state that all occupants should be restrained during takeoff, landing, and turbulent conditions, and that all infants and small children should be restrained in an approved child restraint system appropriate to their height and weight.

Current Federal Aviation Administration recommendations for child restraints are based on Federal Motor Vehicle Safety Standards and typically involve the use of child safety seats restrained by aircraft lap belts. Newer automotive restraint standards use the vehicle structure to restrain the child safety seat. These standards differ between North America (LATCH) and Rest of the World (ISOFIX). Development and testing to determine the optimum means of child restraint and a solution that works in both North America and Rest of the World is needed.

Based on the results from the dynamic sled tests conducted, in this study there is sufficient data to conclude that the ISOFIX and LATCH system can solve the interface issues found in the past between the CRSs and aircraft seats. Both the ISOFIX and the LATCH attachment methods offer similar level of safety for the 12 month and 3 YOLD occupants.

While this study provides an overview of the viability of the ISOFIX and LATCH system, additional research needs to follow in order to develop aerospace standards and recommendations.

INTRODUCTION

The increasing trend toward fractional aircraft ownership has seen a rise in the number of babies and children being transported on corporate and private aircraft. Occupant protection policies for children younger than two years of age on aircraft are inconsistent with all other national policies on safe transportation. Children younger than two years old are not required to be restrained or secured on aircraft during takeoff, landing, and/or conditions of turbulence. In the National Transportation Safety Board (NTSB) 2005-2006 Most Wanted Transportation Safety Improvements [1], NTSB states that all occupants should be restrained during takeoff, landing, and turbulent conditions, and that all infants and small children should be restrained in an approved child restraint system appropriate to their height and weight.

A child restraint system (CRS) provides specialized protection for small occupants whose body structures are still immature and growing. Child restraint designs vary with the size of the child, the direction the child faces, the type of internal restraining system, and the method of installation. Current Federal Aviation Administration (FAA) recommendations for child restraints are based on Federal Motor Vehicle Safety Standards (FMVSS) and typically involve the use of child safety seats restrained by aircraft lap belts. Newer automotive restraint standards use the vehicle structure to restrain the child safety seat. These standards differ between North America (Lower Anchors and Tethers for Children or LATCH) and the rest of the world (International Organization for Standardization FIX or ISOFIX). Development and testing to determine the optimum child restraint and a solution that works with both the ISOFIX and LATCH system is needed.

CRS-AIRCRAFT SEAT INTERFACE ISSUES

According to NIAR CRS fitting studies and previous research conducted by van Gowdy & DeWeese [2], interface issues were found using conventional aircraft restraint systems to anchor the CRS.

The most common type of CRS/Aircraft seat interface issues are:

- Interference with the lap belt latching mechanism
- Insufficient belt webbing length
- Two-point aerospace belt geometry issues

- Lack of adjustment features for aerospace 2-point belts
- CRS dimensional compatibility with aircraft seat structure

Figure 1. Typical Aerospace/CRS Interface Issues.

The dimensions shown in table 1 and 2 were taken for typical CRS and Part 23 (General Aviation) and 25 (Business Jet) seats.

Table 1.

Typical child restraint dimensions

Seat Type	Height (inches)	Width (inches)	Depth (inches)
Convertible – 1	26.8	17.7	16.3
Convertible – 2	24.2	18.9	17.7
Booster	26.4	16.5	13
Infant	18.1	10.2	21.3

Table 2.

Typical aircraft seat dimensions

Seat Configuration	Width Between Arm Rests (inches)	Width of Seat Cushion (inches)	Depth of Seat Cushion (inches)
1	17.5	19.5	21
2	18.5	20.5	21
3	18.5	20.5	21
4	16.5	20.5	21
5	18	22	21
6		19	19
7		18.5	19
8		19.5	19
9		19.5	19
10		18.5	22.6
11		20	22
AVG	17.9	19.8	20.5
MIN	16.5	18.5	19
MAX	18.5	22	22.6

The Lower Anchors and Tethers for Children (LATCH) and the ISOFIX System are designed to make installation of child safety seats easier by requiring child safety seats to be installed without using the vehicle's/aircraft seat belt system.

LATCH System

According to FMVSS 213 [3]; as of September 1st 2002, two rear seating positions on all cars, minivans and light trucks are equipped with lower child safety seat anchorage points located between a vehicle's seat cushion and seat back. New child safety seats have two attachments which will connect to the vehicle's lower anchorage attachment points. In addition, all new vehicles have top anchor points that connect to a child safety seat's top tether strap. Together, the lower anchors and upper tethers make up the LATCH system [4].

Figure 2. LATCH Equipped Seat.

ISOFIX System

The International Organization for Standardization FIX constitutes a standardized quick rigid connection system for CRS. This rigid interface between the CRS and motor vehicle permits proper installation in all cases, regardless of the vehicle's seat belt system. The child restraint system is attached to vehicle anchorages by means of two rigid attachments at the bottom of the CRS [5].

It should be noted that for the aircraft seat tested, the upper tether was not used in order to reduce the complexity of the aircraft installation, and to asses whether or not this feature is necessary to prevent large ATD excursions and CRS rotation in the aircraft environment.

Anchorage System Specifications

Per FMVSS 225 [6] and ISO 13216-1 [5], anchorages shall be 6 mm + 1 mm in diameter transverse horizontal round bars with a minimum effective length of 25 mm. The transverse spacing of the bars shall be 280 mm, center to

center. They shall be supported to extend from the adjacent vehicle or seat structure so they are readily accessible. Note that the general dimensions are compatible with both the ISOFIX and the LATCH standards.

Figure 3. ISOFIX Equipped Seat.

DYNAMIC SLED TESTS EVALUATIONS

In 1982, the Department of Transportation (DOT) had two standards for CRS. CRS for use in motor vehicles were required to be certified as complying with the requirements of FMVSS No. 213. CRS for use in aircraft were required to be certified as complying with the requirements of FAA's Technical Standard Order (TSO) C100. In 1983 it was proposed that NHTSA would be the sole agency responsible for administering the new FMVSS No. 213, which would be applicable to both CRS designed for use in motor vehicles and CRS designed for use in aircraft (Title 49 of the Code of Federal Regulations (49 CFR) part 571, § 213) [7].

For a CRS to be approved to be used on aircraft, it must meet the dynamic sled test requirements, and an inversion test (simulate turbulence condition) as specified in FMVSS 213 and ECE R44. As shown in figure 7, automotive pulses exhibit higher decelerations and changes of velocity than those specified in aircraft interior regulations described in FAR 23/25.562.

A series of sled tests without upper tether were conducted at the National Institute for Aviation Research Crash Dynamics Laboratory in order to evaluate the dynamic performance of child restraint systems when subjected to Parts 23 and 25.562 emergency landing conditions.

Description of Aircraft Passenger Seat Test Articles

Two types of aircraft seats were used for testing. A rigid seat was used to study occupant behavior and interface loads with the CRS, and a modified (ISOFIX attachments) part 25 business-jet seat was used to evaluate the implementation and performance of the ISOFIX interface on a production aircraft seat.

Description of Child Restraint Seat Test Articles

The following child restraint devices were provided for evaluation:

- Rear Facing Infant Seat: These seats are designed to be installed facing the rear. They are recommended for infants, from birth to at least age one and weighing less than 20 pounds. These seats have an integrated five-point restraint system. The seats used in these tests were fitted with either an ISOFIX base or a LATCH interface (see figure 4).

- Forward Facing Convertible Seat: Children over one year old and weighing at least 20 pounds may ride in a front-facing child safety seat. The maximum recommended occupant weight for these CRSs is 40 pounds. These seats have an integrated five-point restraint system. The seats used in these tests were fitted with either an ISOFIX base or a LATCH interface (see figure 4).

Figure 4. Convertible and Infant Seat.

Anthropomorphic Test Dummies

Two types of child ATDs were utilized in these tests:

- CRABI 12-Month: This ATD was developed to evaluate a small child restraint system in automotive crash environments, in all directions of impact, with or without air bag interaction [8]. The ATD weighs 22 pounds (10 kg), has a seating height of 18.9 inches (0.48 m), and a stature of 29.4 inches (0.75 m). The instrumentation used for testing is summarized in table 3.
- 3 YOLD Hybrid III: This ATD was developed by SAE and NHTSA to evaluate child restraint systems and airbag aggressiveness (out-of-position) in automotive crash environments. It weighs 34.5 pounds (15.6 kg), and has a seating height of 21.5 inches (0.55 m) and a stature of 37.2 inches (0.94 m) [8].

Table 3.

ATD instrumentation

Instrumentation	CRABI	3YOLD
Head Accelerometer	√	√
Upper-Neck Load Cell	√	√
Thorax Accelerometer	√	√
Lumbar Spine Load Cell	√	√
Pelvis Accelerometer	√	√

Dynamic Sled Pulse Definition

Tests with the rigid seat were conducted per FAR 23.562 Emergency Landing Conditions [9]:

- For the first test, the change in velocity may not be less than 31 feet per second. The seat/restraint system must be oriented in its nominal position with respect to the airplane and with the horizontal plane of the airplane pitched up 60 degrees, with no yaw, relative to the impact vector. For the seat/restraint systems, peak deceleration must occur in not more than 0.06 second after impact and must reach a minimum of 15 g.

- For the second test, the change in velocity may not be less than 42 feet per second. The seat/restraint system must be oriented in its nominal position with respect to the airplane and with no 10 degree yaw and no pitch relative to the impact vector. For the seat/restraint systems, peak deceleration must occur in not more than 0.06 second after impact and must reach a minimum of 21 g.

Figure 5. Type I Test setup with PART 25 Aircraft Seat.

Tests with the FAR 25 aircraft seat were conducted per FAR 25.562 Emergency Landing Conditions [9]:

- For the first test, the change in downward vertical velocity may not be less than 35 feet per second, with the airplanes longitudinal axis canted downward 30 degrees with respect to the horizontal plane and with the wings level. Peak floor deceleration must occur in not more than 0.08 second after impact and must reach a minimum of 14 g.

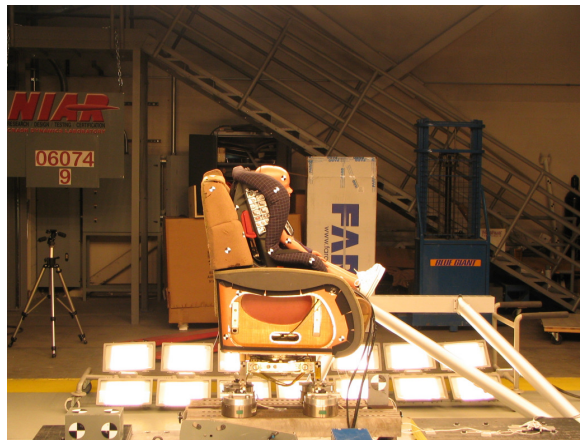

Figure 6. Type II Test setup with PART 25 Aircraft Seat.

- For the second test, the change in forward longitudinal velocity may not be less than 44 feet per second, with the airplanes longitudinal axis horizontal (no 10 degree yaw). Peak floor deceleration must occur in not more that 0.09 second after impact and must reach a minimum of 16 g. Where floor rails or floor fittings are used to attach the seating devices to the test fixture, the rails or fittings are not misaligned (no 10 degree pitch and no 10 degree roll).

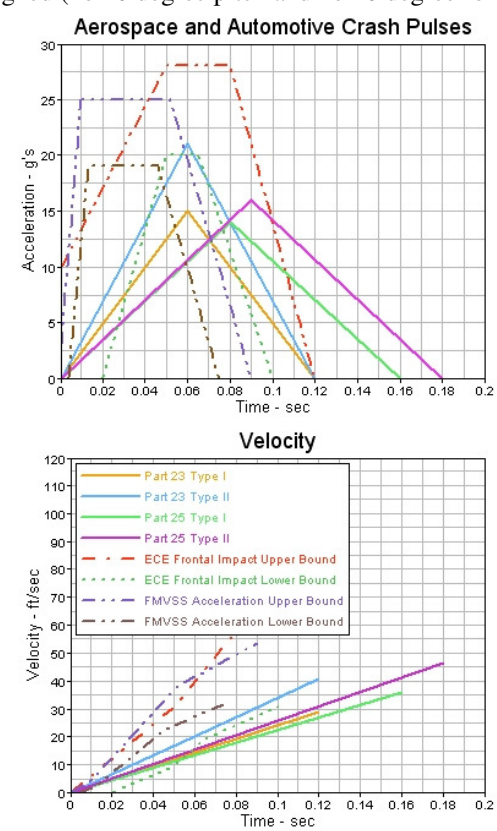

Figure 7. Automotive vs. Aerospace Crash Pulses.

Evaluation Criteria

The following factors extracted from FMVSS 213, ECE R44, FAR 23.562, and FAR 25.562 were applied to evaluate the dynamic performance of the child restraints.

Table 4.

Evaluation criteria

Criteria/Regulation	ECE R44	FMVSS 213	FAR 23 and 25 *
HIC 36	NA	1000	1000
Chest Z + Acc 3 ms	30 g's	NA	NA
Chest Res Acc 3 ms	55 g's	60 g's	NA
Lumbar Force Z	NA	NA	1500 lbf
Head Excursion	21.65 / 23.6 in	28.34 in	NA
Knee Excursion	NA	36.02 in	NA

* This value corresponds to a 50th percentile occupant, further research is required to find the appropriate scaling factor for children

12-Month-Old FAR 23.562 Rigid Seat Type I Dynamic Performance Comparison: ISOFIX vs. LATCH

As shown in the following figures in this section and in table 5, the dynamic performance of the 12-month-old CRS with either the ISOFIX or LATCH attachment is very similar. Forty three milliseconds into the crash event, there is a slight difference in the CRS horizontal acceleration due to the flexible construction of the LATCH system. This instantaneous increase in acceleration level induces a small increase in head-x acceleration, neck moments and seat pan reaction forces.

Table 5.

Summary injury values type I test 12 month

	TYPE I				
	ISOFIX	**LATCH**			
Test No.	06074-4	06074-5			
Pulse	Part 23.562	Part 23.562			
Seat Type	Rigid	Rigid	**ECE R44**	**FMVSS 213**	**Unit**
HIC 36	120	86	NA	1000	
Chest Z + Acc 3 ms	0.7	2.2	30	NA	g
Chest Res Acc 3 ms	31	31	55	60	g
Lumbar Force Z	-76	-72	NA	NA	lbf
Seat Excursion	25.86	28.32	NA	NA	in
Knee Excursion	NA	NA	NA	NA	in

Figure 8. LATCH and ISOFIX Configurations.

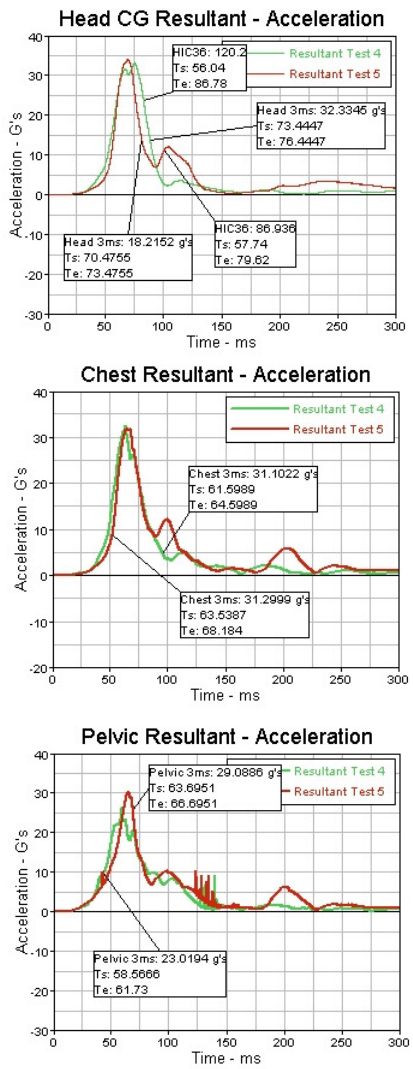

Figure 9. Head, Chest, and Pelvis Acceleration.

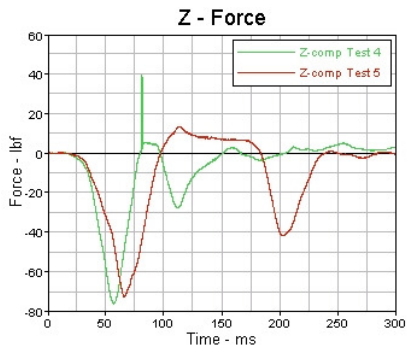

Figure 10. Lumbar Load.

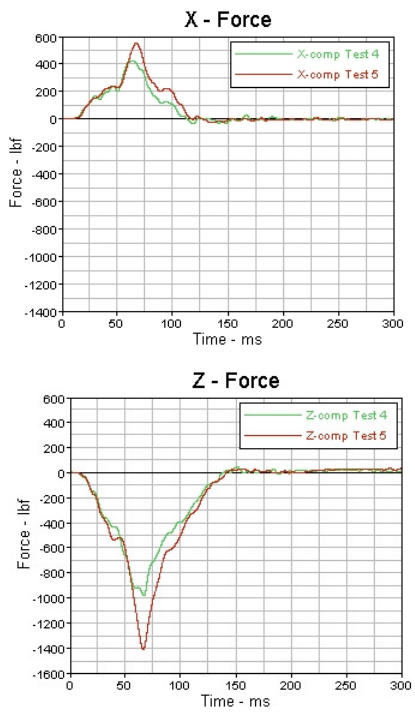

Figure 11. Seat Pan Reaction Forces

12-Month-Old FAR 23.562 Rigid Seat Type II Dynamic Performance Comparison: ISOFIX vs. LATCH

The dynamic performance of the 12-month-old CRS with ISOFIX or LATCH attachment is very similar. Thirty milliseconds into the crash event, there is a slight difference in CRS horizontal acceleration due to the flexible construction of the LATCH system. This instantaneous increase in acceleration level induces a small increase in head, torso, and pelvis accelerations, neck moments, and seat pan reaction forces.

Table 6.

Summary injury values type II test 12 month

	TYPE II				
	ISOFIX	LATCH			
Test No.	06074-3	06074-12			
Pulse	Part 23.562	Part 23.562			
Seat Type	Rigid	Rigid	**ECE R44**	**FMVSS 213**	**Unit**
HIC 36	233	340	NA	1000	
Chest Z + Acc 3 ms	26	29	30	NA	g
Chest Res Acc 3 ms	33	40	55	60	g
Lumbar Force Z	-5	-14	NA	NA	lbf
Seat Excursion	27.57	31.37	NA	NA	in
Knee Excursion	NA	NA	NA	NA	in

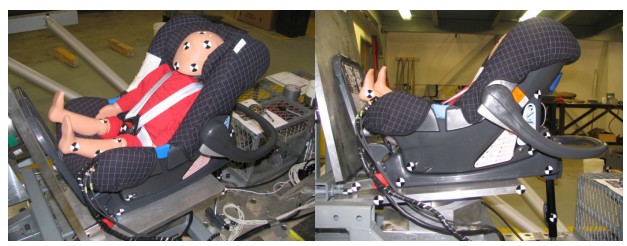

Figure 12. Infant Seat Type I Test.

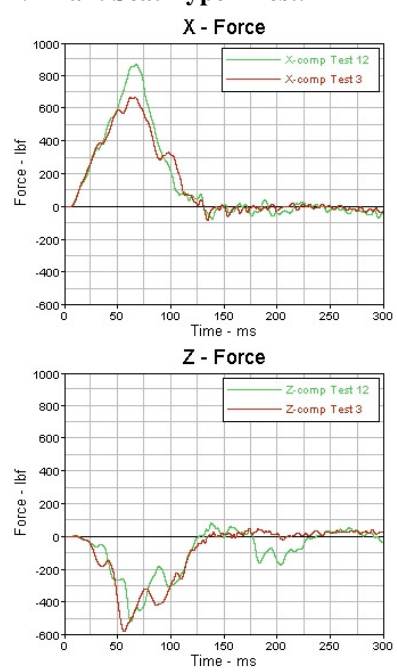

Figure 13. Seat Pan Reaction Forces.

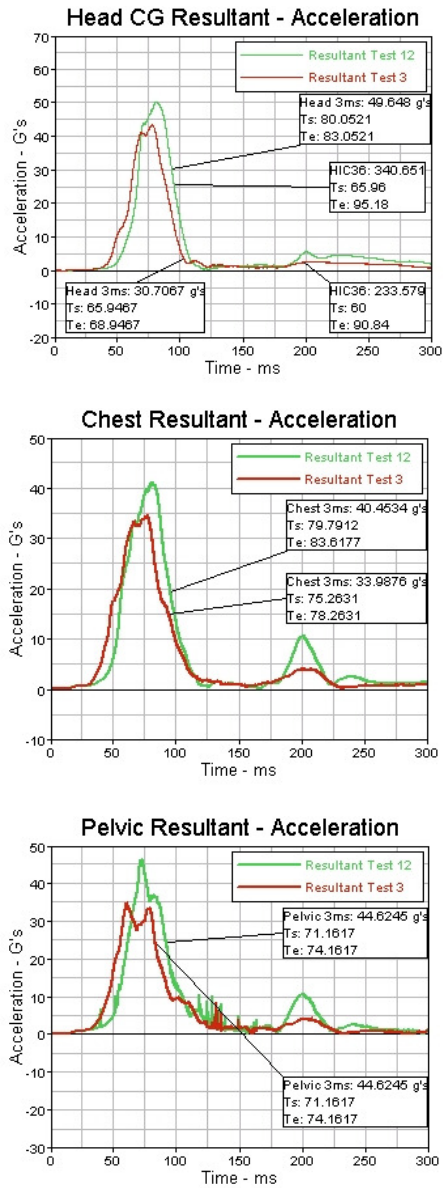

Figure 14. Head, Chest, and Pelvis Acceleration.

Three-Year-Old FAR 23.562 Rigid Seat Type I Dynamic Performance Comparison: ISOFIX vs. LATCH

As shown in the following figures in this section and in table 7 the dynamic performance of the 3 YOLD CRS with ISOFIX or LATCH attachment is very similar. Sixty five milliseconds into the crash event, there is a slight difference in CRS horizontal acceleration (see figure 17) due to the flexible construction of the LATCH system. This instantaneous increase in CRS acceleration level induces a small increase in occupant head, torso, and pelvis accelerations.

Table 7.

Summary injury values type I test 3 YOLD

	TYPE I				
	ISOFIX	LATCH			
Test No.	06074-8	06074-6			
Pulse	Part 23.562	Part 23.562			
Seat Type	RIGID	RIGID	**ECE R44**	**FMVSS 213**	**Unit**
HIC 36	71	93	NA	1000	
Chest Z + Acc 3 ms	3	4	30	NA	g
Chest Res Acc 3 ms	36	41	55	60	g
Lumbar Force Z	-654	-716	NA	NA	lbf
Head Excursion	10.8	17.84	23.6	28.34	in

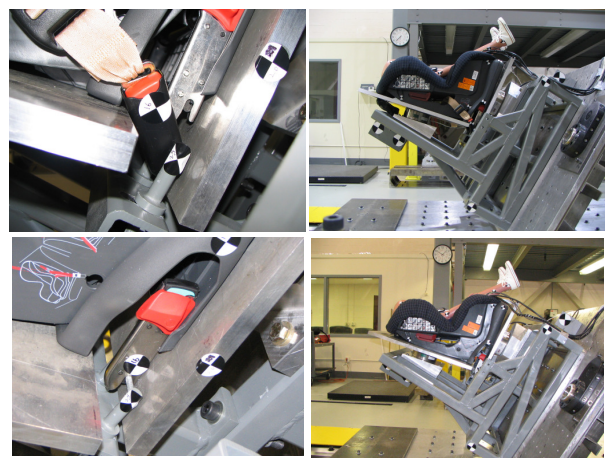

Figure 15. Three YOLD ISOFIX and LATCH Setup.

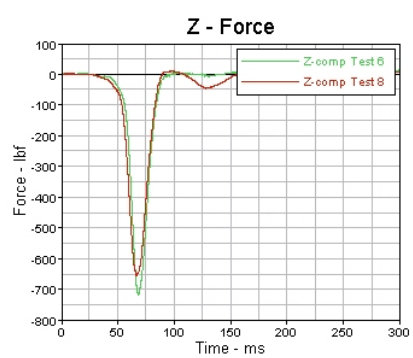

Figure 16. Lumbar Load.

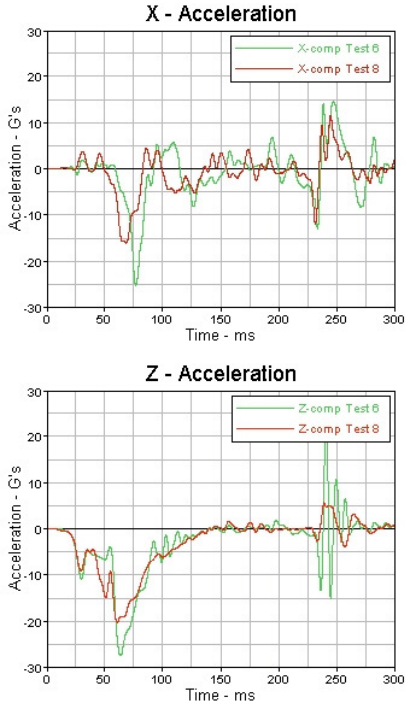

Figure 17. CRS Accelerometers.

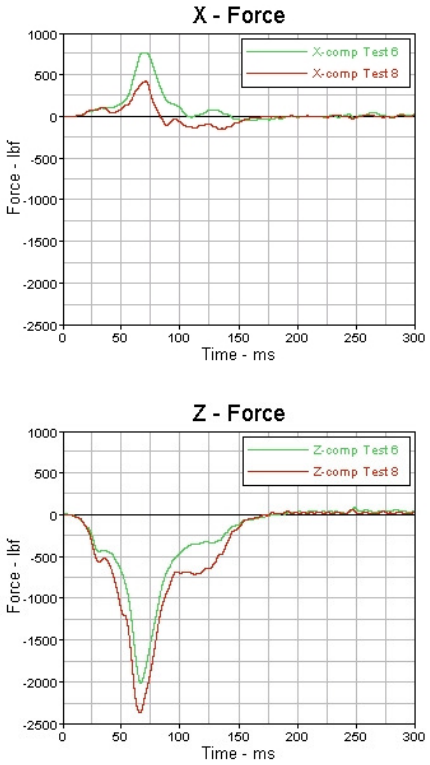

Figure 18. Seatpan Reaction Forces.

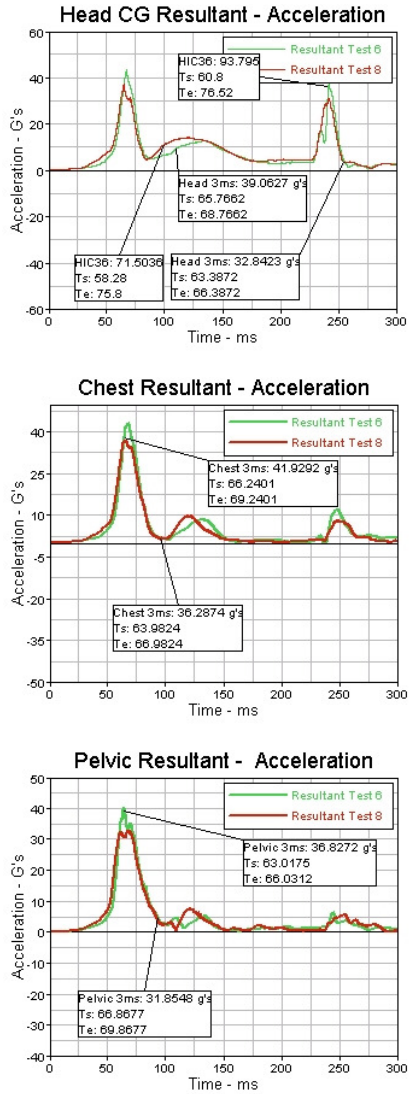

Figure 19. Head, Torso, and Pelvis Resultant Acceleration.

<u>Three-Year-Old FAR 23.562 Rigid Seat Type II Dynamic Performance Comparison: ISOFIX vs. LATCH</u>

As shown in the following figures in this section and in table 8, the dynamic performance of the 3 YOLD CRS with ISOFIX or LATCH attachment is very similar. Fifty five milliseconds into the crash event, there is a slight difference in CRS horizontal acceleration, which induces a small increase in occupant, torso, and pelvis accelerations (see figures 21 and 22).

Figure 20. Three YOLD Type II Test Configuration.

Table 8

Summary injury values type II Test 3 YOLD

	TYPE II				
	ISOFIX	LATCH			
Test No.	06074-16	06074-11			
Pulse	Part 23.562	Part 23.562			
Seat Type	RIGID	RIGID	**ECE R44**	**FMVSS 213**	**Unit**
HIC 36	221	NA	NA	1000	
Chest Z + Acc 3 ms	7	8	30	NA	g
Chest Res Acc 3 ms	32	36	55	60	g
Lumbar Force Z	NA	NA	NA	NA	lbf
Head Excursion	10.75	15.01	23.6	28.34	in

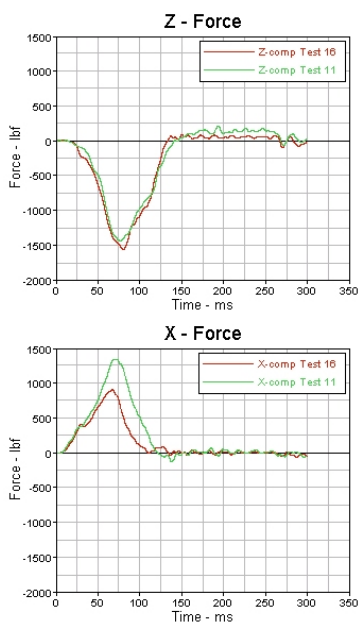

Figure 21. Seatpan Reaction Forces.

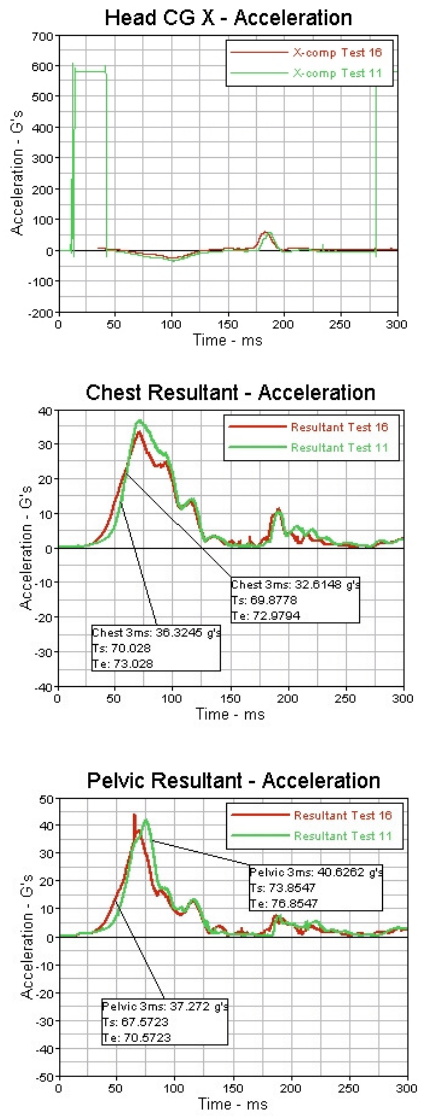

Figure 22. Head, Torso, and Pelvis Resultant Acceleration.

Three-Year-Old FAR 23.562 Type I Dynamic Performance Comparison: Aircraft Seat

The ISOFIX system provided a stable interface for the CRS. This test meets all FMVSS 213 and ECE R44 criteria. According to the video data, the CRS did not have any interaction problems with the aircraft seat cushion during the crash event. This test shows that, for this aircraft installation, it is not necessary to use the upper tether to prevent large CRS rotations or large head excursions. Further work is required to quantify lumbar load values on occupants other than at the 50th percentile. Even though the -458 lbf lumbar load is less than the -1500 lbf specified in the FARs for the 50th percentile, a proper scaling factor needs to be defined in the future for the 12-month-old, 3 YOLD, and 6 YOLD occupants.

Table 9.

Summary Injury Values 3 YOLD Type I Test

	VALUE	FMVSS 213	ECE R44	FAR 23 AND 25	Units
HIC 36	70	1000	NA	1000	
Chests Acc 3 ms Z +	9.81	NA	30	NA	g
Chest Acc 3ms RES	28	60	55	NA	g
Lumbar Force Z	-458	NA	NA	1500	lbf
Head Excursion	17.6	28.34	23.6	NA	in
Knee Excursion	NA	NA	NA	NA	in

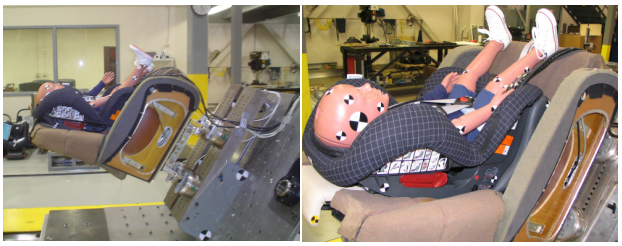

Figure 23. Three YOLD Test Setup.

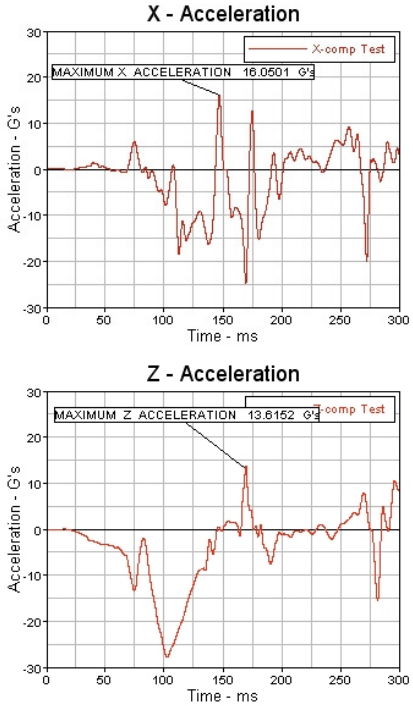

Figure 24. CRS Accelerations.

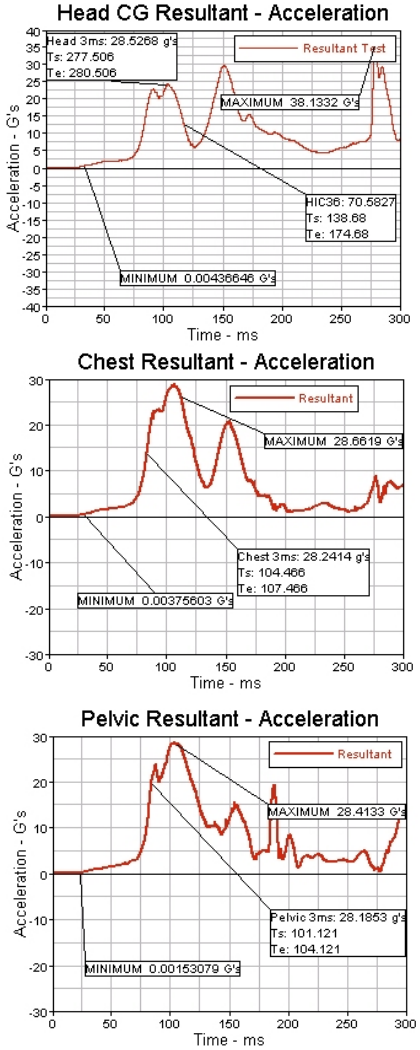

Figure 25. Head, Torso, and Pelvis Resultant Acceleration.

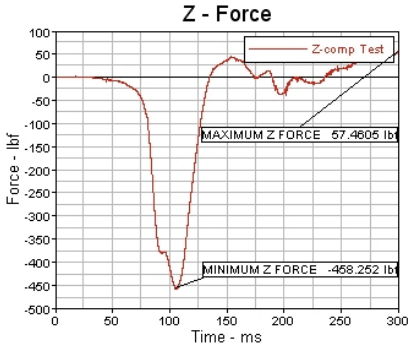

Figure 26. Lumbar Load.

<u>Three-Year-Old FAR 23.562 Type II ISOFIX System Dynamic Performance: Aircraft Seat</u>

The ISOFIX system provided a stable interface for the CRS. This test meets all FMVSS 213 and ECE R44

criteria. Note that no upper tether was used for the test in order to reduce the aircraft installation.

Table 10.

Summary injury values 3 YOLD Type II

	VALUE	FMVSS 213	ECE R44	FAR 23 AND 25	Units
HIC 36	435	1000	NA	1000	
Chests Acc 3 ms Z +	9.8	NA	30	NA	g
Chest 3ms RES	25	60	55	NA	g
Lumbar Force Z	-59	NA	NA	1500	lbf
Head Excursion	23.32	28.34	23.6	NA	in
Knee Excursion	23.2	36.02	NA	NA	in

Figure 27. 3YOLD Test Setup.

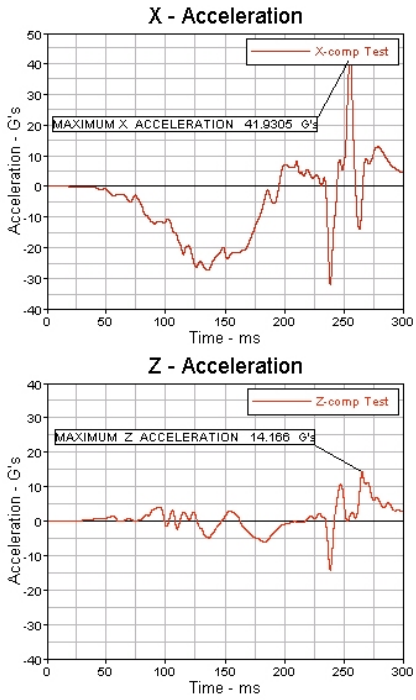

Figure 28. CRS Acceleration.

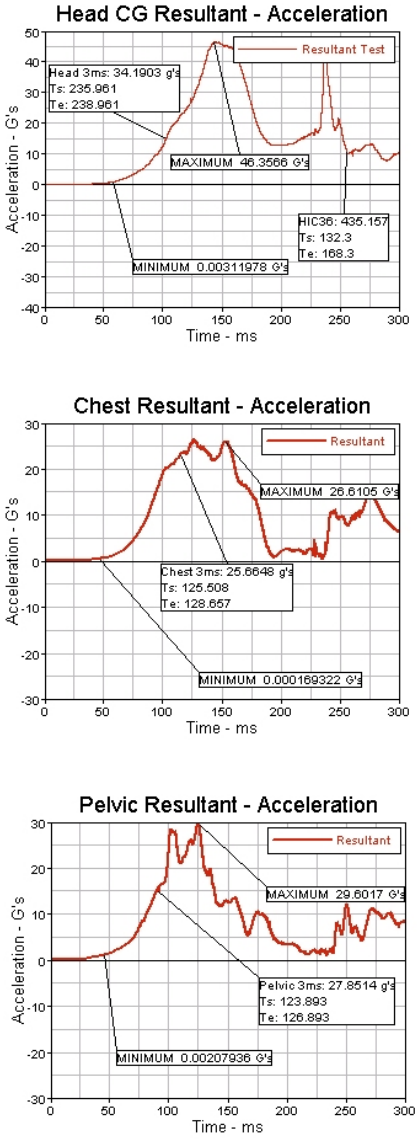

Figure 29. Head, Torso, and Pelvis Acceleration.

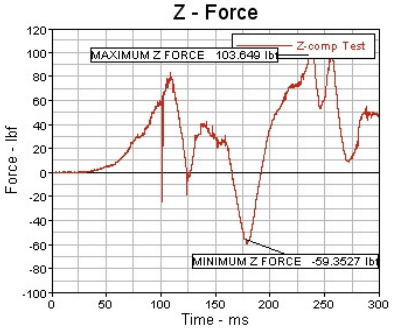

Figure 30. Lumbar Load.

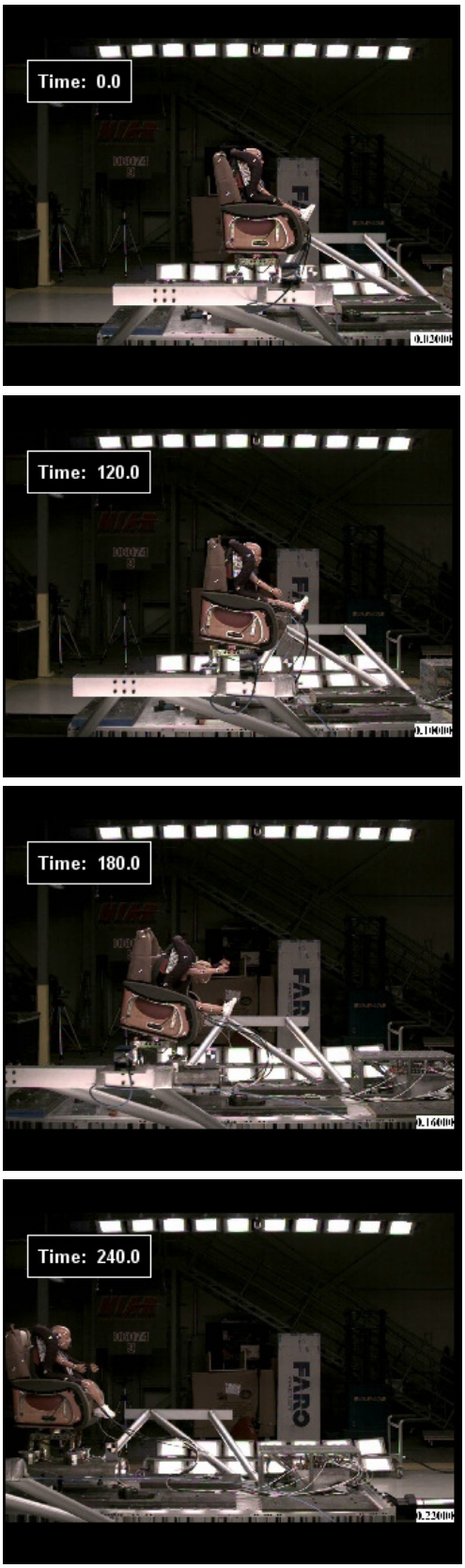

Figure 31. Three YOLD Kinematics.

CONCLUSIONS AND FUTURE RESEARCH

Based on the results from the dynamic sled tests conducted in this study, there is sufficient data to conclude that the ISOFIX and LATCH systems can solve the interface issues found in the past between the CRS and aircraft seats due to aircraft seatbelt incompatibilities. If aircraft seats in the future would be equipped with rigid anchors, the new CRS systems will provide the appropriate level of safety, and issues such as the large CRS excursions found in the past when the CRSs were secured by the aircraft two point belt system will be eliminated.

While this study provides an overview of the viability of the ISOFIX and LATCH systems, the following additional research needs to occur in order to develop aerospace standards and recommendations:

a) Additional dynamic and static testing with production Part 23 and 25 aircraft seats in order to address the following issues:

- Implementation of ISOFIX/LATCH anchor points in various Part 23/ 25 aircraft seat structure
- Effect of seat back break-over features found in current commercial aircraft seats
- Effect of different aircraft seat cushion materials in CRS performance
- The interaction with other occupants sitting in the row behind the CRS
- CRS/aircraft seat dimensional compatibility studies

b) Studies involving the application of FAR 25.561, 23.561, 25.785, and 23.785 inertial requirements on aircraft CRS attachments or the definition of new static requirements for the seat anchors.

c) Evaluation of CRS products of various manufacturers

d) Definition of a retrofit procedure to implement fixed anchorages on current aircraft seats, and the effect on their current certification status

e) Study the impact of requiring the usage of CRS on commercial aircraft operations and passengers, from both economic and ergonomic points of view

f) Definition of dynamic test criteria for CRS used in aircraft seats

g) Definition of lumbar load injury criteria to evaluate CRS performance

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support and technical contributions of the NIAR Industry State Consortium (NIS), Britax Child Safety, and IPECO.

REFERENCES

[1] National Transportation Safety Board 2005-2006 Most Wanted Transportation Safety Improvements, accessed at http://www.ntsb.gov/.

[2] Van Gowdy, DeWeese, "The Performance of Child Restraint Devices in Transport Airplane Passenger Seats", DOT/FAA/AAM-94/19, September 1994.

[3] Federal Motor Vehicle Safety Standards, FMVSS-571.213, "Child Restraint Systems," National Highway Traffic Safety Administration, DOT.

[4] NHTSA, Occupant Protection for Children Safety Information, accessed at http://www.nhtsa.dot.gov /people/injury/childps/safetycheck/OccProtetcFor_Children1.pdf.

[5] International Standard - ISO 1316-1 – Part 1: Seat Bight Anchorages and Attachments.

[6] Federal Motor Vehicle Safety Standards, FMVSS-571.225, "Child Restraint Systems," National Highway Traffic Safety Administration, DOT.

[7] AC 120-87 A, "Use of Child Restraint Systems on Aircraft", December 2006.

[8] First Technology ATD Specifications, accessed at http://www.ftss.com.

[9] 14 CFR 23.561 and 562 - Emergency Landing Conditions.

[10] Denton ATD Specifications, accessed at http://www.radenton.com/.

[11] American Academy of Pediatrics, Restrain Use on Aircraft, PEDIATRICS Vol. 108 No. 5 November 2001, pp. 1218-122

REVISED ASSESSMENT PROTOCOLS AND SCORING METHODS FOR THE AUSTRALIAN CHILD RESTRAINT EVALUATION PROGRAM

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ABSTRACT

A consumer information based child restraint evaluation program was initiated in Australia in 1992. The assessment and evaluation procedures used in this program were recently reviewed and as a result, the assessment protocols and scoring methods have been significantly enhanced. This paper presents the revised assessment methods currently being used in the Australian Child Restraint Evaluation Program. The program includes both a dynamic performance assessment and an ease of use assessment.

Dynamic assessment includes frontal testing (56km/h and 34g) and two side impact tests (90 degree, 32 km/h and 16g; and 66 degree, 32 km/h and 16g). The side impact test set up includes a non-intruding side door structure. Rearward facing, forward facing and booster seats are subjected to all dynamic tests using dummies corresponding to their upper mass range design limits. An approach based on an objective, pre-defined rating matrix was developed to score and rate the relative dynamic performance.

The ease of use assessment method is based on the North American methods used by ICBC and NHTSA. Some enhancements to the individual items assessed and the ratings used were made to suit Australian conditions. Details of these enhancements are presented.

A scoring system that allows for a four step (A-D) rating system for both the dynamic and the ease of use performance was introduced and this is also presented and discussed in detail in this paper. Exemplar results from the first series of assessments are presented to demonstrate the benefits of the revised protocol and the scope for further improvements to the methods being used.

The process for the release of the test results and the response from media are also outlined.

BACKGROUND

The Australian Child Restraint Evaluation Program (CREP) has been operating in Australia since 1992. Like all consumer information programs, the underlying philosophy is to influence consumers and to provide motivation for manufacturers to market products that are at least equal to the best currently available, and that offer protection above the minimum requirements of the Australian Standard for child restraints (AS 1754). The first CREP was comprised of three assessment units; an assessment of dynamic crash performance; an evaluation of ease of installation and use; and an assessment of vehicle compatibility.

Original ease of installation and use trials were modelled on a draft International Standards Organization (ISO) child restraint system fitting trial standard that required recruitment of child and adult subjects [1]. This method proved to be a relatively expensive and time consuming exercise that did not reflect the observed problems with misuse. Following publication of results from the first CREP series, ease of use protocols were simplified and combined with the vehicle compatibility trial. This combination was then used for CREP Stages 2 (1996) and 3 (1999-2000).

More recently, Rona Kinetics developed comprehensive ease of use assessment protocols for the Insurance Corporation British Columbia (Canada) [2]. These were then adapted further by the National Highways Traffic Safety Administration (NHTSA) [3]. This development, together with concerns that the Australian CREP dynamic performance assessment was not keeping pace with test severities in New Car Assessment Program protocols, led to a review of the CREP assessment procedures in 2005. The outcomes from this review were more comprehensive ease-of-use assessment protocols, a revised dynamic test protocol and innovative scoring protocols [4].

This paper describes the new protocols being used in the Australian CREP and presents exemplar results achieved with these protocols.

EASE OF USE ASSESSMENTS

Misuse of child restraints is a significant problem, both in terms of frequency and consequence [5-12]. Reducing the propensity for misuse through improved restraint design is an important countermeasure to this problem. Review of results from earlier releases of the Australian CREP demonstrated that while substantial comparative information was collected about the ease of use of restraints on the Australian market (showing there were considerable differences between products), little information regarding the outcome of these assessments was actually communicated to the public. Furthermore, the methods used relied wholly upon expert opinion and were not documented in an objective way.

Following this review, significant changes were made to the ease of use evaluations and a methodology developed that allows for more objective rating of features weighted on their likely impact on reducing misuse, and the types of misuse that are influenced. This method is heavily based on the current North American ease of use rating schemes [3].

The ease of use criteria used are summarised in Appendix 1. Full details can be found at http://tinyurl.com/29me5k. The protocol is very similar to that used by NHTSA [3] with additional assessments of some features and a modified feature assessment ranking.

This method requires each feature listed within five 'categories' to be assessed individually. The 'categories' are: Packaging, Instructions, Labels, Securing/Releasing the Child, and, Securing/releasing the restraint within the vehicle (the latter was not used for booster ratings). Good, Acceptable, Marginal and Poor ratings were recorded for each feature according to the criteria set out for that feature (see Appendix 1), and where necessary additional comments were made. Results were stored within an electronic database. Digital photographs of each restraint and relevant components were taken.

As with earlier iterations of CREP, each device was evaluated by a single 'expert' assessor. However, to increase confidence in ratings, a second 'expert' independently did audit style assessments on a small sample of the restraints. A panel then compared the results and where appropriate, reviewed the assessment criteria and ratings for all restraints.

Initially, it was intended to use the same scoring protocol as NHTSA [3]. In this method each feature within each category is assigned a weighting factor of either 3, 2 or 1 according to risk of injury and severity of misuse. The features associated with the highest risk of severe injury if misuse occurs are given a 3 weighting. A numerical scale is also used to score the assessment outcome for each feature, with 3 points equating to good, 2 points to acceptable and 1 point to marginal and zero for poor. Under the NHTSA method, the two numbers are then multiplied together to provide a feature score (from 9 to zero). The scores within each category are then summed and divided by the sum of the applicable fixed weighting factors to provide a weighted average score. Similarly, an overall weighted average score is obtained by dividing the sum of all feature scores by the sum of all fixed weighting factors. The NHTSA weighted average will always be between 1 and 3 and within this range either 'C' 'B' or 'A' ratings are awarded for scores of < 1.7, 1.7 but < 2.4 and 2.4 – 3, respectively.

This approach to scoring had never been attempted in Australia. For this reason, results obtained using this ranking procedure, were carefully examined prior to finalization of the scoring protocol. Early analysis revealed that the "A, B, C" ratings did not usefully discriminate between products. This was contrary to the outcomes from direct observation of restraints during assessment, which identified significant differences. In particular most categories and overall ratings came out a "B" under the tripartite method. To overcome these problems, the weighted average method has been modified to allow A, B, C, and D ratings to be assigned for each category and for the overall performance to be based on a quartile ranking system.

In addition, a weighting factor of 4 was introduced to provide for design features that were innovative and effective in reducing the propensity for misuse. An example is "Audible and visual indication that harness is adjusted correctly" (See Appendix 1).

Under the NHTSA ranking method the range between the maximum and minimum value (with minimum value being 1/3 of the maximum value) is divided into 3 equal segments. Breakpoints are therefore 80% of the maximum score and above for A, 57% of the maximum score and above for B and below 57% for C. Our modification involves dividing this same range (i.e. range between maximum and 1/3 of the maximum) into four, so that breakpoints become 83% of maximum and above for A, 67% and above for B, 50% and above for C. Anything under 50% results in a D.

In the case of the overall rating, it was decided to assign equal weights to each category, since safety-related issues are inherent in the weights assigned to each feature within a category. Therefore an overall

percentage was calculated from the average of the category percentages. The overall rating for a mode (forward or rear facing) was based on the same quartile breakpoints (83%, 67% and 50%). For convertibles, an overall rating was based on the worst mode rating.

The process for determining scores and ratings is graphically illustrated in Figure 1.

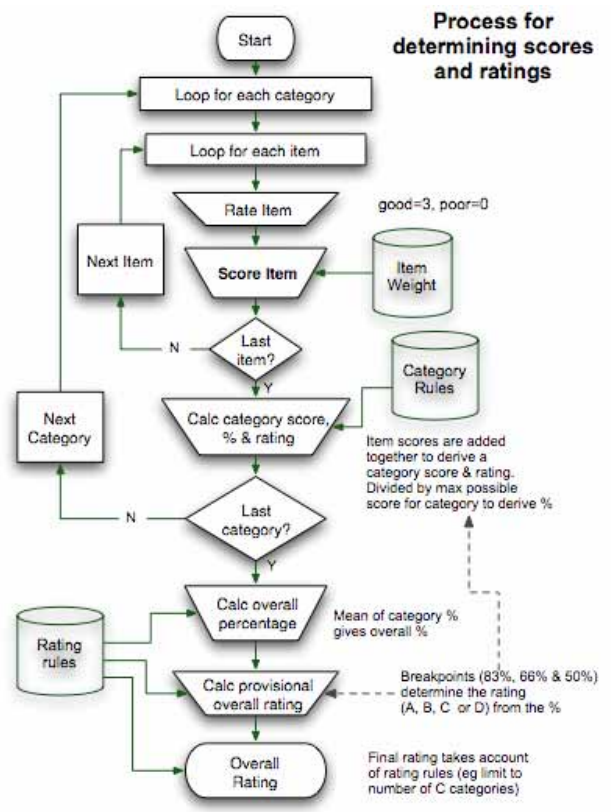

Figure 1. Ease of use rating process.

Exemplar overall ease of use results are shown below in Figures 2-4. As shown in these results all restraints assessed in this series scored an overall B or C rating. While the protocols allowed for discrimination across the spread of results, the spread was still relatively small. Rather than a reflection of the protocols, this is likely due to the fact that less than half of the currently available restraints have been tested and most of these were from a single manufacturer. Therefore instruction booklets and labels etc have the same format.

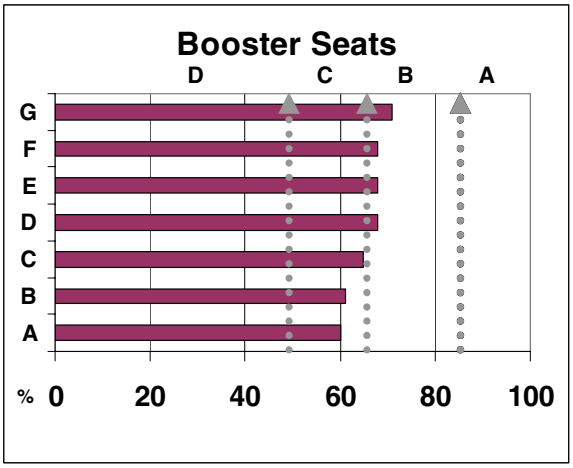

Figure 2. Ease of use overall results – Boosters.

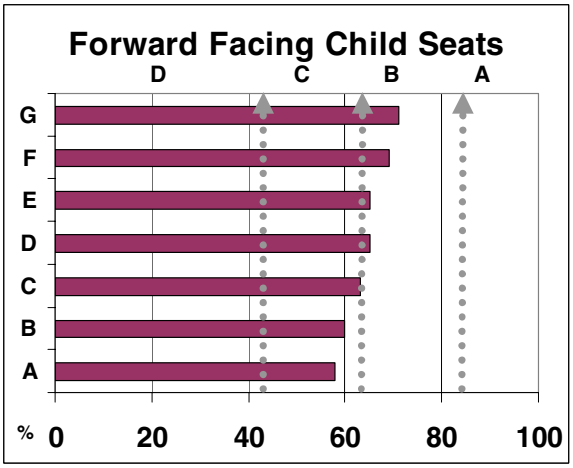

Figure 3. Ease of use overall results - Forward facing child seats.

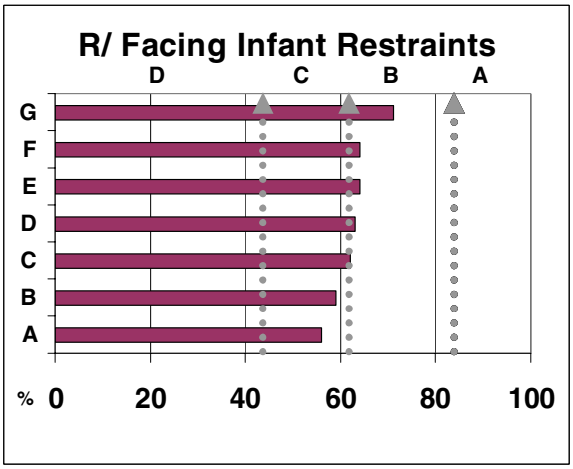

Figure 4. Ease of use overall results - Rearward facing infant restraints.

The fact that no restraint achieved an 'A' rating reflects the scope for improving features that would influence the propensity for misuse.

At this stage only the overall rating score is published in public documents, and available on stakeholder websites. However, scores from the individual categories (shown in Figures 5-7) provide more detailed information, both regarding the comparative performance and the scope for improvement.

Since there is little involved in installing a booster seat into a vehicle, this category was not assessed in this type of restraint. The results from the other categories assessed are shown in Figure 5 and illustrate distinct differences between restraints. While securing a child within a booster seat is relatively uncomplicated, the relatively low scores shown in Figure 5 related to this task (51%-62%) reflect the scope for improvement in this regard. The incorrect use of the seat belt in combination with booster seat use is a common observation in the field. Booster design features that minimise the likelihood of this form of misuse are to be encouraged. Therefore many boosters fell short in providing adequate ease of achieving and maintaining the correct belt path. Booster seats are also required to serve children over a wide range of seated heights. Many seats also failed to provide for children across the full spectrum of anthropometry.

Most of scores shown in Figure 5 related to features related to labelling were in the 78-79%, but 2 devices scored only 64%. There was a similar range in scores in the instruction booklet category. Both labelling and instructions are covered by the Australian Standard, and the major scope for improvement for the boosters seen to date, would be in the clarity and positioning of labels; and the clarity and provision of information in other languages in the instructions.

As shown in Figure 5, there were distinct differences in the quality of packaging, primarily in regard to the level and clarity of information supplied concerning which children should be using boosters. Premature graduation from booster seats to seat belts, and from forward facing child seats to booster seats are widespread problems in the field [11-12]. Providing this type of information clearly on packaging would greatly assist parents and carers in making good choices at the point of purchase.

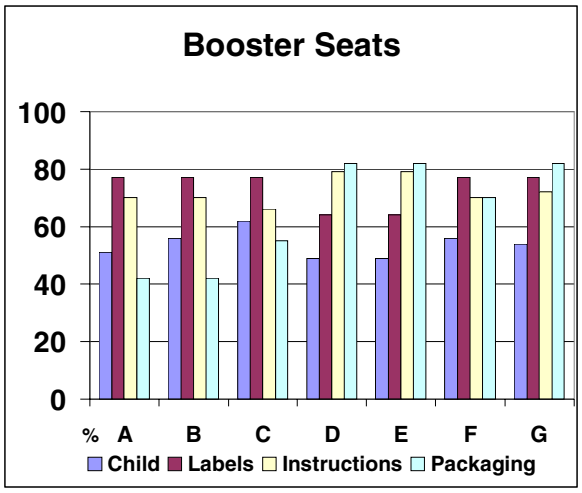

Figure 5. Ease of use category results- Boosters.

Exemplar results from the feature categories for forward facing seats are shown in Figure 6. Features related to ease of installation was assessed in these restraints. There was one restraint that clearly stood above the others in this regard, primarily due to the lack of complexity in achieving the correct belt path. However, there is room for improvement in all restraints, primarily in providing some form of feedback to users when the restraint is not installed correctly.

There were also substantial differences in features related to achieving proper use of the internal harness system, with a range of scores between 48% and 69%. The poorer scoring devices fell short in items related to the ease of removing the restraint cover and rethreading the harness. Again there is scope for improvement in the provision of some feedback mechanism, so that users know when the restraint is being used correctly. The range of scores in the label category was similar (48%-71%). Problems observed in this category included the positioning and clarity of labels. Ideally labels should include pictograms and be positioned near the task to which they refer.

Figure 7 illustrates exemplar results for rearward facing infant restraints. Most of the rearward facing restraints on the market in Australia are convertibles. The need for installation in two different ways results in potential for confusion around the correct seat belt path and is reflected in these reuslts. (This was also apparent in the convertibles among the forward facing restraints). The need for colour coding seat belt paths, labels and instructions for the different modes is high, and the lack of these features in Australian restraints affected the scores across a number of categories.

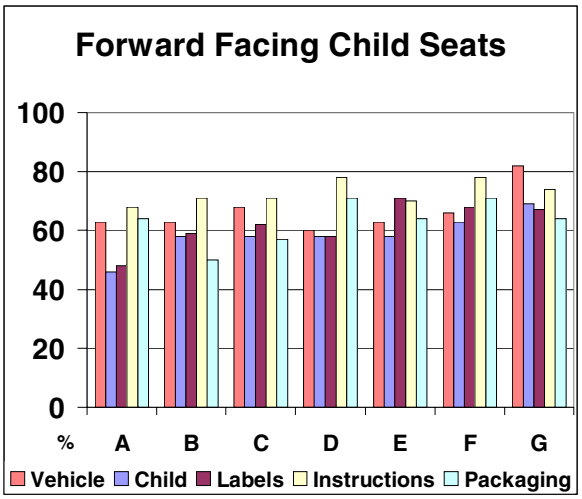

Figure 6. Ease of use category results- Forward facing child seats.

As was the case for forward facing restraints, there were significant differences in the ease of achieving and maintaining proper use of the restraint, with scores ranging from 42-70%. Again the poorer performers did not allow for the easy removal of covers and rethreading of the harness system, and all devices could be improved through the provision of feedback mechanisms to indicate correct use. Similar problems with labelling and instructions to that observed among the forward facing seats were also apparent in the rearward facing restraints.

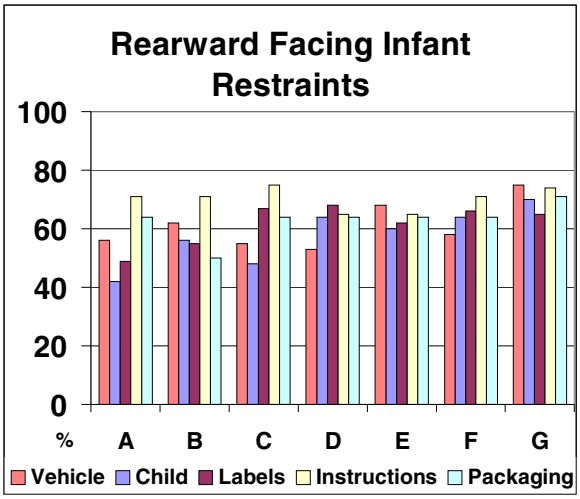

Figure 7. Ease of use category results - Rearward facing infant restraints.

Finally, it is important to note that not all restraints currently on the Australian market were assessed to the new protocols and that the exemplar results presented in the above Figures are a sample of the restraints that have been assessed thus far.

DYNAMIC PERFORMANCE ASSESSMENTS

Since its inception in 1992, the Australian CREP has included an assessment of dynamic performance in front, side, rear, and (for rearward facing restraints) inverted simulated impacts. The dynamic performance has been the focus of the rankings and information provided to consumers.

In the past, two frontal impacts were conducted, one at the same severity as the Australian Standard (49km/h, 20g), and one at a higher severity of 56km/h and 34g. The higher severity pulse originates from peak vehicle floor pan accelerations in the small number of vehicles tested in ANCAP in 1992, and also represents the upper acceleration envelope specified for the frontal tests in the Australian Standard.

In the first series of CREP, all restraints were subjected to both tests. However in all previous series since then, booster seats have been excluded from the higher severity test due to concerns regarding the robustness of the test dummy. Booster cushions (i.e. booster seats with no back) have not been included in the program since the first series of CREP.

Review of results obtained from these earlier evaluations found no worthwhile information was being gained from the lower severity frontal impact test. As a consequence the 48km/hr test has been dropped, and all restraints, including booster seats, are now subjected to the 56km/h test with a 34g pulse.

In frontal impacts in the revised protocols, dummy choice is based on the mass of the dummy being equal to or above the upper end of the mass limit for each type of restraint. The TNO P3/4 (9kg) is used for rearward facing restraints with upper mass limit of 9; the TNO P11/2 (11kg) for rearward facing restraints with upper mass limit of 12kg; the TNO P6 (22kg) for forward facing restraints (upper mass limit of 18kg); and the TNO P10 (32kg) for booster seats (upper mass 26kg).

Underscoring the development of the assessment protocols is a philosophy based on assessing the comparative performance of each type of restraint with respect to what the protective aims of that type of restraint are, rather than one based on biomechanical injury criteria.

For rearward and forward facing restraints in frontal impact, a high level of importance is placed on head displacement and measures that assess how well the restraint manages dummy deceleration.

No pre-defined limits of head excursion performance were set. Instead, the revised protocols allow for an objective comparison of restraint performance. Head excursion is recorded and scores assigned based on the range of excursions obtained. The best score (4) is given to that restraint with the least head excursion, the next best (3) to those within 50mm of that excursion, and so on. Similarly, head energy management is scored using the range of HIC36 scores obtained. The range is divided into 3 and the best score given to those devices in the lowest third and the worst score given to those in the highest third.

One of the primary design objectives of rearward facing restraints should be ensuring the distribution of crash forces is through the back of the child (or dummy). In earlier versions of CREP, head accelerations were used to assess how the crash forces were distributed in frontal impact, but review of the results from earlier programs demonstrated that chest accelerations are more reliable. If crash forces are distributed through the back of the dummy, the chest g's in the x axis should at least be equal to the those in the z axis, and a restraint that does this really well should have a higher deceleration through the x-axis than through the z-axis. Load distribution scores were assigned using a range reflecting this concept. An 'unacceptable' rating (i.e. a score of zero) was assigned if the chest X-axis peak g was less than 100% of the Z-axis peak g, but ≥ 90% of the Z-axis value. The next lowest score (1) was given when the acceleration in the x and z direction was approximately equal, and the higher scores awarded when more of the load was being distributed through the x direction. The highest possible score was awarded when the peak g in the x-axis was 130% or more of that in the z-axis. This ratio was chosen as it represents the best performing device currently on the market.

A complementary measure of restraint ride down was also made in the assessment of rearward facing restraints in frontal impact. This measure, called TEM (torso energy management) is calculated from the resultant chest acceleration over a specific time period (in a similar manner to HIC) and was scored in the same way as HIC. That is the range of TEM values obtained were divided into three and scores awarded accordingly.

Booster seats aim to improve the fit of the adult lap sash belt and their performance, particularly in frontal impact, should be assessed in these terms. In frontal impact tests, a high priority is therefore placed on the pre impact and during impact positioning of the sash and lap parts of the belt. High scores (4) were given when:

- the pre impact position of the sash was across and in contact with the dummy's shoulder and chest and essentially remained in place during impact, and
- the lap portion of the belt remained in place over the dummy's pelvic region, during the impact phase of the test.

Unacceptable (0) scores were given to those restraints that failed to meet these criteria and there was no criterion in between.

No attempt was made to compare head excursion or any measure of head energy management in booster seats in frontal impact. These types of measures were found to give misleading results since while they are heavily influenced by sash and lap strap positioning, low head excursion can be the result of submarining. This appeared to be the case in at least one of these tests.

Dummy retention in booster seats was assessed using three possible scores. A high score was awarded for complete retention and an unacceptable (0) score for complete ejection, of if the dummy's torso came free of the sash during the impact phase. A third low score (1) was available if the dummy's torso rotated so that it was only partially restrained by the sash.

To date, side impact performance in CREP has involved subjecting child restraints to two simulated side impacts; one test at 90 degrees and another at 45 degrees. The pulse used is the same as that required by the Australian Standard. To increase the severity of the test, a simulated side door structure was positioned adjacent to the test seat. The door which replicates a simplified rear door of a sedan, in shape and size, is a static structure.

Since the last CREP series and prior to the review of assessment procedures, the Australian Standard test methods and performance requirements in side impact were modified to also include the side door structure. This differs from the CREP door in that a poly carbonate inner door skin replaces the metal one used in CREP. Except for this detail, the 90 degree CREP side impact test now replicates the Standard test. In the Standard, booster cushions are exempt from this requirement.

The Standard also now requires all restraints to prevent head contact with the door. However for forward facing restraints and booster seats, the dummies specified by the Standard represent children at the lower end of the restraints size range, in terms of seated height. For this reason, the 90 degree test continues to be included in the CREP assessment, but

the dummies used are modified to better represent the seated height of children at the upper end of the size range. For forward facing restraints, tests are conducted with a TNO P3 with a seated height modified to 605mm. Similarly, the booster seats were tested with the seated height of a TNO P6 increased by 40mm. Assessments were made on the absence or presence of head contact as well as the degree of head containment.

During the review of the original procedures, the 45 degree test was also found to be providing limited information useful in discriminating between the performances of the restraints. As a consequence, the 45 degree test has been replaced with one that more closely resembles a US NCAP side impact - that is at 66 degrees. The same dummies and performance aspects assessed in the 90 degree test are used in the 66 degree test.

The same door structure was used in these tests as that used earlier iterations of CREP. At this stage, the side impact test pulse remains at 32 km/h and 17g. Review of recent Australian NCAP side impact data suggests that this is an adequate severity.

All restraints are subjected to both these tests. Booster cushions (i.e. boosters without backs) remain excluded from CREP assessment.

To provide high levels of protection in side impact, child restraint systems need to minimise contact between occupants and the vehicle interior and, if contact occurs, minimise the severity of that contact. The greatest priority is head protection. In earlier versions of CREP, head displacement was assessed through noting any contact between the dummy's head and the test rig. The inclusion of a comparative HIC score was considered in this revision of the CREP protocols. However data from past (and this current) test series revealed the HIC values obtained depend more on the stiffness of the location of the contact between the door and the restraint than on the properties of the restraint. Even for restraints that completely contain the head, the variability in restraint/door contacts results in this measure being a poor indicator of any individual restraint's energy absorption features. Therefore no assessment of this type was included in this revision, but work continues on the development of an appropriate way to assess this important feature.

While the inclusion of head/door contact requirements in the Australian Standard has resulted in all devices providing some degree of head containment for the TNO P3 dummy, there is variability. For this reason the degree of head retention in side impact is also assessed. The highest score (4) is given if the head remains completely within the confines of the side wings, and a low score (1) is given if part of the dummy's head is exposed over the rim of the side wings during the impact phase of the test, but a head strike does not occur out side the device. Similarly, the Australian Standard requires the dummy to be retained in the device, however observations made in past and the present series revealed that in some cases one shoulder escaped from the harness in side impact. A high score for dummy retention was awarded when the dummy was fully retained and a low score (1) awarded if the dummy's torso was only partially restrained (one shoulder restrained) by the harness.

The rear impact and simulated inverted impact used in CREP in the past have been dropped from the new protocols because during the review, they were found to not be providing useful comparative data.

Summarised details of the revised dynamic test protocols are provided in Appendix 2, full details can be found at http://tinyurl.com/26qjqp.

In earlier versions of CREP, ranking and scoring of results consisted of, "preferred buy" ratings being given to a number of devices in each restraint type category. These were awarded to restraints that performed well in a number of areas, however the method was relatively subjective. The recent review of the program determined that there was significant scope for development of a more objective rating system that included formal documentation of objective protocols. A ratings system similar in methodology to the system being used in the ease of use assessment (and based on the method used by NHTSA) was therefore developed.

The features being assessed in the dynamic component are divided into a set of performance categories. Within each category, there are a set of items or individual performance aspects (PA). Each PA has been given a weight between 1 and 4 based on their importance in terms of offering crash protection in the real world. A numerical scale of 4 (good) to 0 (unacceptable) is used to rate the outcome for each PA. Scores for each PA are obtained by multiplying the outcome score by the weight for that PA. Category scores are arrived at by adding the scores obtained for that category and calculating what percentage this is of the maximum possible score for that category. Each category is then awarded an A, B, C or D ranking based on the breakpoints set out in Table 1.

These breakpoints have been set on the basis that any device scoring less than or equal to 50% of the maximum score is judged as 'unacceptable' and given a 'D' ranking. The range between 50% and 100% has then been divided into 3 equal ranks.

There is also one limiting rule applied to category and overall rankings. This rule is that if any device receives two or more '0' scores (i.e. an 'unacceptable') score that device can not be awarded an A or B ranking for that category or for an overall ranking.

'Performance Aspect' Set Score	Overall Score
The 'PA' set score ≥ 83% of maximum 'PA' scores that could be obtained for the set	The sum of the 'PA' scores ≥ 83% of the sum of the maximum scores that could be obtained for all the 'Performance Aspects'
The 'PA' set score < 83% but ≥ 67% maximum 'PA' scores that could be obtained for the set	The sum of the 'PA' scores ≥ 66% but < 83% of the sum of the maximum scores that could be obtained for all the 'Performance Aspects'
The 'PA' set score < 66% but ≥ 50% of maximum 'PA' scores that could be obtained for the set	The sum of the 'PA' scores ≥ 50% but < 66% of the sum of the maximum scores that could be obtained for all the 'Performance Aspects'
The 'PA' set score < 50% of maximum 'PA' scores that could be obtained for the set	The sum of the 'PA' scores < 50% of the sum of the maximum scores that could be obtained for all the 'Performance Aspects'

Table 1.
Ranking score calculations –Dynamic Testing

Exemplar overall dynamic performance results are shown in Figures 8-10. As shown in these figures there was a wide range in performance both between restraints of the same category and different restraint types. Booster seats achieved the lowest ratings, with most restraints achieving a C. There were no A level performances awarded, only one B and a D, the latter to a very poor performing seat.

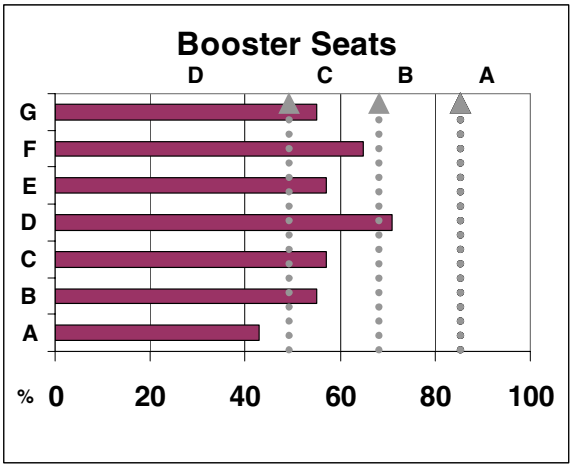

Figure 8. Dynamic overall results – Boosters.

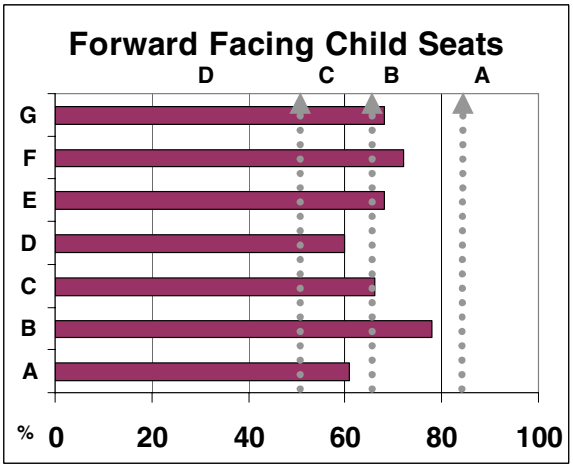

Figure 9. Dynamic overall results - Forward facing child seats

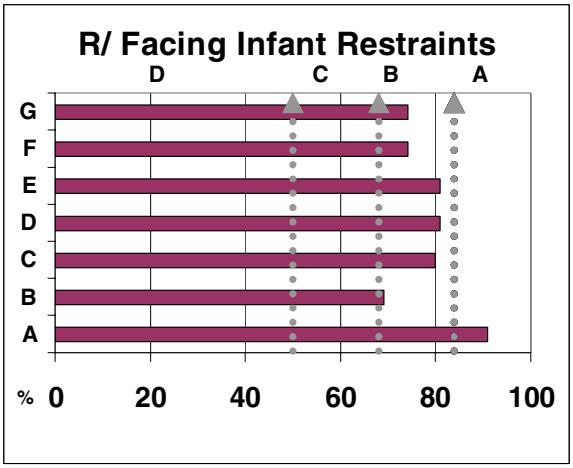

Figure 10. Dynamic overall results - Rearward facing infant restraints.

Similarly, there were no A levels among the forward facing seats. The majority achieved a B, with the two poorest performers achieving a C. Among the

rearward facing restraints, one device scored an A, and the rest scored a B. Overall then, the rearward facing restraints appeared to be performing the best, and booster seats the worst.

These results illustrate the significant differences in performance that exists among restraints on the market in conditions beyond the minimum performance requirements of the Australian Standard, and the scope for further improvement in performance, particularly among booster seats and forward facing restraints (albeit it to a lesser degree).

As was the case for ease of use, only the overall scores are being published at this time, and these scores are not weighted by performance category. However review of the performance in different impact types provides some useful information.

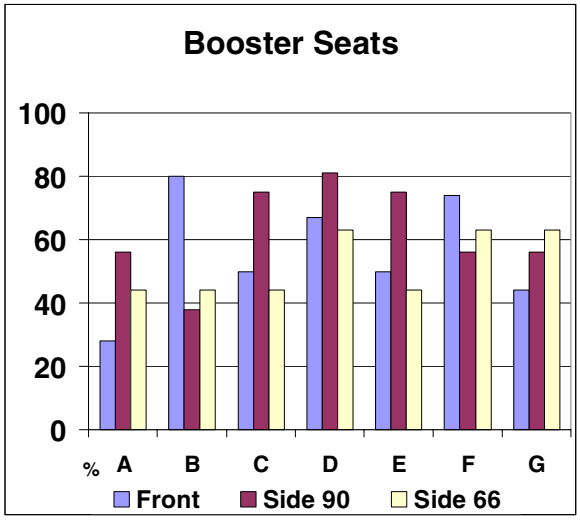

Figure 11. Dynamic category results – Boosters.

In boosters in frontal impact (see Figure 11), there was clear distinction between restraints with scores ranging from 28-70%. The best performing restraints had well positioned sash guides and crotch straps. Well placed sash guides correctly positioned and maintained the position of the sash part of the belt. This feature also controlled the dummy motion in a desirable way. Devices fitted with crotch straps (also called anti-submarine clips) maintained the position of the lap belt low down on the dummy pelvis throughout the impact. Those devices without these features performed poorly.

Among the boosters in the 90 degree side impact tests, there were 3 'groups' of devices - those that scored higher (75-80%); those that scored comparatively in the middle (50-60%; and one device that scored poorly (38%). Features affecting performance in side impact were:

- side wing height - higher side wings were better able to prevent contact between the dummy's head and the door,
- well positioned sash guides – these appeared to have a role in preventing the dummy's shoulder, and
- the use of a non-frangible material in their construction.

In the 66 degree tests, there was also a clear distinction in performance with scores grouped around 45% and 66%. The primary difference between the groups was that head contact with the side door occurred in the lower scoring devices.

Overall it appears that for booster seats in general, there are a number of areas where there is significant scope for improvement. These include:

- the provision of side structures that match the seated height of all children within the weight range of booster seats,
- improved torso restraint in side impact - this includes better structural integrity,
- better maintenance of the sash position during the impact phase in frontal and side impact, and
- improved lap belt geometry and maintenance during the impact phase.

Well positioned sash guides and crotch straps (or anti-submarine clips) appear to do address the latter two issues to some extent.

Results from the individual performance categories for forward facing child seats are shown in Figure 12. From this figure it appears the results obtained were more consistent across restraint types than they were among the booster seats. The biggest difference in performance was in frontal impact with 2 restraints scoring much better than the others. These restraints significantly outperformed the others in achieving reduced head excursion and HIC values.

There was much less difference between the overall category scores for forward facing seats in the 90 degree impacts. While all of the restraints are approved to the Australian Standard (and therefore must be able to prevent head contact between the TNO P3 and the door), only one prevented head contact using the dummy with a boosted seated height. However this restraint, as well as many of the others had difficulty in completely containing the head since the side wings allowed ½ to a 1/3 of the dummy's head (with boosted seated height) to be exposed.

The 66 degree impact tests provide better distinction between performance. Head contact with the window glass of the side door structure occurred in all cases. The primary difference in the poorer performing devices was that they allowed the left hand (nearside) shoulder strap to slip completely off the shoulder during rebound.

Overall points for improvement for forward facing restraints are:

- the provision of a better match between side wing height and the seated height of children in the upper mass range of the device,
- optimization of the belt path to assist in the reduction of head excursion and the stability of the device during rebound, and
- maintenance of good harness fit during the impact phase and rebound in side impact.

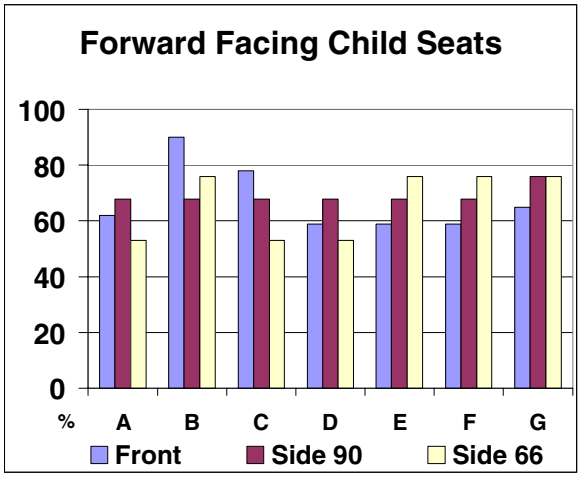

Figure 12. Dynamic category results - Forward facing child seats.

Among the rearward facing restraints there was one device with clearly superior performance in both the frontal and side impact categories (See figure 13). This device scored 96% in the frontal tests, performing the best in all aspects except the TEM (torso energy management) measurement (where it scored second best). The other restraints fell short primarily in their management of head and torso energy during the impact. The poorest performing restraints also failed to distribute the loads as well as the others, and retain the dummy's head.

There was no difference between the restraints in the 90 degree tests, all prevented head contact. This exemplifies the need for an adequate method for assessing the energy absorption ability of the restraints when the head is contained. Similarly, there was no head contact in the 66 degree tests. However there was one significant difference between the restraints. Some (scoring 100%) prevented head contact and contained the head fully within the confines of the restraint, while others allowed at least part of the head to move beyond the rim of the restraint.

The greatest scope for improvement observed in rearward facing restraints lies in the inability of some restraints (particularly convertible restraints) to completely contain the head in frontal and side impact. It is imperative that these features be addressed since exposure of the head of an infant over the rim of the restraint increases the risk of head contact with the vehicle interior and/or intruding structures. The other area of concern, also primarily observed in convertible restraints is the amount of vertical motion occurring during rebound.

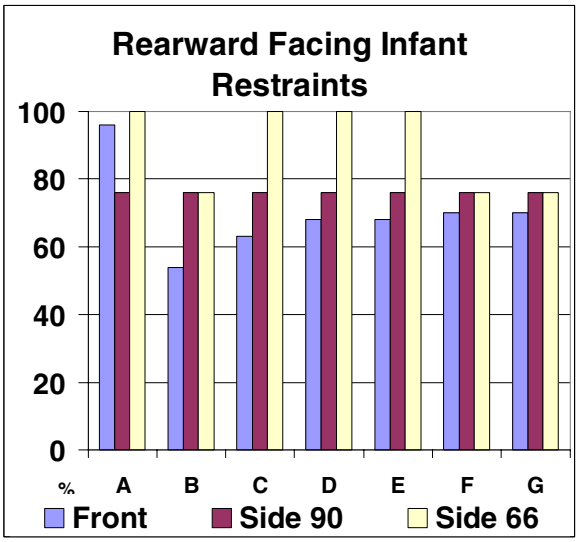

Figure 13. Dynamic category results - Rearward facing infant restraints

PUBLIC RELEASE OF RESTRAINT RATINGS

Experience from other vehicle safety advocacy programs, such as the Australian New Car Assessment Program, and the Used Car Safety Ratings shows that consumers want complex scoring information distilled into a simple form they can understand. In this case, it was felt that the dynamic and ease of use scores were quite different and should be presented separately. This would enable consumers to make their own judgement if they thought one factor was more important than the other.

The release of ratings is supported by a brochure and a media release. The brochure lists the restraints in

categories in order of performance, best performing at the top of each table. This information is also published on stakeholder websites as close as possible to the time and date the media release is circulated.

Media releases are drafted by one stakeholder, circulated to other stakeholders for comment, then the final agreed version is legally reviewed.

The media release is embargoed and, on the day of the release, stakeholder representatives make themselves available for interviews. The response normally includes television interviews, as there is good video from the crash test facility, with high rating morning TV shows being particularly interested in the subject.

Newspaper coverage has also been widespread, as the information is appreciated in a range of areas, including maternity hospitals, child injury prevention groups and parent/consumer groups.

There is an ongoing significant level of enquiry to telephone information lines that confirms that the CREP stakeholders are strongly associated in the public's mind with the distribution of child restraint rating information.

DISCUSSION AND CONCLUSIONS

The overriding objective of a program such as CREP is to provide children with improved levels of crash protection - beyond the minimum required by the Standard. Firstly the program aims to influence consumers to buy restraints which rate well, and avoid the restraints which do not. This secondly provides an economic incentive for manufacturers to develop and market better performing products. Thirdly, to assist manufacturers, the program provides detail of where their products rate well and where they do not. Therefore it also provides useful step-by-step guidance on where and how the product needs to be improved.

Ensuring that useful, credible information is provided to consumers relies first and foremost on a reliable and appropriate assessment protocol. This was the driving force behind the recent review of the Australian CREP protocols.

It is important that assessment procedures meet three primary objectives. Firstly they must allow discrimination between restraints to allow for comparisons between the best and worst performers within a category; secondly they must encourage even the best performers to improve designs in necessary areas, and thirdly they must reflect issues relevant to the real world protection of children in cars.

The newly revised protocols, as presented here, clearly meet the first two objectives. Intuitive and anecdotal experience suggest they are also likely to meet the third, however scientifically robust validation methods are required to make sure. Two projects are currently underway to achieve this, and the results will be used to refine and enhance the CREP methodologies where necessary.

In addition to refinements following validation of the methodologies, it is intended that these protocols will undergo regular review. This is particularly important to allow the objectives of the protocols to continue to be met as changes occur in the design of restraints on the market and/or the requirements of the Standard. Feedback from those conducting the assessments is a useful source of potential refinements and enhancements.

Following the conduct of this most recent series using these newly revised protocols, a number of issues were raised for consideration in updated revisions.

For example the ability to discriminate adequately between the energy absorption features of restraints containing the head in side impact would be a significant enhancement.

While consumer information-based assessment programs focusing on child restraint design are likely to enhance the ease of use and dynamic performance of child restraints, the child restraint is only one piece of the protective system in the real world. There is also a need to encourage vehicle manufacturers to improve the ease of installing and using child restraint systems in specific models of vehicle and the development of effective strategies to achieve this is required. One possible measure raised in the past is the addition of some form of child restraint compatibility assessment to programs such as NCAP. An example of a possible scoring system is outlined by Brown et al [13].

Once there is an adequate assessment and scoring procedure, the critical part of the process is to ensure that the CREP results are readily available to consumers and that consumers use this information in making their purchasing decisions.

An important part of the consumer evaluation process is to provide guidance to manufacturers regarding where the highest priority areas for significant gains in performance lie. This recent series of ease of use assessments has indicated a number of features where specific attention is warranted. These include;

- provision of information regarding correct and appropriate use in languages other than English on packaging and within instruction booklets,
- one page pictorial set up and usage guides,
- better clarity in diagrams such that the information contained with diagrams on packaging, labels and in instructions books conveys all necessary information with no need to read any additional text,
- placement of labels on restraints in the vicinity of the task to which they refer, and
- colour coding of instructions, labels and seat belt routing (particularly for individual modes of use in convertible restraints).

The incorrect use of in-built harness systems (in forward facing and rearward facing restraints) and the sash of seat belts (in booster seats) are areas raising concern in the field. There is a need to encourage manufacturers to optimise their designs to reduce the propensity for this form of misuse. Bonus points were available in this series for restraints that provided some means of warning when the harness/belt was being used incorrectly (or conversely some feedback system denoting correct use). No restraints currently have any features like this and this would be one area where manufacturers could gain some edge for future programs.

In the dynamic assessments, the philosophy of assessing performance with respect to what the protective aims of that type of restraint are, rather than one based on biomechanical injury criteria is a relatively new approach, and resulted in some significant changes to the way restraint performance, (particularly in the case of booster seats) was assessed. Results indicate that this assessment approach allows for the useful discrimination between products based on observable differences in performance in the laboratory.

Of note, there was a substantial difference in the head excursion allowed between the best and the worst performing forward facing restraints. Overall, the results suggest there is specific scope for improving the performance of;

- convertible child restraints generally,
- booster seats, particularly those that do not incorporate adequate sash guides and crotch straps, and
- forward facing and booster seats in side impact, particularly in the head protection provided in side impact at the upper end of their mass limits.

Finally, it should be noted that due to differences in both the protocols and the scoring systems, it is not possible to compare the ease of use of Australian restraints and those in North America, or the dynamic performance results with those conducted elsewhere.

ACKNOWLEDGEMENTS

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REFRENCES

[1] ISO/TC 22/SC 12WG 1N649 (2003) "Road vehicles - Child Restraint systems – Compilation of safety regulations and standards." September, 2003

[2] Pedder, J., Hillebrandt, D. and Christensen. L. "Usability Rating of Child Restraints". 6th World Conference on Injury Prevention and Control, Montreal, May 2002

[3] NHTSA, US Department of Transportation "Consumer Information Regulations; FMVSS; Safety rating Program for Child Restraint Systems; Notice and Final Rule" Federal Register Part II. Vol. 67 No 214:67448-67465 November 5, 2001

[4] Brown J, Kelly P, Griffiths M "Review of the Australian Child Restraint Evaluation Program" Report prepared for the RACV, NRMA Motoring & Services and the NSW Roads and Traffic Authority April 2005.

[5] Weinstein EB, Sweeney MM, Garber M, et al. "The effect of size appropriate and proper restraint use on injury severity of children". In: 2nd Child Occupant Protection Symposium; 1997; (SAE); 1997. p. 181-186

[6] Eby DW. Kostyniuk LP. "A statewide analysis of child safety seat use and misuse in Michigan". Accident Analysis & Prevention. 31(5):555-66, 1999

[7] Paine M and Vertsonis H (2001) 'Surveys of child restraint use in New South Wales', in proceedings of 17th Enhanced Safety of Vehicles Conference, Netherlands 2001.

[8] Lalande S, Lagault F, Pedder J."Relative degradation of safety to children when automotive restraint systems are misused". In proceedings of 18th Enhanced Safety of Vehicles Conference; 2003; Nagoya, Japan; 2003. p. Paper No 85

[9] Decina LE. Lococo KH. "Child restraint system use and misuse in six states." Accident Analysis & Prevention. 37(3):583-90, 2005 May

[10] Brown J., and Bilston L.E., "Misuse of Child Restraints and Injury Outcome in Crashes" in Proceedings 2006 Australasian Road safety Research Policing and Education Conference" October, 2006

[11] Winston FK. Chen IG. Elliott MR. Arbogast KB. Durbin DR. "Recent trends in child restraint practices in the United States". Pediatrics. 113(5):e458-64, 2004 May.

[12] Brown J and Bilston LE. High Back Boosters: In the field and in the laboratory. 50th Annual Conference American Association of Automotive Medicine, Chicago 2006.

[13] Brown J, Griffiths M, Paine M "Effectiveness of child restraints: The Australian Experience" Research Report 06/02 prepared for Australian New Car Assessment Program, June 2002

APPENDIX 1: EASE OF USE ASSESSMENT PARAMETERS

CATEGORY	DESCRIPTION
CHILD	Buckle secured in reverse
CHILD	Indication buckle secured correctly
CHILD	Easy access to harness adjustment
CHILD	Ease of harness adjustment
CHILD	Indicator of correct harness adjustment
CHILD	Range of harness slots
CHILD	Visibility of slots
CHILD	Ease of changing slot position
CHILD	Threading straps when changing slot position
CHILD	Liner/harness interaction
CHILD	Consistency
CHILD	Removal of cover
CHILD	Removal of child when top tether attached
CHILD	Indication of correct harness us
CHILD	Seat belt path
CHILD	Indication of correct seat belt
CHILD	Height adjustable
CHILD	Ease of height adjustment
INSTRUCTIONS	Instructions generally
INSTRUCTIONS	Quick set up/reference guide
INSTRUCTIONS	Easy to read font
INSTRUCTIONS	Easy to understand diagrams
INSTRUCTIONS	Size range clearly indicated
INSTRUCTIONS	Modes of use clearly indicated
INSTRUCTIONS	Belt routing
INSTRUCTIONS	Using isofix
INSTRUCTIONS	Belt/harness use
INSTRUCTIONS	Correct use of top tether
INSTRUCTIONS	Using correct harness slot
INSTRUCTIONS	Warnings related to correct use of harness/belt
INSTRUCTIONS	For maintenance
INSTRUCTIONS	Location
INSTRUCTIONS	Accessibility
INSTRUCTIONS	In other languages
LABELS	Labels generally
LABELS	Easy to read font
LABELS	Easy to understand diagram
LABELS	Child size range indicated
LABELS	Modes of use indicated
LABELS	Instructions for belt path
LABELS	Instruction correct use of top tether
LABELS	Instructions for using correct harness slot or belt guide
LABELS	Warnings related to correct use of harness
LABELS	Labels Consistent with Instructions
LABELS	Durability of labels
LABELS	Location of labels
LABELS	Visibility of labels
LABELS	Identification of stabiliser Bar
LABELS	Colour coding for mode of use
PACKAGING	Easy to read font
PACKAGING	Child size range indicated for mode
PACKAGING	Modes of use clearly indicated
PACKAGING	Accommodation (vehicle)
PACKAGING	Appropriate use information provided in other language
INSTALLATION *	Indication that seat belt is routed correctly
INSTALLATION *	Correct belt routing evident
INSTALLATION *	Ease of achieving belt path
INSTALLATION *	interaction between harness and adult seat belt
INSTALLATION *	Ease of using belt positioning feature
INSTALLATION *	Ease of removing belt slack
INSTALLATION *	Top Tether adjustment
INSTALLATION *	Top Tether attachment to CRS
INSTALLATION *	Seat back angle
INSTALLATION *	Ease of changing recline angle
INSTALLATION *	EASE OF USING STABILISER BAR
INSTALLATION *	Accommodation in large family sedan
INSTALLATION *	Ease of removing restraint

* Does not apply to Booster Seats

APPENDIX 2: DYNAMIC ASSESSMENT PARAMETERS

CATEGORY	Applies*	DESCRIPTION
FRONTAL	RF	Head retention
FRONTAL	FF	Forward head excursion
FRONTAL	RF, FF, BS	Dummy retention
FRONTAL		Upward and/or rotational displacement of the CRS in rebound
FRONTAL	RF, FF,BS	CRS security and integrity
FRONTAL	RF	Load distribution
FRONTAL	RF	Head energy management
FRONTAL	RF	Torso energy management
FRONTAL	RF, FF	Adjuster slip
FRONTAL	FF	Operation of quick release device
FRONTAL	BS	Seat belt sash strap location
FRONTAL	BS	Submarining
FRONTAL	BS	Seat belt strap location

*RF – Rearward Facing Infant Restraint, FF – Forward Facing Child Seat, BS – Booster Seat

CATEGORY	Applies*	DESCRIPTION
SIDE	RF, FF, BS	Head retention
SIDE	RF, FF, BS	Dummy retention
SIDE	RF, FF, BS	CRS security and integrity
SIDE	RF,FF	Adjuster slip
SIDE	BS	Seat belt sash strap location
SIDE		Labels generally
SIDE		Easy to read font
SIDE		Easy to understand diagram